# A History of the Water Resources Division U.S. Geological Survey:

## Volume VI, May 1, 1957, to June 30, 1966

## The Years of Change

Earlier volumes (unpublished), Robert Follansbee, author:

Volume I: 1866 to June 30, 1919;

Volume II: July 1, 1919, to June 30, 1928;

Volume III: July 1, 1928, to June 30, 1939;

Volume IV: July 1, 1939, to June 30, 1947; and

Volume V: July 1, 1947, to April 30, 1957, by George E. Ferguson and others

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# A HISTORY OF THE WATER RESOURCES DIVISION

# U.S. GEOLOGICAL SURVEY: VOLUME VI,

# MAY 1, 1957, TO JUNE 30, 1966

## The Years of Change

*By* Hugh H. Hudson, Joseph S. Cragwall, Jr., *and* others

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director



UNITED STATES GOVERNMENT PRINTING OFFICE 1996

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For sale by the U.S. Geological Survey
Information Services
Box 25286
Denver Federal Center
Denver, CO 80225

**Library of Congress Cataloging-in-Publication Data**

Hudson, Hugh H. 1923–
A History of the Water Resources Branch of the United States Geological Survey. Volume VI, May 1, 1957, to June 30, 1966—The Years of Change / by Hugh H. Hudson, Joseph S. Cragwall, Jr., and others. Includes indexes.
Supt. of Docs. no.: I 19.2:H62/2/V.5
Contents: v.1. From predecessor surveys to June 30, 1919; v. 5. From July 1, 1947, to April 30, 1957; v. 6. From May 1, 1957, to June 30, 1966.
1. Geological Survey (U.S.). Water Resources Division—History.
2. Water resources development—United States—History.
3. Hydrology—United States—History. I. Title. I. Follansbee, Robert, 1879–1952.
TC423.F47 1996 353.0082'325

# FOREWORD

The publication of this volume completes the summary documentation, in a series of six volumes, of nearly a century of water-resources investigations by the U.S. Geological Survey and is the third in this series to be published by the USGS for public use. The first four volumes were initially prepared for the internal use of the organization. Volumes I and V have been published and current plans are to publish volumes II, III, and IV as public documents, also. The preparation of volume VII of this series is well underway. With its publication, summaries of the activities and achievements of the Water Resources Division and its predecessor water-related units in the Geological Survey will be documented from soon after the Civil War to September 1979.

All volumes in this series were prepared largely by individual initiative and volunteer efforts of hundreds of active and retired Geological Survey employees, which is indicative of their individual pride of accomplishment and of collective pride in the results of the water-resources investigations of the Geological Survey.

Robert M. Hirsch
Chief Hydrologist

## PREFACE

This volume is the sixth in the series of reports on the history of the water-resources activities of the United States Geological Survey (USGS). The first four volumes were written by Robert Follansbee and each is titled "A History of the Water Resources Branch of the United States Geological Survey." The periods of Follansbee's reports are as follows:

Volume I: from 1866 through June 30, 1919
Volume II: from July 1, 1919, through June 30, 1928
Volume III: from July 1, 1928, through June 30, 1939
Volume IV: from July 1, 1939, through June 30, 1947

Volumes II through IV have not yet been published by the USGS. Details of the completion and transmittal of each by Follansbee to headquarters are described by George E. Ferguson in the Preface to Volume V of this series. According to Ferguson, Volumes II, III, and IV were never approved for distribution other than for internal use in the USGS. Volume I was published in 1994.

Volume V, published in 1990, was researched and written by George E. Ferguson and others, and covers the period from July 1, 1947, through April 30, 1957. In 1949, the Water Resources Branch became the Water Resources Division (WRD); hence, the Ferguson volume is "A History of the Water Resources Division of the United States Geological Survey."

Volumes I, II, III, and IV were prepared by Follansbee partly as a Survey employee and partly on his own. Volume V was written by Ferguson under similar circumstances--partly as a reemployed annuitant, partly on his own, but also during a brief period under contract. Volume VI was prepared under contract but with the mutual understanding that the principal authors were to contribute large blocks of time. Although the authors of all volumes of WRD history may have marched to a different drumbeat, all shared a deep pride in having been long-time members of an outstanding earth-sciences organization, believed in the worth of its programs, respected and admired their associates and desired to see their collective accomplishments preserved in a human context.

Volume VI provides a permanent source of information for WRD administrators and others who find it desirable—at times necessary—to look back into the history of the Division for clues to the technical, administrative, or legal circumstances that led to the birth or demise of certain activities. As WRD moves into its second century of water-resources work and as memories fade, files fall victim to records management, and as new generations of employees move through the ranks, the systematic preservation of WRD history becomes ever more important.

Each volume after Volume I was given a subtitle related to its major emphasis. The subtitle of Volume II is "Years of Increasing Cooperation," Volume III, "Years of 50-50 Cooperation," Volume IV, "Years of World War II" and for Volume V, "The Paulsen Years," paying tribute to the Chief Hydraulic Engineer during that period. In view of the events that dominated the 1957 to 1966 years, Volume VI is subtitled "The Years of Change."

Some of the history reported in Volume VI is based on a series of videotaped interviews of key Branch, Division, and Bureau leaders. In many of the interviews, contemporaries were paired as interviewee and interviewer, thus enhancing the historical content of each interview. The videotapes were made to add a new and informative dimension to the documentation of the WRD history for the period. Copies of the tapes are filed in the USGS library at the National Center in Reston, Va., in the National Training Center in Lakewood, Colo., in the office of the Chief Hydrologist, and in each Regional headquarters office. Those interviewed and videotaped during the preparation of Volume VI were Frank Barrick, Jr., Frank E. Clark, George E. Ferguson, Albert G. Fiedler, O. Milton Hackett, Ernest L. Hendricks, S. Keith Jackson, Philip E. La Moreaux, Elwood R. Leeson, Luna B. Leopold, S. Kenneth Love, Robert H. Lyddan, Thomas Maddock, Jr., Charles C. McDonald, Garald G. Parker, Sr., Kenneth N. Phillips, Fred M. Veatch, W. Finch White, and Harry D. Wilson. Before the preparation of Volume VI began, videotaped interviews were made of Paul C. Benedict, Joseph S. Cragwall Jr., John H. Feth, Stanley W. Lohman, Arthur M. Piper, Hugh H. Shamburger, C.V. Theis, and Harold E. Thomas.

Acronyms and other abbreviations were used throughout the volume as a means of space conservation and readability. Most follow the full name of the agency, program, or publication series that appear earlier on the page or within the immediate subject. Some acronyms are used so frequently throughout the text, however, that a general identification may be desirable. Most relate to organizational entities: "AEC" refers to the Atomic Energy Commission, "BOB" to the Bureau of the Budget, "BOR" to the Bureau of Reclamation, "CSC" to the U.S. Civil Service Commission, "DOI" and "the Department" refer to the U.S. Department of the Interior, "EPA" refers to the Environmental Protection Agency (its functions were earlier in "USPHS" or U.S. Public Health Service and then in "FWPCA" or the Federal Water Pollution Control Administration), "FPC" refers to the Federal Power Commission, "SCS" to the Soil Conservation Service of the U.S. Department of Agriculture, "TVA" to the Tennessee Valley Authority, and "WRC" to the U.S. Water Resources Council.

"USGS" and "the Survey" refer to the U.S. Geological Survey and within the Survey, "WRD" refers to the Water Resources Division and within WRD, "GHB," "GWB," "QWB," and "SWB" refer to the General Hydrology, the Ground Water, the Quality of Water, and the Surface Water Branches. References to USGS publications are abbreviated to "WSP" for Water-Supply Paper, "PP" for Professional Paper, "Circ." for Circular, "Bull." for Bulletin, and "HA" for Hydrologic Investigations Atlas. Personnel on part-time assignments are sometimes referred to as "WAE" (when actually employed) employees. Fiscal year is sometimes shortened to FY. Readers who find major errors in this volume are invited to report those errors to the "CH" or Chief Hydrologist.

## ACKNOWLEDGMENTS

The contents of Volume VI would be incomplete and its preparation virtually impossible without the assistance of more than 200 volunteer writers, nearly all WRD retirees. Each writer was provided with a starter kit containing a few basic facts. Their good memory of events, familiarity with programs and people, recollection of where to find useful documents, and a cordial relationship with former coworkers assured lively and accurate accounts of Division activities.

Credit is due the late Robert C. Averett, Associate Chief Hydrologist in 1987, who provided the Headquarters initiative to get the preparation of Volume VI underway.

The assistance of the Reston staff, led by Chief Hydrologist Philip Cohen's strong support of the project, was invaluable, selfless, always gracious, and given with unfailing good humor. William B. Mann, Assistant Chief Hydrologist for Operations, was the principal headquarters liaison for the project and was always supportive and responsive. Files meticulously organized and left behind by the late Warren S. Daniels and scrupulously maintained by George E. Williams were a valuable source of information, particularly on details of projects. John C. Kammerer provided much helpful advice and reference material. The Branch of Manpower (WRD), particularly Beverly A. Pittarelli, helped locate career records and biographical data for many former key personnel.

The work of the principal authors was made much easier by the assistance of George W. Edelen, Jr. Edelen, a reemployed annuitant in the Office of Surface Water, located, retrieved, duplicated, and sent to the writers nearly all the material recovered from Headquarters files and the National Archives. Volume VI was typed and electronically filed by Virginia R. Jesser who, before her retirement, had worked in District, Region, and Headquarters offices for nearly 30 years. The writers were extremely fortunate to have had George E. Ferguson's advice and experience available to them. As WRD historian emeritus, he was completing Volume V as Volume VI was getting underway.

Finally, there was a small army of active and retired members of the Division and of cooperating agencies, and their wives in some cases, who voluntarily provided material, advice, review, and typing. Because of genuine interest in the project, they were delighted to help. Although the title page of Volume VI bears, as authors, the names of two WRD retirees, their contribution to the volume pales in comparison with the cumulative contributions of more than 300 others without whose gracious assistance the preparation of Volume VI would have been impossible. It was with the gracious and competent assistance of Linda J. Britton, Chief of the Colorado District's Publication Section, John E. Atencio, Editorial Assistant, John M. Evans, Scientific Illustrator, Dennis J. Garcia, Physical Science Aid, Mary A. Kidd, Editor, and Edward J. Swibas, Visual Information Specialist, that the manuscript was prepared for printing.

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# INTRODUCTION—THE YEARS OF CHANGE

Luna B. Leopold became chief of the Water Resources Division in May 1957 and stepped down in January 1966 to resume his research in geomorphology. Ernest L. Hendricks succeeded Leopold as chief of the Division in May 1966. The dates May 1, 1957, and June 30, 1966, bracket a period of profound change in the organization and programs and in the philosophy of operations of the Water Resource Division and indeed in the entire field of investigational hydrology both within and outside the Geological Survey.

Leopold brought into his new position a conviction that water on and beneath the Earth's surface and the quality of both were interdependent parts of one water-resources system and that the organization and operation of WRD must change to reflect that oneness. He was also convinced that the research program of the Division was inadequate in scope, staff, and funding to meet the operational needs of the Division and the needs of the community of water-resources planners, developers, and administrators in the near and distant future. Leopold's vision of a Water Resources Division properly staffed to meet current and future technical challenges included the imposition of rigorous selection standards on new professional recruits and the development of specialized training in-house and at university undergraduate and graduate levels. The period of Leopold's administrative and technical leadership of the WRD was indeed the "Years of Change."

Field operations of the WRD in 1957 consisted largely of the separately developed programs of the Surface Water, Ground Water, and Quality of Water Branches, each staffed predominantly by engineers, geologists, and chemists. The Surface Water Branch (SWB) was traditionally dominant in Division affairs by virtue of its long-time presence in the field and its significantly larger staff and budget than those of Ground Water Branch (GWB) and Quality of Water Branch (QWB). Operations of SWB were highly decentralized; GWB and QWB, less so. Collecting and publishing basic water data, mostly on streams, and ground-water studies of specific areas were the principal program objectives. There were only a few national, regional, or multidistrict programs that required centralized supervision or coordination by the Technical Coordination Branch (TCB) [later, the General Hydrology Branch (GHB)].

Technical training available to WRD staff was limited to that provided by each Branch. The WRD had no legal authority to select and support employees for graduate-school training. Selection of new professional employees was guided only by the qualification standards established by the U.S. Civil Service Commission (CSC) for each entrance grade and traditional discipline. WRD supervisors had no uniform selection standards for use in judging the academic proficiency of those who applied for work with the Division.

All this was to change. When Leopold stepped down in 1966, field operations had been integrated or were soon to be integrated under the leadership of Division-level District Chiefs and staffed by hydrologists who were beginning to apply basic data to describe and interpret hydrology rather than using the data solely as an end product. New hires were selected from university graduates who met the uniform academic standards of the WRD. With passage of the Government Employees Training Act, the Division made liberal use of its new authority to send employees to graduate school. More and more universities, with assistance and advice from senior Division staff, initiated academic programs leading to undergraduate and graduate degrees in the new science of hydrology. By 1966, the WRD research program was greatly enlarged in scope, funding, and staff.

Not all changes that began or were completed during this period of history were internally mandated or inspired. Some came from legislation, some from actions of the Bureau of the Budget (BOB), and others came from the ground swell of environmental interests that began to emerge—for example, public and Congressional concerns over stream and aquifer pollution and disposal of nuclear and toxic wastes. New agencies with water-related missions came into being at all levels of government with needs for water-resources information that placed unprecedented demands on the Division. Evolutionary changes in the nature of water-resources problems and the concomitant need to develop new techniques of investigation, improved instrumentation, and new methods of presenting the results of its studies also influenced the Division.

The authors of Volume VI have attempted to describe the WRD as it entered the years of change, the organizational, philosophical, technical, and program changes that occurred between 1957 and 1966, and as it emerged in 1966. The Division, as viewed by the authors, is made up of people, budgets, programs, and projects, laced together by an organization that extends from field or project offices up through District, Region, Division, and Bureau Headquarters. Included, too, was consideration of the internal and external forces that affected the Division and how it responded in its work to technical, administrative, and policy changes and to new legislative mandates of the Congress. Much of Volume VI is devoted to field activities—particularly those termed "District activities." The districts are where most WRD employees begin and end their careers and are the source of most of the water-resources reports of the Division. Reports, being the ultimate product of the WRD, are described in relation to changes in policy, types of publications, and in volume of output.

It would be misleading to describe the Division during its years of change without acknowledging the dissension that accompanied at least some of the major, internally mandated changes. Not all the changes were strongly or unanimously supported by the midlevel and senior staff of the Division. Branch loyalties, discipline rivalries, and allegiance to established programs combined to provide less than universal support for some of the changes in the organization and programs. The emphasis on research was perceived by some as an eventual, inevitable relegation of the basic-data programs to a minor rank in priorities for staff and funding.

## PART I—THE PERIOD IN RETROSPECT

A little hindsight can be a wondrous thing. It is not as tenuous as prophesying, as evidenced by Clarence Dutton's prediction in 1885 to G.K. Gilbert on the fate of the USGS (M.C. Rabbitt, 1980, Minerals, Lands, and Geology for the Common Defence and General Welfare, v. 2, 1879—1904, p. 104):

> ...Our Survey is now at its zenith and I prophesy its decline. The "organization" is rapidly "perfecting," i.e., more clerks, more rules, more red tape, less freedom of movement, less discretion on the part of the geologists and less out-turn of scientific products. This is inevitable. It is the law of nature and can no more be stopped than the growth and decadence of the human body.

The USGS zenith had not even been reached in the 1960's, and it continues today to develop as a prestigious scientific organization.

In reflecting on the years 1957–66, it is difficult to improve on a contribution sent by Robert M. Beall early in the preparation of this volume. He titled it "Prologue," but his observations serve equally well "In Retrospect." He wrote on February 6, 1989:

> It is difficult to write of this 1957–66 period, I find, without reflecting on the state of knowledge and technology and on the social, political, and economic conditions that existed prior to and during that time.
>
> From my somewhat limited perspective, water resources were thought of largely in terms of surface-water resources in the late 1950's and the significant municipal and industrial developments that exploited those resources. Water-quality concerns were chiefly those of mineral constituents and sediment, and their effects on industrial processes and agriculture. Health related aspects were the domain of State and local health agencies. The dominant Division activities were connected with quantifying surface-water resources while struggling to educate the user community to the utility and importance of ground-water resources. Surface-water measuring activities and aquifer analyses were empirical subfunctions of fluid mechanics and hydraulic engineering. Rapid computation involved electric calculators, and concepts of statistical theory were beginning to be applied to the years of accumulated data. Rapidograph pens were a big advance in the hand preparation of maps and graphs.
>
> Field operations and program development were largely delegated to District Engineers and Geologists. Project management was beginning to be recognized as a necessary (and even useful) process that could be applied to Division activities when engineers, geologists, and other discipline specialists began to work together on integrated water-resources studies. Calculators gave way to room-size computers (owned by agencies with real money), card punching became a specialized office skill and computer programming began to be a sub-specialty of some of the professional staff.
>
> In national historical perspective, the period spanned the years of [President Dwight David] Eisenhower's second term, the abbreviated [President John Fitzgerald] Kennedy years, and the beginning years of the [Lyndon Baines] Johnson presidency.
>
> In addition to other significant events, the times saw the beginning of a direct involvement in South Vietnam (February, 1955), inauguration of the interstate highway system (June 1956), continuing civil rights conflict, our first orbiting satellite (January 1958), U.S. troops to Lebanon (July-October 1958), the first jet airplane service (December 1958), Senate Select Committee on National Water Resources (April 1959), statehood for Alaska (January 1959) and Hawaii (August 1959), opening of the St. Lawrence Seaway (April 1959), launch of the first weather satellite (April 1960), Kennedy's Message on

Natural Resources (February 1961), the ill-fated invasion of Cuba and the Cuban missile crisis (April 1961), manned space flight (May 1961), Rachel Carson's Silent Spring (1962), buildup in Vietnam (1963), rioting in Panama (January 1964), interdisciplinary AWRA founding (March 1964), OWDC creation in response to BOB Circular A-67 (1964), U.S. troops to the Dominican Republic (April 1965), Water Quality Act passage (September 1965), massive involvement in Vietnam (1966), and continued civil unrest. Surprisingly, the consumer price index gained but 18 percent in the 1957-66 period. Organizations, people, and their way of life changed, in most case irreversibly.

Within this period and as a reflection of massive change nationally, it is not surprising that the mundane water-data-collection activity of the Division should change also. Hydrology emerged as a recognized general science, still largely bifurcated, however, by mode of occurrence (surface-water hydrology and geohydrology). Data collection dominance lost ground to emerging analytical studies, research and water quality concerns. The organizational structure, program content, planning perspective, funding priorities, training, and cooperator/collaborator relations; all were subject to the inevitable process of change, impacting on the lives of most members of the Division.

Indeed the years 1957–66 were "years of change" in all aspects of national and governmental concerns. The Water Resources Division certainly experienced its share; the theme of change is dominant in every part of this volume.

Leadership changed, not only in terms of the individuals who served, but in their style of leadership, their aspirations for the Division, and their personal interests in water science and engineering. In retrospect, the changes they wrought during the 9 years covered in this volume were right for the Division in timing and in substance.

It took the leadership a little more than a decade to accomplish the needed organizational changes. It was a stressful and exciting period for WRD personnel. Stress dominated the period for field supervisors who had to execute change and for Branch-level managers who had to give up much of their former line authority. Excitement dominated the period for the younger professionals who were eager for more diversified opportunities in research and field investigations.

The changes in program objectives and priorities that provided for a larger and stable research program as well as for more problem-relevant field studies was markedly successful. The diversity of programs and projects summarized in Parts IV and X of this volume confirms the success of leadership's policy and direction.

Fortunately this period of change in WRD was at a time of sustained national economic growth which permitted the political leadership of the Nation to provide increased budgetary support for broader public services. The Survey and WRD shared in the "good times," thus establishing a base of Federal funding for the enlarged program of research and investigation. This was accomplished without a significant slowdown of growth in the traditional data-collection, fact-finding role long enjoyed by the Division and relied on by its water-planning and management constituency, foremost among them being the cooperating State and local agencies. In fact, the cooperating and other Federal agency programs contributed greatly to the research and investigations emphasized by Division leadership.

To increase staff and improve its professional credentials, recruiting standards were raised to obtain the best-qualified university graduates, intense in-house and on-the-job training of existing staff occurred to meet new program objectives, and graduate-school opportunities were provided for promising young professionals. Extensive use and concentrated training of technicians in field offices freed the professional corps for the newer tasks in research and investigations. All of these practices have prevailed to the present, attesting to their worth as implemented during the 1957–66 period.

As part of professional development, the Division and several universities worked together to install degree programs in hydrology. This effort proved to be highly successful in ensuing years, and such curricula are commonplace today. Concurrently, the Division led the way with the Civil Service Commission in establishing the new professional classification series of "Hydrologist," and subsequently reclassified most of its engineers, geologists, chemists, and other professionals in the new series. Reclassifying, however, was not without some professional staff being concerned over loss of their discipline titles. To date, such titles as "hydrologist (engr.)," "hydrologist (geol.)," and so forth, reflect the individual academic specialty, so important to scientists and engineers.

The Division underwent many changes in management and operations during the period. Strengthening of District Councils followed by Division-line reorganization created centralized administrative services units at District level, improved coordinating program planning, and finally led to Division-level Districts. Oversight and control of designing and conducting projects moved from District supervisors to Division Hydrologists and their staffs, who were delegated more responsibilities. The advent and growth of the digital computer tended also to centralize at headquarters more administrative and some technical services formerly performed at the field level. The technical-support charge to fund headquarter's activities was increased accordingly, much to the dismay of many District supervisors and cooperating officials. Personnel pay scales barely kept pace with inflation throughout the period, but benefits in retirement and in health and life insurance improved considerably.

External issues and events began to affect program planning and budget formulation, especially in water-resources planning and development, international cooperation, atomic-energy development, and water-quality and environmental-quality enhancement. What early in the period had been discouraged as "service work" for other agencies became "national program priorities" when framed within the budgetary requests of the Survey. By the mid-1960's these national programs were having a dominant influence on Division programs and budgets.

Division leadership reviewed the modes, timeliness, and content and quality of publications, and significant changes were made. More reports were directed toward the "informed public" to promote general familiarity with water and water resources. More projects and resulting reports focused on specific water problems, as well as issues important to a region and (or) the Nation. Publishing methods to improve the usefulness and timeliness of data were adapted to computers and automatic data processing. Extreme hydrologic events, such as floods and droughts, received more attention in documenting and reporting.

Now, with 25 years of hindsight, there is little doubt that the "years of change" were good and right for the Division and the Survey. The overall redirection, led by Luna B. Leopold as Division Chief and supported by the Director, executed by Division and Branch officers must be credited conceptually to a number of individuals and events that preceded the period. Change was perceived to be necessary by the Directorate, by several advisory groups of outside experts, and by a number of senior Division officials, all of whom had voiced specific recommendations that led to the initial reorganization steps taken by Carl G. Paulsen in 1956.

Leopold, however, must be accorded the credit for making it happen. He was persuasive, persistent, even tenacious in pursuing his aspirations for making the Division the leading hydrologic research and investigative arm of the Federal Government, staffed by well-trained personnel of impeccable professional credentials, with opportunities to publish their findings in a format satisfying to the needs of a growing community of water interests. Through the 9 years of his leadership, Leopold always found the time to stay involved in his own research and to publish reports on his work and on a wide spectrum of water and environmental issues. The period must have been as stressful and as frustrating at times to him as it was to the "troops," but all took it all in stride and not without a sense of humor.

On May 4, 1964, 7 years into his tenure as Division Chief, Leopold called a special meeting of his immediate headquarters staff to recite his personally created "The Seven Year Itch," a self assessment of how things stood. It began this way in verse 1 of 24:

I've got a fancy office,
Some drapes with hue of blue
And a chair to match, so I suppose I'm rich.
But I have a fancy yearning
For the field and for the lab
That is scratchy as a seven year-old itch,

lauded a number of key staffers, as in verses 13 and 14:

I've got a top drawer scientist
The best in all the world,
Who's so quick his words get jumbled end on end.
If he needs a flume he makes one,
Writes the paper while he does,
But so brief that none of us can comprehend

I swiped one from the Navy
(Don't know where he learned to work)
But he's so tough he laughs at everybody's gripes.
But to keep the fellow happy
I must send him round the world
Where he likes to peek inside of people's pipes,

apologized to the soon-to-be defrocked Branch Chiefs in verses 22 and 23:

Then I have a bunch of Branch Chiefs
Who have served beyond a year
And now they get more jitters day by day.
They'd like to have it back
As it was in good old days

When the pie was cut and they had all the say.

I must say I can't blame them
Then they see the Branches die
And recruiting taken over by the Div.
Perhaps there's satisfaction
In our centralized research
Without making all their budgets like a sieve,

and finally reiterated his continuing itch in verse 24:

Yes, I have much to please me
But the itch won't go away.
Even though I have a building for my flume
I've an appetite still gnawing
For a thousand PhD's.
So I guess I have the itch up to the tomb.

Much earlier in Leopold's tenure, but with his goals and objectives well understood, his influence on the troops was joyfully expressed in song at the December 1960 national meeting of the Surface Water Branch District Engineers. It began like this, with apologies to Gilbert and Sullivan as corrupted, according to rumor, by Kenneth N. Phillips:

### THE ALL-AROUND HYDROLOGIST

(Recited by E.R. Leeson)

VERSE

I am an ardent member of the Survey Geological,
I've talent hydrologic, and in matters morphological,
The Froude and Reynolds numbers are to me a mere simplicity;
And I can estimate the right allowances for vorticity.
I know how often rivers flow across their plains alluvial.
With instruments in my back yard I gather data pluvial.
I get my wife to read the gage, with fervent importunity,
And make a note of bankfull stages at ev'ry opportunity.

CHORUS

And make a note of bankfull stage at ev'ry opportunity!

and chorused through 10 more verses by Fred Veatch, John McCall, Wayne Travis, and Trigg Twichell to end in:

VERSE

But scientific Research in the field of Probability
Shows 10 to 1 I can't do that before I reach senility.
So now my biggest problem is to keep the boss from firing me
Before I reach the age when Civil Service is retiring me!

CHORUS

But still in matters geophysic, meteoric, hydrological,
He is the very model for the Survey Geological.

In ending this retrospection of the Leopold years, it was noted in the September 17, 1991, issue of the Washington Post that 38 of the Nation's top scientists, engineers, and industrialists were awarded the National Medal of Science and Technology by President George Herbert Walker Bush. One of the recipients was Luna B. Leopold, indeed a fitting climax to an illustrious career.

## PART II—LEADERSHIP

Reviewed *by* Russell H. Langford, Alfred Clebsch, *and* George E. Ferguson.

In the more than 50 years after the formation of what is now the WRD from the Geologic Branch, there were only five Division Chiefs. Changes in Division leadership from Newell to Leighton to Grover to Parker to Paulsen had occurred without profound changes in program emphases and content, in philosophy of management and operations, or in the general structure of the organization of the Division. Changes over the years were more evolutionary than revolutionary, were never a part of a plan to redirect Division programs, and were rarely, if ever, the immediate result of a change in leadership. Primary concerns were with increasing the scope and intensity of coverage of basic water-resources information across the National domain.

The change in Division leadership on May 1, 1957, was markedly different in its near- and long-term effects on the Division. Director Thomas B. Nolan's appointment of Luna B. Leopold as Chief Hydraulic Engineer to lead the WRD signaled a major change in program emphasis. Both Nolan and his predecessor, William E. Wrather, had sought the addition of scientific eminence to the technical proficiency that had long characterized the work of the Division. Both had sought the means to increase the research component of WRD programs. Nolan perceived Leopold to be a forceful advocate of a strong research program, an accomplished scientist, and at 42, a relatively youthful, energetic, and nontraditionalist leader. Nolan believed Leopold would add new dimensions to the water-resources activities of the Survey.

Although Leopold obviously played the dominant role in Division affairs during this period from May 1957 through June 1966, there were others in the Director's office, at headquarters, and in the field who played prominent roles. The backgrounds, philosophies, accomplishments, and pictures of those who administered Bureau, Division, and Branch affairs during this period of change follow under "Bureau, Division, and Branch Officers" in Part II. Much of the biographical material is from Survey files and much is from the series of interviews of surviving Bureau, Division, and Branch leaders videotaped in 1988, 1989, and 1990. The remainder is drawn from less discrete sources that include personal observations and is, at best, subjective.

## Bureau, Division, and Branch Officers

The short biographies in this part of Volume VI are presented in order of organizational rank. Beginning with the Director and ending with the Regional Hydrologists, they are of the individuals who served as Director, Associate Director, Assistant Director, Chief Hydrologist, Associate and Assistant Chief Hydrologists, the Branch Chiefs, and Division Hydrologists. From May 1957 through June 1966, several Branch and Division officers occupied more than one key position, moving for example, from Branch Chief to Division officer. Their careers are highlighted from the highest-ranking job they held by mid-1966, the close of the period of history for Volume VI.

Figure II–1 is based loosely on the USGS WRD Family Tree, prepared for the period from 1867 through 1947 by Garald G. Parker, Sr., in 1963 and updated through 1975 by George E. Ferguson in 1975. It is included as a guide to the positions held by the key players and the approximate tenure of each, immediately preceding, during, and immediately following this period.

### Thomas B. Nolan (1901–92)

Thomas B. Nolan, an internationally acclaimed scientist and an accomplished administrator, was elected to the National Academy of Sciences in 1951 in recognition of his status as a geologist. He was awarded the Rockefeller Public Service Award in 1961 in recognition of his administrative achievements.

Nolan was an active participant in national and international technical societies and was honored by several foreign societies. During his many years as a scientist-administrator, he gave generously of his time to serve as a technical member or advisor or to chair such organizations as the CSC's Advisory Committee on Scientific Personnel, American Geological Institute's Committee on Scientific Communication, and the President's Scientific Research Board.

Nolan never permitted the demands of his administrative duties to displace his active participation in geologic research. In the tradition of generations of USGS geologists, Nolan, for years, spent summers in the field. His project and the subject of many of his scientific reports was the Eureka Mining District of Nevada.

Nolan was born in Massachusetts in 1901, his father a doctor, his mother a school teacher. He was graduated from the Sheffield Scientific School of Yale University and continued in graduate school at Yale in metallurgy and geology. His Ph.D. in geology was granted in 1924. He immediately joined USGS as a junior geologist in the Geologic Division and steadily advanced up the career ladder, continuing his research in mineral resources and meeting ever-increasing demands on his time for administrative duties. He was named Assistant Director by Director William E. Wrather in late 1944 and served as Acting Director, indeed *de facto* Director, during Wrather's long illness. Nolan was appointed Director in early 1956.

Director Nolan's staff was small and numbered only about 32. He deliberately kept his staff small, often noted that the important work of the Geological Survey was that done in the operating Divisions: Conservation, Geologic, Topographic, and Water Resources. The principal members of his staff were Associate Director Arthur A. Baker; Assistant Director

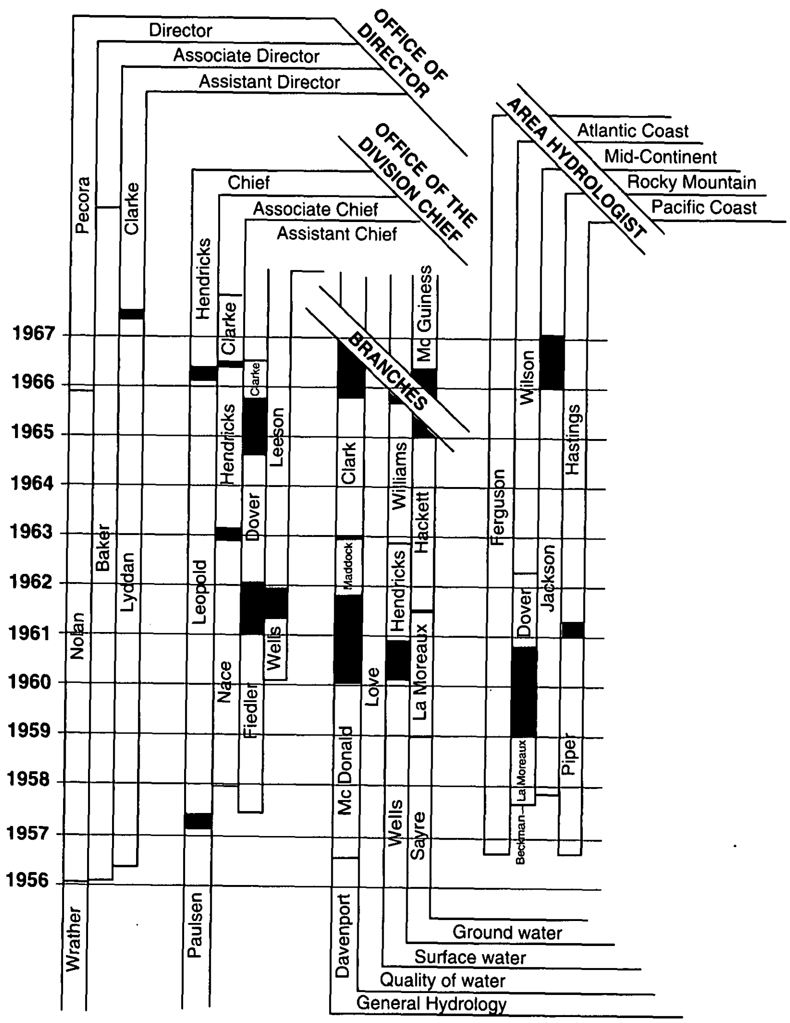



Figure II-1. Leadership—Bureau, Division, and Branch officers.

Robert H. Lyddan; and several staff geologists and staff engineers. Hugh D. Miser, an energetic and astute octogenarian, reviewed reports for the Director, and the fate of each report depended on his recommendation.

Nolan, as is traditional in the Geological Survey, gave full scientific and technical freedom to the Divisions and their members. Also, traditionally, he kept a firm hand on other, primarily administrative matters. His approval, for example, was required for changes in assignment or grade of those in grades GS–13 or higher. This indirectly but effectively required the Director's approval of organizational changes at all but the lowest levels of the Survey. Nor could work be undertaken for or in cooperation with other Federal, State, or local agencies without the Director's approval, except for specifically exempted, minor activities. Also, no reports on the results of Survey work could be published or released for non-Survey publications without his approval.

Routine contacts between the Director's office and the Divisions were assigned to Baker and Lyddan; however, Nolan made clear to all that he was always available. Baker was the day-to-day contact with the Geologic, Conservation, and Publications Divisions; Lyddan, the Topographic, Water Resources, and Administrative Divisions. Nolan, Baker, and Lyddan each kept daily records of visitors and phone calls which provided the agenda for daily staff meetings. Staff-meeting discussions left little doubt as to the Director's position on events relating to Survey policy and operations.

Nolan kept himself remarkably well informed on details of Division operation, programs, and problems. He read, or at least scanned, every newly published Survey report. He was so well informed that, at Congressional Committee hearings, he rarely called on staff to expand or respond to questions from the Committee members.

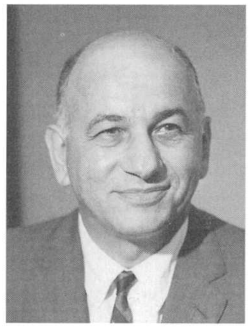
The Director's position on dealings with politicians was crystal clear. Contacts with politicians, including political appointees in the DOI, were to be at arm's length, if at all. In the early 1960's, Nolan was invited to address the politically influential River and Harbors Congress, an organization assiduously courted by water-development interests. Nolan requested a staff assistant with a WRD background to prepare a suitable paper. The staff assistant wrote a speech that was designed to ignite a passion for WRD work heretofore never witnessed. The assistant anxiously awaited Nolan's return to ask him how it went. "Oh, I hit about every other page in the high spots and got out of there."

Nolan also had strong, negative feelings about the Survey contracting any of its substantive work. Nolan believed that having a contractor do Survey work was "hiring someone to do our thinking." Nolan viewed the cooperative program with some anxiety, concerned that cooperator influence, particularly in determining program content, was too great, especially in the WRD.

Nolan's tenure as Director formally began in January 1956; however, he was serving as Acting Director nearly a year earlier when preparations for the fiscal year (FY) 1957 budget were being made. His effectiveness in formatting the budget and guiding it through the hazardous route that ends with an appropriations bill resulted in increased Federal appropriations for water-resources investigations of 18 and 26 percent for fiscal years 1957 and 1958. The momentum for subsequent years of change was created and bore Nolan's advocacy of a stronger water-resources research program and of increased emphasis on interpretive studies.

Nolan resigned as Director in September 1965 and returned to the Geologic Division as a research geologist. Mandatory retirement at age 70 caught up with Nolan in 1971 but made little impact on his work. He became a reemployed annuitant to continue work in the geology and the mineral resources of the Eureka Mining District, an activity that Assistant Director Lyddan humorously noted after the Director had spent many field seasons there and had many more ahead, "This is phase 1." Nolan died August 22, 1992.

### William T. Pecora (1913–72)



William T. Pecora died on July 19, 1972, the year after his appointment as Under Secretary, DOI. Pecora shared many scientific, professional, and career attributes with Nolan, whom he succeeded as Director of the Survey in 1965.

Pecora, like Nolan, was a talented scientist-administrator, a recipient of the Rockefeller Public Service Award, and was honored by many national, international, and foreign technical societies. Also, like Nolan, Pecora was a member of the National Academy of Sciences. He authored numerous papers on the geology and the mineral resources of the Bearpaw Mountains of Montana, his career-long study area in the West.

But in contrast to Nolan's conservative nature and avoidance of things political, a gregarious Pecora enjoyed the rough and tumble of Washington interagency politics, led the Survey into scientific ventures that would not have been considered a few years earlier, and possessed more than a little of the theatrical ham. Although Pecora made his mark in a world of scientific accomplishments and esoteric publications, his sense of humor was never far beneath the surface. But neither was he hesitant to rebuke a subordinate who had done something not quite to his liking.

William A. Radlinski tells of preparing Pecora for an important Senate hearing. Briefing Pecora was never a problem, but his wardrobe was. On the day of the hearing, Pecora was down to one rumpled, baggy suit. Radlinski and other close aides decided Pecora must not go to the Hill looking so disheveled. They relieved him of his pants and coat, took them to a nearby quick-service dry cleaners, and left Pecora seated behind his desk in his undershorts.

Pecora was born in New Jersey, the third son and ninth child of parents who immigrated to this country from southern Italy. Pecora entered Princeton on a 4-year scholarship at 16, majored in geology and geological engineering, and graduated with honors in 1933. He tutored geology students for the next 2 years, then enrolled in graduate school at Harvard in 1935. He was granted the Ph.D. degree by Harvard in 1940.

Pecora's interest in fencing continued during his college days and his proficiency increased. He was selected to serve as a member of the U.S. Olympic team at the Munich games in 1936. He and a partner once put on a fencing demonstration wearing roller skates.

After graduating from Harvard, Pecora joined the Geologic Division of the Survey in its strategic minerals program. In 1943, he studied strategic-minerals deposits in Brazil, then in other South American countries.

After completing the South American assignment, Pecora returned to the Survey's domestic program and resumed his work begun in 1940 in the Bearpaw Mountains. He was named Chief of the Branch of Geochemistry and Petrology in 1957. He left this largely administrative post in 1961 to return to his former position of Research Geologist. In 1964, Pecora became Chief of the Geologic Division. A year later he was appointed Director of the Survey.

One of Pecora's first and major accomplishments as Director was in the novel and high-tech field of surveying the Earth from space. Continuing an association with NASA that began in 1964, Pecora persuaded the Secretary of the Interior to establish a departmental program of systematically observing the Earth by satellite and transmitting data to receiving stations to meet the needs of all Bureaus of the Department. The Earth Resources Observation System (EROS) was established September 21, 1966.

Pecora took active leadership of the Advisory Committee on Water Data for Public Use, and, while Director, served as Chairman of its meetings.

### Arthur A. Baker (1897–1996)

One of Nolan's first appointments after he was named Director was that of Arthur A. Baker as Associate Director. Nolan and Baker shared similar backgrounds: roots in Connecticut, attendance at Sheffield Scientific School, and undergraduate and graduate training at Yale University. Baker's undergraduate degree, a Ph.B. in mining engineering, was awarded in 1919. His Ph.D., in geology, was granted by Yale in 1931.

Baker joined the Survey in May 1921 as a geologic aid in the Alaskan Resources Branch of the Geologic Division. His work in Alaska was investigating petroleum possibilities in the Cook Inlet area and near Portage Bay in the Alaska Peninsula. In 1923, he began a series of geologic-mapping projects in southeastern Utah, an area that became the focal point of his scientific interests for many years. His regional geologic mapping in the Moab, Monument Valley, and Green River Desert areas, accompanied by stratigraphic and structural studies over a larger area in Utah and neighboring States, were widely used in later years in the exploration for uranium and petroleum.

Baker also had administrative skills that were recognized and utilized early in his career. By the late 1920's, he had served a tour as acting administrative geologist on the staff of Director George Otis Smith. His home base, however, was the Fuels Section of the Geologic Division where he was senior, then principal geologist during the 1930's and the 1940's until 1952, when he returned to the Director's Office as Staff Geologist to Director Wrather.

His appointment as Associate Director, the Survey's first Associate Director, was effective in February 1956. It followed by a month Nolan's confirmation by the Senate as the Survey's seventh Director.

Within the organizational structure of the Director's Office, Baker was the principal contact in day-to-day matters concerning the Geologic, Conservation, and Publications Division. He was also the final arbiter in the fates of those reports by Survey authors that were perceived by Hugh D. Miser as containing assertions that were in possible conflict with Survey policy or that might place the Director and the Survey in a difficult but avoidable political or jurisdictional position.

Baker was the Associate Director in every sense of the title. A long-time friend, advisor, professional associate, and confidante of Nolan, he shared in the development, interpretation, and implementation of Survey policies during Nolan's tenure as Director. His conservative and cautious decisions were, at times, the cause of angst among those of his subordinates who were more liberal and aggressive, some of whom referred to Baker as the conscience of the Survey or, at times and more humorously, as "the Abominable No Man." But even with such sobriquets, there was no diminishment of the respect and admiration felt for Baker by his associates.

On his 70th birthday in 1967 and more than 46 years after he joined the Survey, Baker formally retired. But he was immediately rehired and served for another 6 years as Special Assistant to the Director.

### Robert H. Lyddan (1910–90)

Robert H. Lyddan was appointed Assistant Director by Nolan in May 1956, soon after Nolan became Director. Lyddan was an engineer. His appointment broke the tradition of naming only geologists to such positions and quelled murmurs of dissatisfaction from members of Divisions with large engineering staffs—namely, Topographic and Water Resources Divisions. His appointment brought another skilled administrator into the directorate. It also placed a person at this level who was intrinsically compassionate, articulate, and a source of judicious counseling. These attributes and his availability to members of WRD were especially valuable during this period of WRD history when tensions, unease, and uncertainty were palpable.

Lyddan was born in Irvington, Ky., in 1910. After completing high school, he enrolled at the University of Kentucky and was graduated with a B.S. degree in civil engineering in 1931. After several years of various engineering jobs, Lyddan joined the Survey in 1933 as a field assistant in the Topographic Division. Like many of his associates in that Division, he spent years mapping areas from Puerto Rico to Alaska. In 1946, Lyddan was transferred to Washington, D.C., where he rose rapidly through several technical and administrative jobs to the position of Atlantic Region Engineer in charge of topographic mapping in the 20 States east of the Mississippi and in Puerto Rico and the Virgin Islands. From this position, he was appointed Assistant Director.

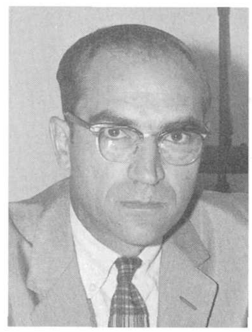
Lyddan later said that at the time of his appointment to the new position with its responsibility for WRD contacts, he knew WRD was a part of the Survey but little more about it. Lyddan obviously needed no assistance in his contacts with Topographic Division. However, to help Lyddan in his routine association with WRD, the Director created the job of staff assistant to Lyddan to be filled for 2 years at a time by someone from WRD. Beginning in about 1957, that job was filled by John Horton, Russell H. Langford, Hugh H. Hudson, William W. Doyel, and Hal K. Hall. Although the position was created primarily to supply staff assistance to Lyddan, it returned benefits to the Division by providing midcareer members with a level of experience not otherwise available.

Lyddan remained as Assistant Director for 12 years, then returned to Topographic Division in April 1968 as Division Chief. He was succeeded by Frank Clarke, formerly of WRD. Clarke's assistant, with a somewhat higher level of responsibility than were Lyddan's assistants, was Albert N. Cameron of WRD.

In his videotaped interview by E.L. Hendricks in June 1988, Hendricks asked Lyddan if there were any reminiscences that he would like to share. Lyddan said that he felt that WRD was the best Division in the Bureau. It had an *esprit de corps* unmatched by any other Division, including his own. It had a system for reaching out to the grass roots that was important in the development of programs and in communicating with the people who benefited from its work that no other Division had. "It is a blue-ribbon Division, in my opinion. I came to know some very fine people from WRD and felt my life was made richer by those associations. They were dedicated to their work and were gentlemanly in all respects. It was a wonderful experience."

Lyddan carried a newspaper clipping in his billfold that he read occasionally. The clipping contained some sagacious observations of philosopher and baseball great, Satchel Paige, including the warning, "Don't look back, something may be gaining on you."

### Luna B. Leopold (1915–)



Luna Leopold was named Chief of the WRD in April 1957 after Carl G. Paulsen's retirement. He began his new job on May 1.

Leopold's route to Chief, WRD, was unconventional. It did not follow the traditional, step-by-step, career ladder. The generations of Division leaders who preceded Leopold were hired at the bottom of the salary scale and spent years learning, practicing, and supervising the fundamentals of field work in their discipline at several field locations before being tapped for a high-level supervisory, administrative, or technical position in the Division. Leopold not only bypassed the normally required field apprenticeship but entered Survey employment at a grade higher than that of most District Engineers, District Geologists, and District Chemists. The circumstances of his entry into the Division precluded his developing a strong loyalty to an operating Branch or to popular Branch programs. His nontraditional background was a favorable quality, if not a prerequisite, for the person selected by Nolan to change the course of the Division. But a background that precluded knowledge of the Division's field programs and of the people who operated the programs was, in a sense, a troublesome attribute for a new chief of a large organization. Lack of knowledge of the large numbers of people in the field was not a crippling deficiency, but it did create a bumpy road.

Leopold was graduated from the University of Wisconsin in 1936 with a B.S. degree in civil engineering. He then worked for the Soil Conservation Service (SCS) in New Mexico as an agricultural and hydraulic engineer until 1942 under the supervision of Thomas Maddock, Jr.

During the 1938–39 academic year, Leopold was enrolled as a graduate student at Harvard, where his major professor was Kirk Bryan. Professor Bryan, a former part-time employee of the Survey, was the mentor of a generation of prominent geomorphologists both inside and outside the Survey.

Leopold transferred to the Corps of Engineers Los Angeles District in 1942; then, in December, he enlisted in the U.S. Air Force. While in the Air Force, Leopold attended the University of California in Los Angeles where he earned an M.S. degree in meteorology in 1944.

After his discharge from the Air Force in early 1946, Leopold applied for a job with the Bureau of Reclamation (BOR). He was hired as an Associate Engineer in its Branch of Project Planning in Washington, D.C., with responsibility for its sediment program. While with the BOR, Leopold became known to, and admired by, Paulsen, partly through personal contact and partly through Leopold's association with senior WRD staff including Harold V. Petersen and Walter B. Langbein. During his brief assignment with the BOR, Leopold persuaded Maddock to leave SCS for a job in the BOR.

In October 1946, Leopold resigned from the BOR to take a job as meteorologist-in-charge, Pineapple Research Institute (PRI)/Hawaiian Sugar Planters Association (HSPA) in Hawaii. He visited Paulsen and Royal W. Davenport, Chief of the Technical Coordination Branch (TCB) before leaving for his new job and was invited to join WRD instead of going to Hawaii. Leopold declined.

His next contact with WRD was on a rare visit by a senior official to Hawaii. Joseph V.B. Wells visited the Honolulu SWB office about 2 years after Leopold began working for PRI/HSPA. Probably at Paulsen's request, Wells contacted Leopold and repeated Paulsen's offer of employment with the Division. Paulsen's offer came when Leopold was planning to return to graduate school. He had discussed his plans with his supervisor, but no agreement had been reached as to employer sponsorship and Leopold's subsequent obligation to PRI/HSPA. Leopold accepted the WRD offer and reported to Los Angeles, his first duty station, in September 1949.

Leopold's office was in a Subdistrict office of the California SWB District, headquarters of which were in San Francisco. Leopold was given the vague assignment of serving as field representative, west of the Mississippi River, of the TCB. Having no supervisor closer than Washington, D.C., and no routine duties, he chose to write his first paper on the hydraulic geometry of stream channels.

In January 1950, Leopold was transferred to Washington, D.C., as a research hydraulic engineer in the TCB. He was given a desk in Royal Davenport's office and complete freedom to pursue his research interests. He remained in that job until June 1956 except for several periods of part-time service in 1950 while in graduate school at Harvard. Leopold was granted the Ph.D. degree in geology by Harvard University in 1950.

Leopold is no doubt well remembered by his graduate school classmates for many reasons, not the least of which was his unrelenting encouraging, cajoling, even berating those who appeared to be lagging in their Ph.D. thesis research.

Leopold was promoted and reassigned as Chief, Branch of Program Control, in summer 1956. He succeeded George E. Ferguson who had been appointed Division Hydrologist, ACA. Almost immediately, the job was changed to Assistant Division Chief for programs and a parallel Assistant Chief for operations was created. Raymond L. Nace was transferred to Washington, D.C., from Idaho to become Assistant Chief for operations.

Events moved rapidly in early 1957. Paulsen retired at the end of April. Leopold's appointment as Paulsen's successor was announced by the Director in an April 18 letter to Division Chiefs advising them of Paulsen's retirement. Thus, Leopold became Chief Hydraulic Engineer of the Survey and Chief, WRD, 8 years after entering on duty.

Leopold was born on October 8, 1915, in New Mexico, the son of Aldo and Estella Leopold and a descendant through maternal lineage of a pioneer Spanish land-grant family.

Aldo Leopold was a founder of the Wilderness Society and was instrumental in establishing the Gila Wilderness Area in New Mexico, a precursor of the U.S. Forest Service wilderness-area program. He founded the profession of game management and authored many books and papers on conservation, including "A Sand County Almanac," an established environmental classic.

In the pattern of scientific eminence set by Aldo Leopold, Luna was elected in 1967 as the first hydrologist member of the National Academy of Sciences. A brother and a sister were also elected to membership in the Academy, remarkable individual and family accomplishments.

Such a family background, deeply rooted in environmental concerns and in science, lent a natural affinity to Leopold's involvement in environmental issues. He was actively and effectively an opponent of the proposed Marble Canyon Dam (Arizona) and the Miami (Florida) jetport, neither of which was built. He wrote an assessment of the damage to the Everglades environment that would have resulted from construction of the proposed jetport that was later said by Leopold to have been the model for the many environmental impact statements on other proposals that followed.

Some of Leopold's associates were able to find humor in his conservationist views. During the summer of 1961, he saw a motorized scooter in the bed of a pickup driven by a Geologic Division geologist in western Colorado. Leopold asked the geologist about its use and learned that scooters were being used to facilitate high-country mapping. On returning to Headquarters, Leopold wrote to the Chief Geologist and expressed his objections on esthetic grounds and on grounds that the Geological Survey should not be associated with motorized excursions into wilderness or potential wilderness areas. The Chief Geologist's reply is not in the record; however, the incident did make the satirical Pick and Hammer Show the following winter.

Leopold brought into his new position a strong commitment to a scientific approach to water as a natural resource and an equally strong commitment to increasing the research content and competence in Division programs. He viewed water in nature as a single resource and felt that the Division's compartmentalization, by programs and organization into surface, ground, and quality of water, was not only artificial but detrimental to the development of the kinds of programs that he fervently desired. He also brought into his new position a strong personality and the ability to forcefully articulate his views.

Leopold's vision of WRD was an organization staffed by a new breed of professionals selected for their academic proficiency in the basic sciences and possessing above-average class standing in the scientific or engineering disciplines that constitute hydrology. He envisioned an organization free of organizational barriers and structured to approach water-resources problems as an interdisciplinary team. His highest priority and most immediate goal was to strengthen the research program of the Division.

An intense dedication to research was antecedent to comments written or spoken by Leopold that did not account for the hundreds of Division employees whose careers were molded around other professional endeavors. Soon after becoming Division Chief he said: "The research man of this Division is in a special class—a caste apart!" Leopold observed later that whatever he then added was lost in the tumultuous objection to that statement.

Leopold's personal research interests were in erosional processes, particularly in the shape of stream channels in alluvial materials and the characteristics of flood flows and of the sediment transported and deposited by the streams. His interests in geomorphological processes were likely stimulated by his experiences and observations under Maddock's supervision when they were employees of the SCS in the Southwest and whetted under the tutorial direction of Professor Kirk Bryan at Harvard. Leopold and Maddock coauthored PP 252, "The hydraulic geometry of stream channels and some physiographic implications," for which they were jointly awarded, in 1958, the Kirk Bryan Award of the Geological Society of America.

Leopold was impatient with the conventional process of obtaining significant increases in Federal-program funds, the only logical source of funds for research. It was and is a process that requires much time and several hazardous levels of review. Data-collection activities in regions of large-scale Federal land ownership, hence "dominant Federal interests," were supported by Federal-program funds. Such areas included Alaska and the Colorado River Basin. Those funds were eyed covetously. Headquarters administrators who held staff responsibility for allocating funds to such activities developed a proprietary interest in their turf and engaged in imaginative and novel ways to protect those funds from being reprogrammed for any other purpose, including research.

There had been talk of reorganizing the Division to consolidate WRD field operations under a single Chief for each District and under one roof for years before Leopold's arrival. The arguments for change were compelling. Cooperators had complained about the inefficiencies created by dealing with Branch representatives in different towns in some States—a few, in different States. Leopold embraced the concept of reorganization and adopted it as a cornerstone of his plans to visibly express Division philosophy. Leopold put the finishing touches on the reorganization plan, got it approved, and set it in motion; but it fell to his successor, Hendricks, to completely implement the plan and to develop complementary organizational changes at Headquarters.

Leopold also brought into his new position a management style that had never before been experienced by the Division. His approach to problems was defensible on purely intellectual grounds but fell short, at times, where real-world considerations were important. He espoused a career-development plan, modeled somewhat after Geologic Division practices, of rotating professional employees between routine district work and research and administrative duties. It was not fully successful and was never implemented on a regular basis.

Leopold resigned as Chief Hydrologist in January 1966 to devote more time to research. He stayed on the rolls for another 13 years during which time he became Professor, Department of Geology and Geophysics, University of California, Berkeley. He also continued to be recognized for his scientific achievements and effective leadership of environmental causes.

### Raymond L. Nace (1907–87)

G. Edward Lewis, Geologic Division, retired, and former professor of paleontology at Yale, reminisced to this writer about Raymond L. Nace as his student. Lewis expressed disappointment and surprise that Nace had chosen a career as a hydrologist because he showed so much promise as a paleontologist.

Nace was an accomplished hydrologist, writer, and administrator. He was graduated from the University of Wyoming in 1935 with a B.S. degree in geology and, in 1936, an M.S. degree, also in geology. Most of the next 5 years were spent in graduate school at Columbia and Yale and in teaching at Wyoming. His first WRD assignment, in 1941, was as Geologist-in-Charge of the Survey's one-man ground-water office in West Virginia. World War II interrupted Nace's career for 4 years. On his return to the Survey in early 1946, he was assigned briefly to ground-water studies in western Nebraska. Then he was reassigned and promoted to District Geologist for Idaho. From 1949 to 1956, Nace was in charge of WRD work related to water-supply and waste-disposal problems at the Atomic Energy Commission's National Reactor Testing Station in Idaho. Owing to his interest and expertise in radiohydrology, which term he coined, Nace was placed in charge of WRD's nationwide radiohydrology program in 1954.

In 1953 and 1954, Nace was temporarily assigned to the Military Geology Branch of Geologic Division to assist in a classified study of natural radionuclides in water. For a few months in 1955 and 1956, Nace served as staff geologist and coordinator of GWB studies in the Pacific Northwest, including Alaska.

In 1956, Nace became the Division's first Assistant Chief for Operations, following the Headquarters reorganization that created two Assistant Chief positions. The other was that of Assistant Chief for Programs, which was filled by Leopold at about the same time. These moves brought Nace and Leopold into contact for the first time and indeed, into a close working relationship. Although the Assistant Chief positions were prestigious, neither exercised much direct-line authority, which largely remained with the chiefs of the Branches.

One of Leopold's first moves on becoming Division Chief was to name Nace as Associate Chief. They had much in common in their strong scientific and academic backgrounds and in their advocacy of greater emphasis on research. Nace, in his new assignment, was asked to give special attention to research activities.

Nace took leave in 1960 to return to Columbia for additional graduate work and was granted a Ph.D. degree in June of that year. He then returned to the Division, where he remained Associate Chief until the fall of 1962, when he became a Staff Scientist in the Office of the Division Chief. As a Staff Scientist, Nace enjoyed the freedom from administrative tasks and the opportunity to apply his talents to "global" hydrology. He is considered to be the father of the International Hydrological Decade (IHD), which was cosponsored by UNESCO, World Meteorological Organization, and the International Association of Hydrologic Sciences (IAHS) (See Part IV, "International Programs.") Because of Nace's leadership, WRD became the largest U.S. contributor of staff and expertise to the 10 or so technical publications that were published by the sponsoring organizations during and immediately after the IHD. Nace was the U.S. delegate to the coordinating council of IHD and chairman during the early years of the program. He later served as Hydrology Liaison Officer for the Central Treaty Organization Economic Commission for several Middle Eastern countries and advised the Governments of Chile and Argentina on their research programs in hydrology. After his retirement in 1977, Nace remained on the rolls as a reemployed annuitant until late 1983, putting the finishing touches on what he referred to as his hydrology treatise, "The Physical Basis of Hydrology," a global account of the nature of hydrology and a contribution of UNESCO and the USGS to the IHD. His final years were spent in Idaho where he died March 6, 1987, in Boise.

### Ernest L. Hendricks (1909–)

Although the development of Ernest L. Hendricks' career with WRD would not be considered extraordinary today, it was unusual 40 or more years ago because of the early, and at that time novel, emphasis on special interdisciplinary studies and research. The circumstances of Hendricks' youth shaped a lifetime of interest in nature and in the environment.

Hendricks was graduated from the University of Florida in 1931 with a B.S. degree in civil engineering. He was graduated at the outset of the Great Depression when jobs with career potential were rarely available, but he and adversity were not strangers. Both of Hendricks' parents were deaf and died when he was young. He was raised by grandparents on a farm in northern Florida where he enjoyed the freedom and the exposure to nature offered by the fields and the woods of the farm.

After working intermittently for the Florida Road Department, Hendricks began preparing himself for a teaching career. He took courses in education and taught high-school math until 1935 when he was offered a job with the USGS. Work with the Survey not only offered career opportunities but also provided an immediate salary increase from $990 a year to $2,000 per year.

Hendricks' WRD career began with the Florida SWB District where he gaged streams and did routine office computations for 3 years. During the last years of his Florida assignment, Hendricks did a comprehensive analysis of the flow characteristics of the Kissimmee River Basin under Walter Langbein's general supervision. That may have been the first such analysis based on modern hydrologic techniques undertaken in Florida.

Hendricks was transferred to Atlanta in early 1942 where he continued stream gaging and processing streamflow records for the next 3 years. In 1949, he was assigned the task of defining the hydrology of limestone sinks in an area of southwest Georgia as a part of a larger project investigating the natural history of malaria. This may have been the first interdisciplinary research project undertaken by the Division.

On completing the limestone-sink project, Hendricks was transferred to Baton Rouge, La., to do the surface-water work required in an investigation of water-quality and water-supply problems of rice irrigation in southwest Louisiana. Although, as Hendricks later reminisced, the project and its final report involved ground water represented by Paul Jones and water quality by Burdge Irelan, efforts to organize and manage the project on an interdisciplinary basis were unsuccessful. Branch rivalries and the personalities involved did not yield to close technical cooperation.

In 1952, the rice-irrigation study was completed and Hendricks was asked to return to Atlanta as a one-man representative of the Technical Coordination Branch (TCB). His mission was to try to achieve some level of technical coordination among the three main operating branches and to stimulate multibranch projects; but lacking authority and control of funds and personnel, his efforts, by his own admission, met with little success. In his spare time, Hendricks devised a small research project to investigate the relationship between floods and channel shapes. This project came to Leopold's attention and resulted in a visit by Leopold to Hendricks in Atlanta—their first contact.

Hendricks was transferred to Washington, D.C., in 1956 to head the new Research Section in the GHB. Royal O. Davenport had just retired and Charles C. McDonald had been brought in from the Northwest to serve as Branch Chief. The research activities of the Branch at that time consisted almost entirely of Soil and Moisture Conservation (S&MC) projects in Western States where WRD was helping the Bureau of Land Management (BLM) in problems involving soils, water supply, and grazing.

After Joseph V.B. Wells' selection by Leopold to become an Assistant Division Chief in early 1960, Hendricks was named to replace Wells as Chief, SWB. Hendricks was not fully comfortable in his new job at first. Although he knew little about the inner workings of the Branch, he had what Leopold wanted infused into the Branch, a strong commitment to research, a belief in the scientific and interdisciplinary approach to water-resources problems, and the ability to articulate those objectives. Hendricks' initial deficiencies in understanding the administrative details of Branch management were more than compensated by the loyal, dedicated assistance of Adrian H. Williams, who had been in SWB at Headquarters for many years and had served as Assistant Branch Chief to Wells.

Hendricks was a participant in the game of musical chairs that seemed to characterize Leopold's management style during the 1960's. After serving temporarily as Assistant and Associate Division Chief, Hendricks was named Associate Chief, WRD, in 1963. He continued his personal involvement in research and collaborated with Robert S. Sigafoos and others in glacial and dendrochronology studies in Arizona and Washington State.

Hendricks was named to succeed Leopold as Chief Hydrologist in June 1966.

### Albert G. Fiedler (1897–)

Albert G. Fiedler retired in March 1961 as Assistant Chief, WRD, with 41 years, 3 months, and 13 days, by his accounting, of service with WRD. His long service with the Division and to the water-resources community were marked by numerous technical and administrative achievements.

Fiedler's WRD career began in 1918 after graduating from Penn State where he earned the B.S. degree in civil engineering. His M.S. degree was also from Penn State. Fiedler's first assignment was as a computer in the Washington office of the SWB; then he served briefly in the military and after being discharged was assigned in 1920 to Boise, Idaho, as Office Engineer to clean up a backlog of unpublished streamflow records. He worked a few months for G. Clyde Baldwin, who was soon assigned to Idaho Falls as Water Master for the Snake River. By Fiedler's admission, he also worked under the scrutiny of Miss Hazel Haugse, the iron-willed District Clerk. Baldwin's successor and Fiedler's next supervisor was Carl G. Paulsen, thus beginning a long period of friendship and mutual admiration and respect. Fiedler was transferred to Texas in 1923, where for the next 2 years he constructed and operated gaging stations for C.E. Ellsworth, District Engineer.

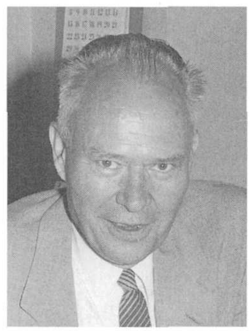
In 1925, Fiedler was asked by O.E. Meinzer to join the GWB. Ground-water studies had traditionally been the realm of geologists who reported mainly on ground water within the framework of the geologic environment. However, the rapid, and in some cases, the uncontrolled development of ground water generated a need for quantitative information that could serve the administrative and legal regulations of ground-water withdrawal. In short, engineers were now needed on the GWB staff to add a quantitative dimension to the qualitative descriptions of ground water traditionally supplied by geologists. Fiedler accepted Meinzer's offer.

Fiedler's first assignment as an engineer for ground-water studies was in the Roswell Basin of New Mexico where he worked with geologist S.S. Nye. Their report on the geology and ground-water resources of the basin provided the basis for a ground-water code applicable not only to the rest of the State but also served as a model for similar legislation in other States.

After completing the Roswell Basin assignment, Fiedler was transferred to Minnesota where he developed a close and beneficial association with well drillers that led to improvements in well construction and in the design of well screens.

Fiedler was transferred to Washington, D.C., in 1931, and in 1942 became Meinzer's assistant. In 1957, after Leopold's promotion to Division Chief, Fiedler was named Assistant Division Chief, the job he held during the first half of the "years of change" and until his retirement in March 1961. His record of technical achievement, proven administrative ability, and field service in two Branches afforded a trusted link between the old and the new. Not part of the record but important attributes were an engaging personality and unfailing sense of humor. He was the author or coauthor of more than 50 reports and papers on ground water, well construction, and legal control of ground water.

### Joseph V.B. Wells (1906–87)



A second Assistant Division Chief position was created in early 1960 and Joseph V.B. Wells was selected for the job. Thus, another strong but short-lived link was forged between the old order and the new. Wells retired in May 1961 after suffering a massive heart attack.

Wells was graduated from Columbia University in 1927 with a B.S. degree in civil engineering. He worked as a land surveyor for a short time before joining the Survey in 1929 as a junior engineer and stream gager in the New York SWB District. Three years later, he was transferred to Pennsylvania and in 1938 was named Assistant District Engineer of the Pennsylvania District. In 1940, Wells was named District Engineer for SWB operations in Kentucky. Wells' extraordinary demeanor and leadership, his excellent rapport with coworkers, and his knack for innovation and progress brought him to the attention of Paulsen, who chose Wells in 1946 to be Chief of the SWB.

Under Wells' leadership, the programs of the SWB increased about 50 percent. To keep pace with increases in program size and diversity, he created the Technical Standards Section, later renamed the Floods Section, enlarged the Annual Reports and Special Reports Sections, and created the Research Section. Wells gave new emphasis to training by creating a Training Section. He further improved Branch administration in 1956 by establishing the Planning Section, the functions of which had been previously handled by individual staff assistants.

Wells brought more than outstanding leadership, knowledge of surface-water programs, and administrative ability to his position as Assistant Division Chief. He brought knowledge of the employees of SWB and of other members of the Division whose acquaintance he consciously sought. His acquaintanceship with staff was not left entirely to chance. Field personnel temporarily detailed to Headquarters for "records review" were pointedly advised to go across the river from Arlington Towers and visit Wells. Wells was never too busy to put his feet up on the desk, put his awe-stricken visitor at ease, and visit a while. Also, he sought out individuals from other Branches who were on detail at Headquarters for similar "visits."

Wells had a special association with Leopold. On a trip to Hawaii, he contacted Leopold and successfully urged him to join WRD. Although Wells supported Leopold in his overall objectives for the Division, Leopold's methods of reaching those objectives did not fully agree with those of Wells. A major concern of Wells was the role of the Cooperative program and of reversals that the program might suffer in a redirection of the Division.

After Wells retired, he continued to serve as Delaware River Master until 1975, a position he had held since Carl G. Paulsen died in early 1961.

### Elwood R. Leeson (1912–95)

Elwood R. Leeson's organizational and administrative talents were prominently displayed when he served as Assistant Division Chief for operations from 1961 to late 1968. These years were a time of major organizational changes at Headquarters and in the field. The status of Branches changed from line to staff, and the operational responsibilities of each Branch at Headquarters were abolished

and replaced by an operations unit serving the entire Division under Leeson's direction. Also during Leeson's administration of Division operations, all Branch district offices were integrated into Division-level Districts.

The selection of Leeson to serve as an Assistant Division Chief marked the first time Leopold filled such a position directly from a District. When selected, Leeson was SWB District Engineer in Kansas.

Leeson began his WRD career in 1937 as a stream gager in the St. Louis, Mo., Subdistrict office. He was graduated from the University of Kansas in 1934, with a B.S. degree in civil engineering. His first job was with the Kansas Highway Commission.

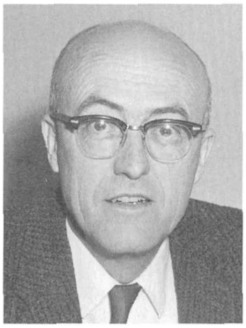
In 1942, Leeson was transferred to Lincoln, Nebr., as Assistant District Engineer and Operations Engineer for surface-water operations in Nebraska. Ten years later, Leeson became District Engineer for Kansas with the charge of upgrading the surface-water program that had become mired in low productivity, poor quality control, and narrow program objectives.

By personal involvement in technical problems and by guidance of engineers under his supervision, Leeson upgraded the streamflow programs in Nebraska and Kansas. In Kansas, for example, he had Lawton W. Furness prepare a series of reports on streamflow characteristics that served as the technical basis for a water plan for the State.

Leeson also had a strong personal commitment to his profession and discipline. He was elected to offices of the American Society of Civil Engineers (ASCE) and State engineering societies up through president in Kansas and Nebraska. He served as national Vice-Chairman of the Society's Council 16 and chaired its National Committee on Younger Members.

Leeson served as Assistant Chief for Operations for more than 6 years, longer than any other Assistant or Associate Division Chief during this period of reorganization and change. His sense of humor, enjoyment of working with people, managerial ability, and knowledge of the details of Division operations enabled him to survive many stressful situations and to ensure administrative and operational continuity during this period.

### Tyrus B. Dover (1922–92)



One of the remarkable aspects of Tyrus B. Dover's 30-year career with the WRD was the rapidity with which he rose from P-1 to GS-15. He was graduated from the University of Arkansas in 1947 with a B.S. degree in chemistry. After 3 months with a paint company in St. Louis (trying, as he said later, to duplicate other companies' products), Dover joined WRD as a chemist, P-1, in the Fayetteville, Ark., water-quality office. In 1948, he was reassigned to Stillwater, Okla., and was promoted to P-2 in 1949. He was promoted to GS-9 in April 1951 and to GS-11 in September of the following year. In March 1954, Dover was transferred to Oklahoma City as District Chemist to supervise QWB operations, statewide. He was promoted to GS-12 in October 1955 and again in December 1958 to QWB Area Chief, MCA, at grade GS-13. Although Area headquarters would later be in St. Louis, no Area office had yet been established, so Dover performed his area duties from Oklahoma City. Dover was promoted to GS-14 in September 1960 when he was transferred to St. Louis as Division Hydrologist. In March 1962, only 15 productive years after joining the Survey, Dover was moved to Washington, D.C., as an Assistant Division Chief and was promoted to GS-15.

More than once, the assignment given Dover was in uncharted waters. He was the first QWB Area Chief in the MCA. When he was transferred to St. Louis as Division Hydrologist, there was neither an office nor a staff. Establishing the office was not easy. Although Director Nolan wanted the office on the campus of Washington University, no campus space was available and adjacent areas were high-rent districts. Dover found space in the downtown Federal Building. Staffing the key Area Headquarters positions was a slow process. On January 1, 1961, Dover was still alone. Of three Branch Area Chief positions, two had been filled since 1957, but those selected found new and imaginative reasons to delay their moves to St. Louis. And, of course, Dover's reassignment to the Area position immediately created a Branch Area Chief vacancy for the QWB. Even Dover, himself, was reassigned to Division headquarters in early 1962.

In Dover's autobiography, he modestly noted that he was reassigned "to Washington, D.C., as an Assistant Division Chief to give particular attention to administrative management matters." But those administrative management matters were the leading edge to new approaches to hiring and training personnel and to establishing the hydrologist series by the CSC. Under Dover's direction and with his personal involvement, selection standards for new professional hires were developed and the hydrologist series of the CSC was established. WRD nominally (and Dover by virtue of capability and interest) devised, with assistance from the Branches, the qualification requirements and the grade-level standards. An important detail of his success with the hydrologist classification is that the CSC allowed it to fall into the same shortage category for pay purposes as engineers and chemists. This achievement was critical to the success of WRD's recruiting efforts and, later, in the reclassification of most WRD professionals as hydrologists.

Because of the ease with which Dover worked with others and because of his ability as a manager and supervisor, he played key roles in the development of other personnel policies and programs during his tenure as Assistant Division Chief. A Division training program for new hires was begun in Denver, and a degree program for hydrologists and a short course in hydrology for mid-career employees were begun at the University of Arizona.

But working as an Assistant Division Chief was not to Dover's liking. After 2.5 years in the job, he asked to be transferred back to the field and was assigned in mid-1964 to the Denver headquarters of the RMA as QWB Area Chief. He was named Assistant Regional Hydrologist in 1967. Dover continued to apply his interests and expertise to regional and national personnel matters as a senior member of the Denver regional staff. He continued developing Division training activities, selecting students for graduate school, and providing jobs and training opportunities to members of minority groups.

On Dover's retirement in 1977, Chief Hydrologist Cragwall said that Dover applied the human factor to personnel matters. Dover died in October 1992.

### Charles C. McDonald (1907–)

Charles C. McDonald became the first Chief of the GHB after its creation from the TCB in 1956. McDonald brought to his new job a solid background in surface-water hydrology, experience in international water activities and interdisciplinary studies, and a keen interest in hydrologic research.

McDonald, like Leopold, grew up in New Mexico. He attended the University of New Mexico and earned the B.S. degree in civil engineering in 1929. After a brief tour with the American Bridge Company in Gary, Ind., he joined the Survey and reported to the SWB District in Tucson. McDonald earned his stripes as a stream gager during the next 6 years as resident engineer at the Lees Ferry gaging station. He designed and built gaging stations elsewhere in the State and supervised operation of the Verde River network of streamflow data-collection sites.

In 1936, McDonald was transferred to Albany, N.Y., to work for A.W. Harrington, first constructing 25 gaging stations and then serving as Engineer-in-Charge of the Ellenville office.

McDonald was transferred to Boston in 1940 as assistant to District Engineer H. Banks Kinnison. He supervised the field and office work of the SWB District until 1945 when he took a special assignment in Washington, D.C., to work on a study of Columbia River hydroelectric-power potential.

After completing the Headquarters assignment, McDonald was transferred in early 1946 to Tacoma, Wash., to investigate and report on the hydrology of the Columbia River Basin in support of the International Columbia River Engineering Board. During the next several years, McDonald undertook and completed several major projects in the Columbia River Basin that included coordinating the Survey's work after the record-breaking 1948 floods and developing a method for use of a base-flow index to improve winter forecasts of streamflow for power generation by the Bonneville Power Administration.

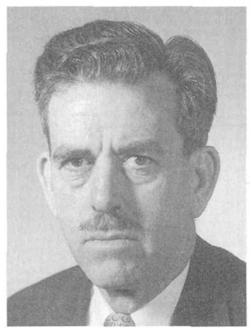
After transferring to the TCB, Washington, D.C., in 1955, McDonald continued to apply his hydrologic skills, particularly his knowledge of the hydrology of the Columbia River Basin and his natural talent for working smoothly with others, to interagency activities. He served as a member of the International Souris-Red Engineering Board and chaired the U.S. Section of the International St. John Engineering Board in 1959 and 1960.

McDonald became Chief of the GHB in 1956 at a time when other changes at Headquarters were taking place. Nace and Leopold moved into Assistant Chief positions, and a year later Leopold became Division Chief.

In 1960, plans were made for a comprehensive study of the water resources of the Lower Colorado River along the main-stem valley. This interdisciplinary project had international and interagency dimensions. McDonald was chosen to be project hydrologist with headquarters in Yuma and with the project assigned to the GWB. (See Part IV, "Lower Colorado River Project.")

With the Lower Colorado study nearing an end by 1968 and river-basin studies under sponsorship of the Water Resources Council gaining momentum elsewhere, McDonald joined the Central Region staff in Denver to assist the Survey and Division in nationwide river-basin planning. He represented the Survey on planning groups of the Upper and Lower Colorado River Basins. McDonald retired in 1970 after more than 40 years of technical and administrative leadership, including interagency and international water activities.

### Thomas Maddock, Jr. (1907–91)



According to Thomas Maddock's recollection of his early days with the Survey, he was recruited from the BOR by Carl Paulsen and reported for work in June 1957. Owing to the long-time association between Maddock and Leopold, it is likely that Paulsen asked Maddock to transfer to the Survey at Leopold's request.

The association and mutual admiration began in the late 1930's when Maddock was with the Soil Conservation Service (SCS), Division of Research, in Albuquerque, in charge of rainfall-and-runoff studies in desert areas. Maddock was Leopold's supervisor during the years 1938 to 1942 and described him as "an energetic young student from Harvard Graduate School." Their association was interrupted by World War II, then resumed after the war.

During the war years, Maddock worked in Central America in an agricultural program developing a farm-marketing system to assure sources of fresh fruits and vegetables for military personnel in the Canal Zone.

After the war, Maddock returned to the SCS. Leopold accepted a job with the BOR and arranged with Maddock for his transfer to Denver to head the sedimentation studies of the BOR's Division of Hydrology.

Maddock continued working for the BOR and was transferred to its Washington headquarters in late 1950. There he held several engineering positions and in 1952 became head of the Branch of Irrigation Operations. In early 1954, Maddock was temporarily assigned to the Water and Power Task Force of the second Hoover Commission on Organization of the Executive Branch of Government as Chief Irrigation Analyst. Meanwhile, he and Leopold wrote The Flood Control Controversy that was published in 1954.

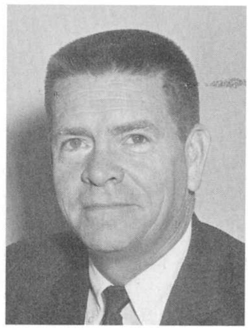
Maddock came to WRD as a Staff Scientist in mid-1957, shared an office with Walter Langbein, and worked on alluvial-channel research and on day-to-day problems as they came up. In August 1961, Leopold asked Maddock to become Chief of the GHB, a position occupied by Charles C. McDonald before his reassignment to the Lower Colorado River study in early 1960. Maddock accepted and remained as Branch Chief until late 1962 when he requested and was granted permission to move to Tucson as Staff Research Hydrologist.

The move to Tucson was a return home for Maddock, an Arizona native and a 1928 graduate of the University of Arizona in civil engineering. After graduating, Maddock worked in the Southwest, except for the war-years assignment in Central America, for the next 22 years. From 1928 to 1935 Maddock worked for several engineering companies in Arizona on construction, largely on pipelines and canals. He began his government career in 1935 with employment by SCS as Assistant Engineer in charge of hydrologic studies for a flood-control report on the Gila River. Maddock transferred to the SCS's Division of Research in 1936 to direct watershed and hydrologic studies in Arizona. He was promoted and transferred to Albuquerque in 1937 as Chief of Watershed Studies in all of SCS Region VIII. He continued in watershed and other types of hydrologic studies in New Mexico and Arizona through 1942. In this location and kind of work, Maddock met Leopold and became his supervisor.

Maddock and Leopold shared much in common, both born and raised in the Southwest, a fascination with arid-lands hydrology, career roots in SCS and BOR activities, and keen scientific interests in and pioneering studies of the relationships between streamflow, sediment, and geometry of alluvial channels. They shared, too, in the international recognition accorded their work.

Maddock served as consultant on water problems in India and Pakistan and to the Justice Department and Federal Courts in several landmark cases involving litigation over land and water. He received numerous awards, including an honorary Ph.D. degree from the University of Arizona and honorary membership in American Water Resources Association (AWRA). Worth noting is that AWRA had granted only four such honors during the previous decade: to C.V. Theis, Abel Wolman, Raymond Nace, and William Ackerman. Maddock continued to serve as Staff Scientist with headquarters in Tucson, and later at Division headquarters in Reston, Va., long after the close of this period of WRD history. He retired from full-time service in 1974, but continued to work as a rehired annuitant for several more years.

### Frank E. Clarke (1913–)



Not unlike many of his contemporaries, Frank E. Clarke was thrust upon the job market in 1935 during the Great Depression with a newly earned degree in chemistry and no opportunities for employment in his field. Clarke did what others did, including Hendricks—he taught school. He also took graduate courses in physical chemistry at the University of Maryland and was granted the M.S. degree in 1942. In 1941, he was offered employment as a subprofessional at the U.S. Naval Engineering Experiment Station at Annapolis. Clarke soon became Chief, Water and Metals Division, and by 1961, he was Chief, Chemical Engineering Division. While at Annapolis, Clarke became an expert in corrosion and scaling problems and in water chemistry.

Also during his time at Annapolis, Clarke came to know and be known by several chemists in the Geological Survey who were prominent in technical-society, water-quality activities, including Kenneth Love, Finch White, and W.D. Collins. Love asked Clarke to transfer to the USGS to help with an anticipated increase in water-pollution work. Clarke accepted the invitation and entered on WRD rolls in 1961 as a Chemical Engineer in QWB to head the Branch Research Section. Paul Benedict was chief of the Section at that time, but was soon to move to Menlo Park to become Regional Research Hydrologist, PCA.

Clarke soon came to Leopold's attention; thus began Clarke's meteoric (by normal Survey measure) rise through the Division, the Director's Office, and on to Deputy Under Secretary, DOI.

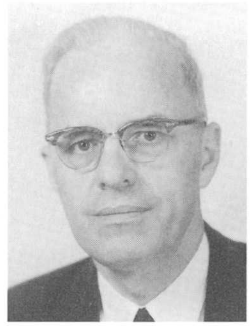
By December 1962, Clarke had been named to succeed Thomas Maddock, Jr., as head of the GHB. Before the change in his assignment became effective, Clarke visited Maddock in his office and found Maddock at work with a slide rule and pages of equations, punctuated by calculus symbols. Clarke asked Maddock if he did much of that: "Oh, yes, all the time." Clarke recalls a sinking feeling and the thought, "I will never make it in this job."

And in a sense he didn't. By the end of 1965, Clarke had been promoted to Assistant Division Chief. When Hendricks became Chief Hydrologist in 1966, he chose Clarke as Associate Chief. Hendricks recalled later that Clarke not only made decisions, but also followed up on them. The next step in Clarke's career was beyond the literal limits of Volume VI but are noted to more adequately describe Clarke's attributes.

William T. Pecora followed Nolan as Director in late 1965 and on Lyddan's return to Topographic Division selected Clarke as Assistant Director for Engineering. In mid-1971, Pecora became Under Secretary of the Interior and asked Clarke to be his deputy. Clarke declined because the job was a Schedule C, or a political appointment, and he might lose his career status and be unable to return to the Survey with the next change of Administration. Clarke accepted after Pecora's assurance that this would not happen and he did return to WRD in late 1972 as a Senior Scientist.

Clarke shared with Leopold an acute environmental awareness and strong convictions that science and its application to hydrologic problems must be the foundation of WRD programs. His systematic and positive administrative style complemented Leopold's unconventional management style. Clarke lent stability, organization, and direction to the rapidly growing research program of the Division, and an engineer's disposition for order to the Division, Bureau, and subsequently to the Department role in the physical sciences and engineering.

### S. Kenneth Love (1903–95)



S. Kenneth Love was raised in Pennsylvania and Florida and immediately after graduating from high school in St. Petersburg, enrolled at the University of Florida where, in 1927, he earned the B.S. degree in chemistry. He studied for a Masters' for another year, then began Survey employment as a junior chemist in QWB headquarters in Washington, at a salary of $1,860 per year. He took leave without pay in 1930 to return to the University to complete work on his M.S. degree, which was granted that year. Except for occasional temporary field assignments, Love's entire 40-year career was spent at Headquarters.

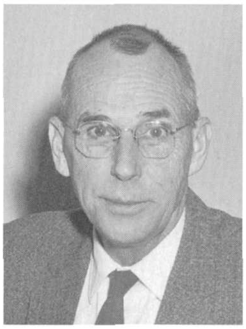
Love's first field assignment, in 1929, was to collect data on sediment concentrations of the San Juan River near Bluff, Utah. During the next dozen or so years, Love did additional field work, mostly in sediment but also in chemical quality, in the Colorado River Basin and on the Boise River in Idaho.

During Love's long and productive career with the Division, he not only witnessed but also guided the QWB through nearly continuous changes in analytical techniques, philosophies of operations, and program directions. In Love's early years in the QWB, emphasis was on sediment and the natural mineral quality of water, mostly surface water. Members of the QWB staff were largely laboratory oriented. But this changed as water-quality problems became more complex and analytical techniques became more sophisticated. Water quality came to be recognized as integral with water resources, and water-quality specialists became essential participants in hydrologic studies. Love was in the vanguard of those changes.

Love was selected as QWB Chief, effective October 1, 1946, by Carl Paulsen, who had become Division Chief earlier that year. Love served as QWB Chief for 22 years—through all of Paulsen's and Leopold's administrations and well into that of Hendricks.' He was at the helm of the QWB during the years of turmoil when the U.S. Public Health Service was establishing its role in national water-quality affairs. He maintained a stable and highly respected course for the water-quality activities of the Survey during the tumultuous years of the Congressional Jones Committee, the forming of the Federal Water Pollution Control Administration (FWPCA) and the emergence of the Environmental Protection Agency (EPA), which sought information, methodology, or staff, and even agency jurisdiction from the Survey.

Love was active in technical-society activities, particularly the American Society for Testing and Materials (ASTM), the American Chemical Society (ACS), and the American Water Works Association (AWWA). Through such activities Love met and recruited Frank Clarke. ASTM awarded Love its Max Hecht Award in 1962. In 1964, Love was granted the Fuller Award of AWWA. He retired in the spring of 1968.

### Melvin R. Williams (1903–71)



Melvin Williams will not be remembered as the horny-handed, hairy-eared engineer as celebrated in his alma mater's fight song, "Ramblin' Wreck from Georgia Tech." Other descriptive phrases more apt to come to mind are courtly, southern gentleman, on the frail side, soft spoken, the epitome of integrity and one with genuine personal concern for the careers and welfare of his people. His supervision of up to 8 or 10 construction crews in an early stage of his career seems out of character.

Williams graduated from Georgia Tech with a B.S. degree in civil engineering in 1926. Until 1929, he worked as a construction foreman, then joined the Survey as a junior engineer in the Chattanooga, Tenn., SWB office to do the office and field duties associated with stream gaging. For 2 years, ending in 1935, he supervised a major gaging-station construction program.

Williams was detailed to the Basic-Records Section in Washington, D.C., for several months in 1937 and then was transferred to Atlanta as office engineer for the newly established Georgia District. He remained in Atlanta during the war years, then in 1946 served for 4 months as a technical advisor to Allied Headquarters in Japan preparing a report with Francis M. Bell on the water-power industry in that country. He returned to Atlanta and helped develop a program with the State Highway Department that became a model to other districts and to other highway departments for applying peak-discharge data to the design of bridge openings.

In 1947, Williams was selected to become District Engineer for surface-water operations in Alabama, where the program was of modest size and scope. During the next 12 years, Williams not only greatly increased the program in size but also pioneered ways to interpret and apply streamflow data to the water-resources problems of State and local water-development and water-management agencies. He authored or co-authored several reports on the water resources of Alabama. Because of its practical applications, technical content, and reception by others, "Water resources and hydrology of southeastern Alabama," which he wrote with Rolland W. Carter, is considered to be his best.

During Williams' Alabama assignment, he served as local section president, ASCE, and was a charter member of the Alabama-Mississippi section of AWWA. His professionalism, keenness of perception, and personal grace made Williams the choice of the Branch Chief to serve on several committees and special assignments.

In 1959, Williams was chosen to head the Research Section of SWB and was transferred to Headquarters. With some 2 dozen people, the Research Section was the largest organizational unit in the Division at Headquarters and included such high-profile members as Manuel A. Benson, David R. Dawdy, Nicolas C. Matalas, H. Charles Riggs, and Vujica Yevdjevich.

Meanwhile, Branch programs and Headquarters responsibilities had grown to the extent that a second Assistant Branch Chief was needed. Williams was selected to fill the position in 1961. From this position and from an unbroken string of technical and administrative successes, Leopold selected Williams in September 1962 to succeed Hendricks as Chief of the SWB.

On visits and details to Washington and later service at Headquarters, Williams participated in and supported the Speakers Club. Despite Williams' interest it died, according to Tate Dalrymple, a long-term charter member, of benign neglect by Division leaders. On its dissolution, the club gavel was presented to Melvin Williams.

Williams guided, counseled, and supported the reorganization and move of many Branch functions, including those of research and operations to the Division. This was virtually completed by 1966. In December 1967, after nearly 40 years of service, Williams retired and returned to the South. He died in Aiken, S.C., on October 2, 1971.

### A. Nelson Sayre (1901–67)

The following was abstracted from C.L. McGuinness' Memorial to Albert Nelson Sayre, prepared for the Geological Society of America.

A. Nelson Sayre became the second Chief of the GWB in December 1946. He succeeded O.E. Meinzer, not only in that position but in maintaining and building on the foundation of scientific ground- water hydrology that was established by Meinzer.

Sayre, an Ohioan by birth, earned the B.S. degree in geology from Dennison University in 1923. He continued graduate studies for several years, first at the University of Kansas, then at the University of Chicago where he was granted the Ph.D. degree in 1928. While in graduate school, he taught geology, first at Kansas, then at the University of Pennsylvania. Dennison University awarded him an honorary Doctor of Science in 1949, and the University of Kansas recognized him as an outstanding graduate by granting him its Erasmus Haworth Award in 1953.

In September 1929, Sayre began his Survey career with an appointment as a junior geologist, GWB, in Carrizo Springs, Tex. Although he transferred to Washington, D.C., in 1937, ground-water investigations in Texas occupied most of his time until the beginning of World War II. In mid-1942, he was detailed to the Military Geology Branch of Geologic Division as its principal ground-water expert. His wartime detail became permanent in early 1943 when he transferred to the Geologic Division but continued as an advisor to the Army and to the Institute of Inter-American Affairs. He landed with the second wave of troops re-entering Leyte in the Philippines, where he helped develop adequate water supplies for the Army. For this, he was awarded the Medal of Freedom in 1945. Also in 1945, Sayre returned to the WRD and to its domestic programs.

Sayre was named Chief, GWB, in December 1946 on the retirement of Meinzer. When Sayre joined the Branch, its staff consisted of less than 30 professionals. When he became Branch Chief, the staff numbered 245. When he retired, it consisted of more than 700 employees. Sayre's tenure as Branch Chief was marked not only by a large growth in staff but also by an increasing recognition of the importance of ground water to the Nation, of vastly increasing program growth and a broadening of the scientific principles of ground-water hydrology.

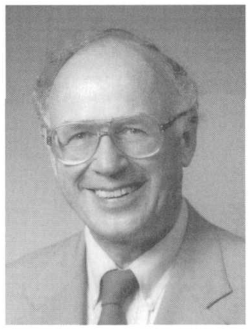
Sayre always had time for leadership in professional societies. He followed Meinzer, not only as Branch Chief, but also as President, in 1948, of the International Commission on Subterranean Waters of the International Union of Geodesy and Geophysics (IUGG). In 1946, he became General Secretary of the American Geophysical Union.

In January 1959, Sayre asked Leopold to relieve him as Branch Chief so that he could devote more time to research and writing. Leopold assigned Sayre to a senior staff position where he remained until January 1962, when he retired.

After retiring, Sayre became a consultant and continued his work with IUGG. He attended the 14th General Assembly of IUGG in Zurich, Switzerland, in 1967, where he was stricken by a heart attack and died on October 12.

### Philip E. LaMoreaux, Jr. (1920–)

Information supplied by Clyde S. Conover on Philip LaMoreaux's achievements as Chief, GWB, is gratefully acknowledged, as is William J. Powell's review of this vignette.



The Pick and Hammer Show in the winter of 1960–61 included a skit of Leopold and Nace discussing which way to go, with LaMoreaux observing. Nace: "Let's follow this channel." Leopold: "No, this is the channel to follow." LaMoreaux: "I don't know if either of you knows where you're going, but I'm going back to Alabama!"

LaMoreaux was graduated from Denison University in 1943 with a B.A. degree in geology. He was immediately hired by WRD as a junior geologist and instructed to report to Tuscaloosa, Ala. LaMoreaux was named District Geologist 2 years later and placed in charge of GWB operations in Alabama. His office, on the University of Alabama campus, provided him an irresistible opportunity to enter graduate school. He earned the M.S. degree in 1949 and became a part-time faculty member for about 20 years, teaching hydrogeology and subsurface methods. In recognition of LaMoreaux's many technical and administrative accomplishments, Denison University awarded him its honorary Doctor of Science degree in 1972.

As District Geologist, LaMoreaux, under the tutelage of State Geologist Walter B. Jones, became a strong advocate of the Coop program. Jones urged LaMoreaux to develop grass-roots support for Survey activities by speaking to service clubs and acquainting public-minded citizens and political representatives with the needs for and economic advantages of adequate water-resources information. LaMoreaux's successes led to an increase in Alabama's Coop program from a few thousand dollars to about a million within about 10 years. LaMoreaux was also summoned to the office of Governor Wallace and requested to cool it or the State wouldn't have any money for other needed programs.

In late 1957, Leopold asked LaMoreaux to chair a temporary committee whose objective was to examine certain major problems in preparing reports from project planning to report processing. At that time, about 85 percent of the Division's report obligations were behind schedule. The committee members were M. Gordon Wolman, Joseph S. Cragwall, George H. Taylor, and Eugene Brown. After about 9 months of close and harmonious teamwork, LaMoreaux submitted the committee's recommendations to the Chief Hydraulic Engineer. The recommendations later became the basis for successful solutions to a grave problem. In his final report to the Chief, LaMoreaux acknowledged the hard and productive work of the committee members and "for having a good time while doing it."

LaMoreaux served as District Geologist until March 1958, when Leopold selected him for the new position, Division Hydrologist, MCA. He retained his office and home base in Tuscaloosa for a while, but in January 1959, Leopold asked him to become Chief, GWB.

As Branch Chief, LaMoreaux had the opportunity to further demonstrate, in a major line position, his considerable management skills. An early change was to strengthen and improve project-management procedures. With assistance from George H. Taylor of the Lincoln, Nebr. office, LaMoreaux designed project-description forms whose use simplified management and surveillance of projects from concept through staffing and from technical procedures through publication of results. This action contributed greatly to relief of the project-completion problems that had long plagued the Branch. Also with Taylor's assistance, a manuscript routing sheet was designed and used to systematically manage preparing and processing of reports.

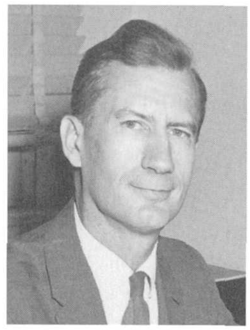
During LaMoreaux's brief tenure as Branch Chief, he developed a procedure to identify hydrologists who showed exceptional promise as leaders. Heads of districts had previously been selected without prior, systematic identification of possible candidates, and the selection was often compromised when the person selected was said by his supervisor to be committed to ongoing work. The new procedure provided a reservoir of names and information on dates of project completion and, hence, availability of each project chief. A novel aspect of the procedure was to place the nominating supervisor on notice that should he, for local expediency, recommend a "dud" for transfer, that person would be returned. This warning was rarely invoked.

LaMoreaux, by personal experiences and academic training, was acutely aware of the training needed in hydrology, and particularly hydrogeology. LaMoreaux became a leader and active participant in the early GWB short courses.

LaMoreaux entered Headquarters when Branch leadership and operations were diminishing and Division control was increasing. He agreed with and supported Leopold's goals for the Division, but disagreed in the choice of avenues to reach those goals.

LaMoreaux resigned from the Survey in May 1961 and returned to Tuscaloosa where he began his WRD career 18 years earlier. He also returned to Alabama as State Geologist and Oil and Gas Supervisor for the State and principal cooperator of the Survey.

### O. Milton Hackett (1920–)



O. Milton Hackett succeeded LaMoreaux as Chief, GWB, in July 1961. He became Branch Chief less than 12 years after he joined the Survey as a technician in Riverton, Wyo.

Hackett enrolled at the University of Minnesota in 1938; however, World War II interrupted his education and it was not until December 1948 that he graduated with a B.A. degree in geology. He immediately entered graduate school, but after one semester was recruited by George H. Taylor, supervisor of WRD ground-water investigations under the Missouri River Basin (MRB) program. Hackett's first assignment was to assist Donald A. Morris on the Riverton Irrigation Project (Wyoming) in an area placed under irrigation by the BOR and later beset by water-logging problems.

Hackett passed the CSC exam for geologists and was soon promoted to P-1. After completing the Riverton project, Hackett worked on other short-term MRB studies and then moved to Lincoln, Nebr., to help Taylor clear a backlog of reports. In 1951, he was assigned to Bozeman, Mont., to head a study of the Gallatin Valley, also under the MRB program. After completing the Gallatin Valley project in 1954, Hackett was transferred to Boston as Geologist-in-Charge of the ground-water program in Massachusetts. He arrived with instructions to redirect the ground-water program from one emphasizing data collection to one emphasizing interpretive studies. As evidence of Hackett's success, he was promoted to District Geologist in 1956 and put in charge of the ground-water programs in Massachusetts, New Hampshire, and Maine.

By 1961, Hackett's abilities as an organizer, supervisor, and administrator had come to the attention of the Division Chief. LaMoreaux had submitted his resignation as Chief, GWB, and Leopold chose Hackett as LaMoreaux's successor.

From February to July, 1961, Hackett divided his time between Boston and Washington. In July, he was officially installed as Chief, GWB. His accomplishments in that position included reorganizing the Publications Section of the Branch. He was involved in personnel, staffing, and training activities and served on the Geology Panel, Board of Civil Service Examiners. Like many of his contemporaries with strong technical backgrounds and a tactful way of working with others, Hackett also served as consultant to water agencies in third-world countries and participated in other international activities.

In late 1964, the Bureau of the Budget (BOB) released Circular A–67, which mandated a procedure for coordinating the activities of Federal agencies in acquiring water data and called for the development of a national water-data network. Implementation of A–67 became the responsibility of WRD. Hackett was chosen as the first Chief, Office of Water Data Coordination (OWDC). He organized and staffed the office, established coordination procedures, developed initial methodology for network design, and organized the advisory committees that were to become prominent in OWDC and in Division affairs.

After Frank Clarke moved to the Director's Office in 1967, Hendricks selected Hackett as his associate and shared with Hackett the responsibility for the development, coordination, and execution of Division policies, programs, and plans. Hendricks also depended on Hackett to properly match people with jobs.

### Charles L. McGuinness (1914–71)

Charles Lee McGuinness was named Chief, GWB, in May 1966, where he remained until he retired in the spring of 1971. The illness that forced his retirement took his life in April 1971.

McGuinness was graduated from the University of New Mexico in his native State with the B.S. and M.S. degrees in geology in 1934 and 1936. He worked briefly for the SCS before accepting an appointment as a geologist, P–1, in GWB headquarters in Washington, D.C. His 32 years of service to the Geological Survey and to the field of ground-water hydrology were marked by numerous contributions to the science, to the Nation, and to the art of clear expression in scientific reports.

McGuinness' "Role of ground water in the National water situation" was published as Water-Supply Paper (WSP) 1800 in 1963. This report, about 2 years in preparation, was a product of his perception of the national ground-water picture gained during World War II when he handled inquiries concerning ground water from the War and Navy Departments, the War Production Board, and other Federal agencies engaged in the war effort and from his later service to the President's Water Resource Policy Commission. McGuinness was awarded the O.E. Meinzer Award of the Geological Society of America for WSP 1800.

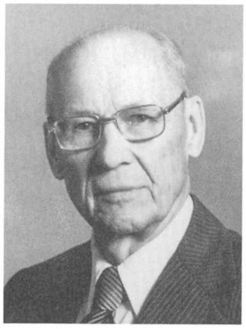
In 1962, McGuinness was designated as the Interior Department representative on the Task Force on Coordinated Water Resources Research, an outgrowth of the Senate Select Committee on National Water Resources. In 1964, he was temporarily assigned to the Department's Office of Water Resources Research (OWRR) to devise criteria for reviewing research proposals from the newly established Water Resources Research Institutes.

Although McGuinness authored or coauthored more than 40 papers and reports, it was during his 15 years as Chief of the Technical Reports Section of the GWB from 1946 to 1961 that he left his most indelible mark on Geological Survey reports. During those years he personally reviewed more than 7,000 reports prepared by other members of the GWB. His reviews served as a forum for sharing his mastery of the craft of understandable technical writing. His writing skills, teamed with those of Helene L. Baldwin, a specialist in nontechnical writing, made "A Primer on Ground

Water," published in 1963, a report valued by the general public and educators who wished to understand the principles of ground-water occurrence.

In late 1965, McGuinness became a Division Staff Scientist. Soon afterward, he was selected to become the fourth Chief of the GWB to serve during this period of history.

### George. E. Ferguson (1906–)



When George Ferguson retired in June 1972 he simply shifted gears and applied his considerable energy and management abilities to new challenges.

George H. Taylor, after retiring, complained to Ferguson that retirement was the pits because he missed his former associates and there was no system available for retirees to maintain contact with each other. Therefore, Ferguson's first major task after retiring was organizing the "WRD Retirees," starting a retirees' newsletter, obtaining Division support, and otherwise providing the forum for former employees to maintain contact with each other and with current staff. By 1989, more than 1,000 retirees had joined "WRD Retirees," 64 quarterly newsletters and 15 membership directories had been issued, and four national reunions had been held.

After "WRD Retirees" was safely underway, Hendricks and Hackett asked Ferguson to update the history of the Division. The new task involved researching, writing, and coordinating the participation of others to producing Volume V of the Division's history covering the period 1947 to 1957. Probably no other retiree could bring into this task the years of experience and successes in the variety of positions as had been earned by Ferguson.

Ferguson graduated from the University of Minnesota in 1928 with a B.S. degree in civil engineering. He entered on duty with WRD about 2 months after graduation as a trainee with the SWB in Columbus, Ohio, where C. Vernon Youngquist took him on his first stream-gaging trip. After less than 2 months of training he was transferred to Texas; then 2 years later, to Hawaii.

Stream gaging in Hawaii was arduous, and access to many gaging stations was virtually impossible after heavy rains. Defining complete stage-discharge relationships by conventional or any other method was difficult. But to Ferguson it was another challenge. With the encouragement of Max Carson, District Engineer, Ferguson built large Parshall flumes designed for self-cleaning when flows were high and debris loads were large. The geometry of the flumes permitted the use of theoretical stage-discharge relationships. Ferguson also directed the building of miniature models of gaging-station sites below a reservoir. Releases of water from the reservoir simulated floods and defined the shape of the stage-discharge curve.

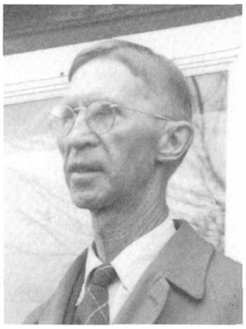
After a temporary detail to the Washington Headquarters in early 1938, Ferguson was assigned to Headquarters, then to College Park, Md. While there, he developed the first crest-stage gage and designed it to be an inexpensive, easily installed piece of equipment for recording peak stages of streams.

In mid-1941, Ferguson became District Engineer, SWB, Florida. He led the District from routine streamflow-data collection into such varied and well received endeavors as investigations of large springs of Florida, determination of the water budget of Lake Okeechobee, and a comprehensive study of the water resources of southwestern Florida. Also during his Florida assignment, Ferguson became active in the American Water Works Association (AWWA), for which he was a National Director from 1946 through 1948, and was granted its Fuller Award.

Inevitably, Headquarters beckoned and Ferguson, in 1946, was asked to return to Washington on detail to work on the reorganization of the Division. In 1947, the detail became a permanent assignment as a staff officer to the Chief Hydraulic Engineer. The Program Control Branch of the Division was formed in 1951, and Ferguson became its first Chief. Ferguson remained in that job until June 1956 when he was selected by Paulsen to become Division Hydrologist, ACA. As a key officer of the Division, Ferguson influenced the pattern of reorganization adopted in 1956 and in 1965–66. Leopold succeeded Ferguson and assumed the responsibility for the Program Control Branch but with the title of Assistant Division Chief.

Ferguson shared with Arthur M. Piper in Menlo Park the distinction of being the first to occupy the Division Hydrologist's position; but by the time of Ferguson's retirement in June 1972, he alone held the record for length of service as a Division/Area/Regional Hydrologist. He had served three Division Chiefs, had overseen the reorganization of all the Districts within his area, and had directed Survey participation in such major interagency efforts as the Northeast drought study in 1966.

### Henry C. Beckman (1888–1962)



Henry C. Beckman, an Iowa native, was born in Muscatine and was graduated from Iowa State in 1913 with a B.S. degree in civil engineering. He began his Survey career in 1914 in the Madison, Wis., office of the Upper Mississippi District of the SWB. In 1916, he was transferred to Chicago. In 1927, he moved to Rolla, Mo., to become District Engineer, SWB, Missouri. Beckman remained in Rolla for the rest of his life.

Beckman, the first formally appointed Division Hydrologist in the MCA, had carried out many of the duties of a Division Hydrologist long before such positions were established. He was less than 2 years from mandatory retirement age when he was appointed Division Hydrologist in mid-1957.

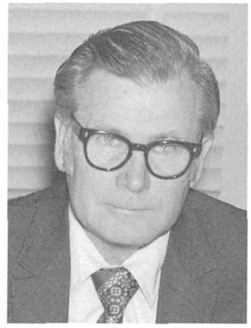
When the MRB program was getting underway in 1946, each of four rather autonomous WRD Branches had a stake in the program. Beckman was selected by Paulsen to serve as Division spokesman and MRB program coordinator with the title of Regional Engineer. Also in 1946, the Secretary of the Interior created the Missouri River Basin Field Committee and the Director named Beckman USGS representative on the Committee. To provide a central figure for coordinating Conservation, Geologic, Topographic, and Water Resources Divisions interests in the MRB program, the Director also designated Beckman MRB Program Coordinator for the Survey. Beckman coordinated the stream-gaging programs that were operated by the several SWB Districts for the U.S. Army Corps of Engineers Districts in the Mississippi and Missouri River Basins.

Beckman's personal characteristics included honesty, integrity, devotion to duty, thrift, and a dislike of airplanes. He was known affectionately as Uncle Henry, not only by his associates in WRD but also by those in the BOR and the Corps of Engineers with whom he met as regional coordinator of WRD programs.

His coordinating responsibilities required traveling to meetings in cities throughout the Upper Mississippi and Missouri Basins. He traveled by train despite inconvenient schedules and the long days required to make the round trip between Rolla and such distant cities as Billings, Mont. Beckman's defense of the time required to travel by train was that it gave him time to read Survey reports and to become better informed about Survey projects.

Beckman became 70 in 1958 and his retirement was mandatory. He was immediately rehired to carry out his duties as Federal representative and Chairman of the Red River Compact Commission. He died December 15, 1962, after a heart attack caused by running to catch a train.

### Harry D. Wilson, Jr. (1919–)



Harry Wilson was an engineer and an exceptionally capable administrator, organizer, and manager. Because of the latter attributes and a long career of energetic and creative service in the USGS, Director Pecora selected Wilson to become Chief, Publications Division, in December 1969.

Wilson began his career with the WRD as a part-time field assistant in the Jamaica, N.Y., GWB office 8 years before graduating from college. World War II interrupted his academic and his Survey careers. In 1947 he was graduated with a B.S. degree in civil engineering from Manhattan College. He immediately resumed his Survey career as an engineer in the Jamaica office.

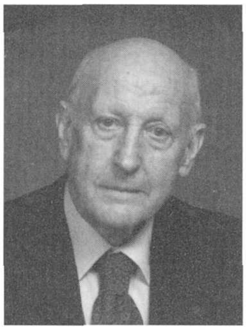
Wilson was transferred to California in early 1958. He served as Engineer-in-Charge of the GWB Subdistrict office in Santa Barbara then as Assistant District Engineer in the Sacramento District office. In October 1958, Wilson was named District Engineer and placed in charge of the ground-water program in California. In less than 2 years, with Wilson's personal participation, the District cleared out a backlog of 45 reports, consisting of more than 3,300 manuscript pages. That caught the eye of the Chief, GWB. Wilson was chosen to be Branch Area Chief in the MCA. He reported to St. Louis in March 1962 just before Dover was reassigned from Division Hydrologist, MCA, to Assistant Division Chief, Washington. Five days after Wilson reported to St. Louis as Branch Area Chief he was named Acting Division Hydrologist. In late April 1962, Wilson was appointed Division Hydrologist.

During the next 5 years, Wilson divided his attention and time between his duties as Division Hydrologist and assisting the Division with management and organization problems. Barely into his tenure as Division Hydrologist, he helped organize the Division's training program for new professional employees. Long a staunch advocate of developing management skills, Wilson began a management-training program for District supervisors in MCA.

In 1965, Leopold asked Wilson to draft a headquarters reorganization plan—a challenging task requiring extraordinary skill, diplomacy, and persistence. Wilson submitted his proposal to the Chief Hydrologist in May 1966 and the reorganization was implemented in the months that followed.

Wilson requested a transfer from St. Louis to Washington in March 1968 to become Division Program Officer. After about a year as Program Officer, Director Pecora selected Wilson to be Chief, Publications Division. His next assignment was as Assistant Director, Minerals and Water. After 2 years as Assistant Director and increasing vision problems, Wilson retired in 1979 to a life of boating and golf.

### Sherman K. Jackson (1907–)



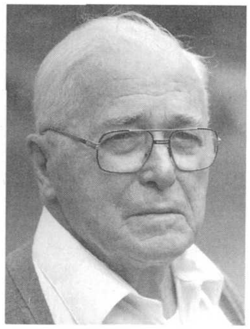
Sherman Keith Jackson was one of the first Division Hydrologists and the first to occupy that position in the RMA. Jackson moved into his new job in March 1957 when the Branches were strong and their lines of authority linked Headquarters with District offices through Branch Area Chiefs. In short, the Division Hydrologists were more representative than authoritative. In December 1964, Jackson and other Division Hydrologists became line officers of the Division; they were titled "Area" and later "Regional" Hydrologists.

But even without line authority, Jackson was an effective Regional Hydrologist. His effectiveness stemmed from quiet competence, logical approach to problems, and years of experience as a field supervisor. He not only was admired and respected by his associates but was also given solid backing from his staff and from the field in later differences with Headquarters over program policies.

Jackson was an honors graduate in civil engineering from Kansas State University in 1930. He joined the Survey in April 1931 as a hydraulic engineer in SWB headquarters, Washington, D.C. He worked 4 years in the Iowa City District after a transfer there in late 1933. Jackson was then selected to be Assistant District Engineer under John L. Saunders in Fort Smith, Ark. The SWB District at that time consisted of Arkansas and Oklahoma. The increase in work in Oklahoma lead to a separation of the two-State District and Jackson was chosen to head the Oklahoma operations with headquarters in Oklahoma City. He moved to Oklahoma City in January 1948 and was District Engineer, SWB, until March 1957 when he was transferred to Denver as Division Hydrologist. The surface-water program in Oklahoma under Jackson's leadership grew in size and scope primarily because of his effective and cordial relationships with State cooperators and with representatives of other Federal agencies.

Jackson retired from the Survey in December 1966 and was immediately chosen by Governor Winthrop Rockefeller to become Director, Arkansas State Soil and Water Conservation Commission. He served for several years and retired again, for good this time, in May 1972.

### Arthur M. Piper (1898–1989)



Arthur M. Piper shared with George Ferguson, Henry Beckman, and Keith Jackson the distinction of being selected as one of the first four Division Hydrologists. Piper became Division Hydrologist, PCA, in 1956. In 1961, he asked to be returned to technical work. His successor was Warren W. Hastings.

Piper was an easterner by birth, but made his career and home in the Far West. Born in Maine, he attended Tufts University where he was graduated in 1919 with a B.S. degree in chemical engineering. He then took his long first step westward by enrolling in graduate school at the University of Idaho, where he obtained an M.S. degree in meteorology in 1920. He continued in graduate school at Idaho for several years and earned a second M.S. degree in 1925, this one in geology. While working on his degree in geology, Piper also held a job with the Idaho Bureau of Mines and Geology.

Piper joined the Survey in 1926. His first two assignments were to ground-water studies in Pennsylvania and Tennessee. In 1931, he was transferred to California where he was placed in charge of the complex and comprehensive Mokelumne Area investigation, a pioneering study of its type. When the project was completed in 1935, Piper was promoted to supervisor of GWB activities in the States of Washington, Oregon, California, Idaho, and Montana—a responsibility not markedly different from the Branch Area Chief positions that were later established.

After war broke out in 1941, Piper worked on military water-supply problems at mainland training camps and at bases in the Pacific. After the war ended, he was designated staff scientist with headquarters in Portland, Oreg. He remained in Portland until 1956 as senior advisor to the Chief Hydraulic Engineer and as the Director's representative in interagency activities involving the Survey. During his Portland assignment, Piper wrote such diverse reports as, "Are you concerned about water?--You will be" (Circular 425, 1960) and "Interpretation and current status of ground-water rights" (Circular 432, 1960). Piper was transferred to Menlo Park, Calif., in 1956 as Division Hydrologist.

After Piper resigned as Division Hydrologist in 1961, his nominal assignment was research in the dispersion of by-products of nuclear explosions in the hydrologic environment. But his research efforts repeatedly gave way to needs for his technical skills in other jobs and his ability to work efficiently with others outside the USGS. In 1962, he was asked to assist the BOR with water-quality problems in the Upper Colorado River Basin that were of departmental concern. Again, in 1963, Piper was asked to assist the Science Advisor to the Secretary of the Interior. In 1964, Piper chaired a DOI Task Force in preparing a program to develop the resources of the Truckee and Carson River Basins in California and Nevada. In Water-Supply Paper 1797 (1966), "Has the United States enough water?", his analysis of water supplies and water requirements, including domestic in-stream flow needs, was a pioneering effort at regional-scale water-resources assessment. Piper retired in 1968 but continued to work part-time for the next 8 years.

### Warren W. Hastings (1911–88)

The principal authors of Volume VI had lunch with Warren and Isabel Pickens Hastings in June 1987 at a Seven Corners, Va., restaurant of the Hastings' choice. It was not intended that Hastings pick up the check, but with characteristic generosity and with gestures, winks, and other dramatic motions to the restaurant owner and friend, he maneuvered the check into his hand. One purpose of the lunch was to acquaint Hastings with plans for Volume VI and for the series of interviews with those former Division officers, including Hastings, who participated in reshaping the Division during the period 1957 to 1966. But Hastings' physical, not mental, health was failing and he passed away before his recollections and accounts of key events and people could be recorded.

Hastings was a Headquarters veteran at the time of the events documented in Volume VI. He was an acute observer, a lover of intrigue, and a skillful analyzer of people and their motives. His would have been a valuable contribution to the series of interviews.

Hastings was graduated from the University of Maryland in 1935 with a B.S. degree in chemistry and a minor in agricultural science. For several years before and after graduation, he worked for the Department of Agriculture in Arizona and Maryland. After joining the Survey in 1937, he worked as a laboratory chemist for the QWB at Headquarters under the supervision of C.S. Howard and W.D. Collins. The next year, Hastings took part in a water-quality study of Lake Mead. In 1939, he was transferred to Pecos, Tex., as chemist-in-charge of water-quality investigations in the Pecos River Basin. When that study ended in 1941, Hastings was moved to Austin to oversee QWB water-quality work throughout Texas. The program prospered under Hastings' supervision, and by 1947, quality-of-water studies in Arkansas, Oklahoma, and Louisiana were added to his area of supervision. The Washington headquarters exercised its traditional prerogative of recruiting the most capable from field operations and moved Hastings to Headquarters in 1948.

The QWB, before the late 1940's, was primarily a laboratory operation whose professional staff worked mostly from sampling sites in the field to benches in the laboratory. But this was changing; the number of Branch staff was increasing rapidly, water-quality problems were becoming more complex, and water-quality specialists were being called upon to interpret their findings rather than publishing the results of analyses only. In short, the Division's water-quality specialists were on the threshold of equal partnership in water-resources investigations with their surface- and ground-water counterparts. These were the very general operating circumstances of the Branch when Hastings was transferred to Washington in 1948. In about 1950, the production of interpretive water-quality reports was increasing, but there was no unit in QWB to process such reports. A Technical Reports Section was organized and Hastings, on reporting to Headquarters, became its first Chief.

Because of Hastings' skill at working with people, he was soon designated Assistant to Branch Chief S. Kenneth Love and was given much of the Branch programming and personnel-management responsibilities. In 1953, Hastings was selected as the delegate from QWB to work with Harold E. Thomas, GWB, and H. Banks Kinnison, SWB, to develop reorganization plans for the Division. Hastings said later, "Our thinking proved so shocking that the results were carefully interred for many years, though certain recommendations did see a glimmer of light in the Van Pelt Committee report to the Secretary of the Interior."

The increase in the number of QWB employees and the concurrent need for an in-house technical training program again became a reason for calling on Hastings' management skills. He developed long-range personnel management policies and started a scientific training program in the Branch.

In early 1961, Piper announced his plan to retire, and William L. Lamar, Area Chief, QWB, PCA, had retired. Hastings moved to Menlo Park in June 1961 to replace Lamar and, as heir apparent to the Division Hydrologist position, to understudy Piper. Hastings became Division Hydrologist in December 1961.

As Division/Area/Regional Hydrologist for the next 10 years, Hastings served as an articulate proponent of WRD programs and represented the Chief Hydrologist and the Director in contacts with Federal and State agencies involved with water-resource planning, development, and management in the seven Pacific Coast Area States. During his tenure as Area Hydrologist, all WRD Districts in the area were reorganized as Division-level Districts. Because of Hastings' smooth management style and skill in person-to-person relationships, the reorganizations were completed with minimal disruption of programs, cooperation, and personnel.

In 1972, Hastings was transferred back to Headquarters to succeed Roy E. Oltman as Assistant Chief Hydrologist for Research and Technical Coordination. Hastings' retirement in March 1973 ended a 36-year career with WRD. He continued to work until 1982 as a reemployed annuitant and as treasurer of the International Association of Hydrological Sciences (IAHS). He died June 18, 1988.

## Division Staff Scientists

The Headquarters organizational unit containing those senior and technically accomplished members of the Division who were designated Division Staff Scientists was created by Luna Leopold shortly after he became Chief. This group first appeared in the Organization and Personnel Directory of January 1, 1959, when Walter B. Langbein, Thomas Maddock, Jr., A. Nelson Sayre, and Robert M. Myrick were listed as Division Staff Scientists. Others listed in the next 7 years were Ethel M. Coffay, George H. Drury, William W. Emmett, Michael J. Kirby, Leo A. Heindl, Lee Horner, Russell L. McAvoy, Charles L. McGuinness, Raymond L. Nace, Deric O'Bryan, Roy E. Oltman, John E. Parkes, Edward J. Pluhowski, William J. Schneider, Victor T. Stringfield, Herbert A. Swenson, and Adrian H. Williams. As the senior staff scientists of this group and key advisors to Leopold, vignettes of Langbein, Stringfield, Swenson, and Oltman are included in this part of Volume VI.

In the field, Charles V. Theis, although not formally designated a Division Staff Scientist, served as technical representative of the Division Chief in work for the Atomic Energy Commission (AEC) and the federally funded radiohydrology program of the Division. Because of his preeminence in those activities and because he served as an extension of the Office of the Division Chief throughout this period of history, Theis' vignette is also included in Volume VI.

### Walter B. Langbein (1907–82)

Walter B. Langbein was intolerant of administrative details and diligently avoided all jobs in his long career with the Geological Survey that led to supervisory responsibilities. Soon after joining the WRD as a junior engineer, he was given the job of building a gaging station, a task that was usually done by hiring some help, buying the materials, and supervising the construction. But Langbein's approach was different. He hired a contractor, supplied him with lumber and concrete, then stayed out of the way.

Langbein's approach to problems was usually different, and his solutions gained him national and international recognition and awards. Among the honors granted Langbein's achievements in hydrology are the Bowie and Horton Medals from AGU, the J.C. Stevens award (shared with Thomas Maddock, Jr.) from ASCE, the Distinguished Service Award from DOI, and the Warren Prize from the National Academy of Sciences (NAS), of which he was elected a member in 1970, the year after he retired. A month before his death in December 1982, Langbein and a hydrologist from the Soviet Union were co-recipients of the International Prize in Hydrology for 1982 by the IAHS.

Langbein was born and raised in New Jersey. He attended Cooper Union in New York City and was graduated in 1931 with a B.S. degree in civil engineering. After working for a construction company for several years, he joined the SWB District in Albany, N.Y., in 1935. Less than a year later, he transferred to Trenton, N.J. A few months later he joined the Water Utilization Branch (WUB) at the Washington, D.C., headquarters.

The functions of the WUB were modified during the next several years, and its name changed to Technical Coordination, then General Hydrology Branch. When Langbein joined the Branch in the fall of 1936, the WUB staff was being enlarged to supervise flood investigations and to prepare reports on major floods. Thus began Langbein's interest in floods, not only from a hydrologic point of view, but also from the social and economic risks. As Nicholas C. Matalas pointed out in his memorial to Langbein (Retirees Newsletter 38), Langbein's book "Floods," coauthored with W.G. Hoyt, directly contributed to the development of Federal interest in flood insurance, first in the Federal Flood Insurance Act of 1956 (P.L. 84–1016) and later in the 1968 National Flood Insurance Act (PL 90-448: August 1, 1968).

Langbein was the originator of the concept of network design or comprehensive systematic approach to hydrologic data collection. Many years ago, he wrote a letter to the editor of the WRD Bulletin, the WRD house organ, and raised the then-heretical question, "Are we operating gaging stations too long?" He signed the letter N.A. Quandary. In the book "Water Facts for the Nation's Future" published in 1959, coauthored with W.G. Hoyt, the authors made a cogent case for systematic data collection, for the economic worth of such data to the development of water-resources systems, and for the need for designed data-collection networks. The book influenced the development, in 1964, of the Bureau of the Budget Circular No. A–67.

Langbein enjoyed sharing his thoughts with his associates. This was done, partly through the WRD Bulletin, to which he contributed his ideas on topics such as adapting a rain gage to a standard water-level recorder; a light-weight field-conductivity bridge; simplifying the Gumbel flow-distribution graph; frequency of overbank flooding; the use of tritium for determining the age of ground water; and the use of trees for reference marks. His active curiosity extended also to things beyond hydrology. In the early 1960's, after the Post Office Department began using zip codes, Langbein mailed a card to himself, addressed to his Social Security number as:

579–50–6864
4452 N 38
22207

The Post Office promptly and correctly delivered his card.

Langbein kept himself well informed of advances in other technical fields that might be applicable to problems within his wide area of interests. When he read of the successful application of the queueing theory to the relief of freight-handling problems at the Liverpool docks, he immediately saw that the queueing theory might be applicable to a logjam of reports in the Publications Division. In a letter to Robert Moravetz, then Chief of the Publications Division, Langbein laid out a plan, based on the queueing theory, that might relieve the problem. Moravetz, his associates, Langbein, and the queueing theory didn't speak the same language. There was no response.

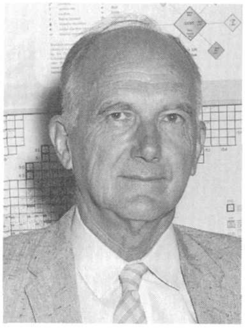
Langbein moved from GHB to the Office of the Chief Hydraulic Engineer in August 1956 as Research Hydraulic Engineer. About a year later, and soon after Leopold became Chief Hydraulic Engineer, he was joined by Maddock; then both were designated Staff Scientists.

Langbein and Leopold had worked together for years in the GHB and its predecessor Branches. They shared interests and collaborated in several publications on topics such as river morphology and "A Primer on Water."

Leopold turned to Langbein when BOB Circular A–67 requiring network design was delegated to the Survey and WRD by the Secretary of the Interior in 1964. Leopold asked Langbein to head a small group within WRD to devise a plan for network design to meet the requirements of A–67. Leopold then left town; on his return he looked over the results of Langbein's efforts. He didn't like what the committee had done and summarily "fired the whole kit and caboodle," as Hendricks later said, and appointed another group. Langbein was humiliated.

Langbein remained a Staff Scientist until he retired in February 1969. Immediately reappointed, he worked for another dozen years as a reemployed annuitant. In 1982, he wrote Open-File Report 82-0256, "Dams, reservoirs and withdrawals for water supply--Historic trends," an analysis of reservoir effectiveness, one of his major interests. He died in December 1982.

### Victor T. Stringfield (1902–89)



Victor T. Stringfield's contribution to science spanned 47 years, 42 of which were in the service of WRD. He was a college professor and a prolific writer with more than 30 technical publications to his credit.

He was recognized in American Men of Science, Leaders in American Science, and Who's Who in the South and Southwest. He was winner of the Geological Society of America's O.E. Meinzer Award and recipient of Interior's Distinguished Service Award.

After graduating from Louisiana State University in his native State with a B.S. degree in geology in 1925, Stringfield worked briefly for an oil company in Texas. He then taught at Washington University in St. Louis, Oklahoma A&M, and at the New Mexico School of Mines. While at the New Mexico School of Mines, Stringfield became involved in a cooperative project with the USGS and worked under the supervision of G.F. Loughlin, later Chief Geologist of the Survey. The project included geologic mapping of a limestone area where an abandoned mine was used as the source of a municipal water supply. Thus began a new phase of Stringfield's career centering on limestone terranes and ground-water hydrology.

Stringfield applied for a job with the (then) Ground Water Division of the Water Resources Branch and was accepted in 1930. His first duty station was Tallahassee, Fla.; however, only a few months later, he was transferred to Washington, D.C., where he remained for the rest of his career.

Although Washington was his headquarters, Stringfield continued to study ground water in Florida for several years and played the key role in assessing geology, hydraulics, and hydrology of the 90,000-square-mile artesian aquifer in Florida and adjacent States. His Water-Supply Paper 773–C, "Artesian water in the Florida peninsula," (1936), illustrated the damaging effects of the proposed trans-Florida ship canal on the regional water supply.

In 1938, Stringfield was named Geologist-in-Charge, Ground Water Investigations, in the Southeastern States. In that job, he devised a plan to investigate the ground-water resources in the Miami area, the results of which not only provided solutions to Miami's water-supply problems but also significantly contributed to the subject of saltwater encroachment in aquifers. He was named Chief, Section of Ground Water Geology, GWB, in 1947.

Stringfield was an effective advocate of large-scale, regional ground-water studies and was instrumental in gaining approval and funds for such studies, including the Mississippi Embayment project. (See Mississippi Embayment project in Part IV.)

In 1957, Stringfield was selected to head the new Radiohydrology Section of the Division. He left this job in 1960 to become a Division Staff Scientist and principal staff consultant on nuclear waste and to write and to advise younger members of the Division, particularly in the technical problems of limestone hydrology. His monumental Professional Paper 517, "Artesian water in Tertiary limestone in the southeastern United States," was published in 1966. He remained a Staff Scientist until his retirement in 1972 and then was a rehired annuitant for additional years. Stringfield died June 19, 1989.

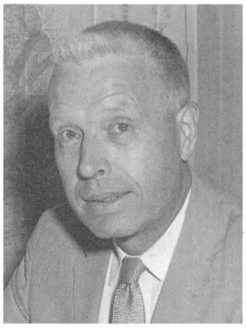
### Herbert A. Swenson (1911–85)

Herbert A. Swenson's water-resources career began with his appointment in 1938 as a junior science aid in the (then) Quality of Water Division of the Water Resources Branch of USGS and ended with his retirement in 1974 from OWRR of DOI. From 1939 through 1974, Swenson was on field assignments from Portland, Oreg., to Miami, Fla., completing a military career as a Colonel in the Army Reserve, authoring or coauthoring 45 technical publications, serving as Vice Chairman of the President's Water for Peace Program, and receiving the Distinguished Service Award from the DOI.

A native of Oregon, Swenson was graduated in 1935 from Oregon State with a B.S. degree in chemistry. His first field assignment was in Idaho, in 1939. The next year, he transferred to Miami, Fla., where he worked on a saltwater-encroachment study. Service in the Chemical Warfare Corps of the Army occupied the war years. On his release from active duty in 1946, Swenson was assigned to the Missouri River Basin program in Lincoln, Nebr., as Chief of the Chemical Quality Section. He remained in this job until 1953 when he returned to his birthplace, Portland, Oreg., as District Chemist, QWB, Pacific Northwest. Headquarters beckoned in 1958, and Swenson transferred to Washington, D.C., to serve on the staff of the QWB. In

1965, Leopold invited Swenson to become a Division Staff Scientist, which he remained until 1967 when he was selected to join OWRR. He served as senior advisor in OWRR until his retirement in 1974. He died September 8, 1985.

### Roy E. Oltman (1911–77)



Roy E. Oltman, a Minnesotan and graduate with the B.S. degree in civil engineering of the University of Minnesota, began his Survey career in 1938 as a junior engineer and stream gager in the St. Paul District office of the SWB.

Oltman's skills in hydraulics, hydrology, and writing, coupled with an enjoyment of working with people and a zest for being the leading edge in new organizational and technical ventures, placed Oltman in the leadership role in a wide range of SWB, Division, and DOI activities.

After the 1951 floods in Kansas, Oltman directed the field work and subsequent report preparation. He developed a method of large-scale flood investigations that has since been used as a pattern in similar studies elsewhere in the Nation.

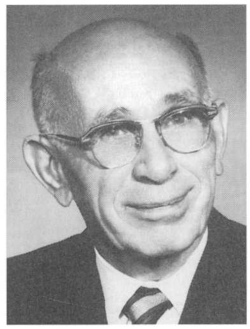
In 1955, Oltman was transferred to SWB headquarters to head the Branch's new training program. Two years later, Leopold asked Oltman to move to the Division and take charge of the newly established Career Development Section and to organize and direct recruiting and training activities.

In 1960, when the Senate Select Committee on National Water Resources requested assistance in summarizing and depicting national water resources and problems, Leopold named Oltman to lead the four-man WRD work group assigned to assist the Committee.

Two years later, after reassignment to the SWB as Chief, Hydrologic Studies Section, Oltman was again tapped to head a novel technical venture. He organized and directed the measurements of flow and physical and chemical characteristics of the Amazon River in collaboration with the Government of Brazil. This pioneering work was reported in Circulars 486 (1964) and 552 (1968). (See Part IV, "International Programs.") Oltman remained as Chief, Hydrologic Studies Section, SWB, until March 1965, when he was selected to fill a key position in the new OWRR in the Office of the Secretary of the Interior. OWRR resulted from recommendations of the Senate Select Committee, which Oltman had helped equip for a better understanding of the water-resources problems of the Nation.

Oltman returned to WRD in mid-1967 to become Assistant Chief for Research and Technical Coordination, a key leadership position in the reorganized WRD. He remained there until he retired in 1972. Oltman then became Executive Director of the Virginia Society of Professional Engineers. He died in 1977.

### Charles V. Theis (1900–87)



Charles V. Theis, with a B.S. degree in civil engineering from the University of Cincinnati in 1922 and a Ph.D. in geology from the same university in 1929, was foremost a geologist. Although he did not publish extensively in his more than 55-year career with the Survey, his famous "Theis Equation," published by the American Geophysical Union in 1935, revolutionized the science of ground-water hydrology.

After joining the Survey in 1930, Theis was assigned to the small group of geologists and engineers who were investigating the problems of diminishing artesian flow in the Roswell Basin of New Mexico. During this study, he perceived an analogy between the flow of water in aquifers and the flow of heat in solids. His thesis was received with some skepticism by his associates, including the venerable O.E. Meinzer. Meinzer was not fully convinced that Theis had discovered the basic theory of ground-water movement that eluded his more seasoned scientists even after pumping tests near Grand Island, Nebr., in the late 1930's confirmed the Theis equation. But Meinzer did become convinced after C.E. Jacob, working from the basic principles, showed the Theis equation to be correct.

During the war years, Theis worked with the AEC as one of its principal ground-water consultants. For years prior to, during, and following this period of history, he served as WRD coordinator of water-resources studies for the AEC and advisor to others in WRD who were involved in investigations involving the radioactivity of water. Throughout the period of Volume VI, he reported to the Chief of WRD as a Division Staff Scientist.

Theis adopted New Mexico as home and worked and lived in Albuquerque until he fully retired in 1985 and died in 1987. During his illustrious career, Theis served as chief advisor to members of WRD who worked at the National Reactor Test Site in Idaho and as advisor to others facing problems of radioactive containment and disposal at other locations, including Los Alamos, the Nevada Test Site, and Oak Ridge. He also served on a nuclear-waste disposal panel of the National Academy of Sciences. Among the honors and awards received by Theis are the Horton Medal of the AGU and the Distinguished Service Award of the DOI.

## PART III—ORGANIZATION

From his appointment as Chief Hydraulic Engineer in May 1957 onward throughout his 9 years of leadership of the Water Resources Division, Luna B. Leopold vigorously pursued his goal to make the Division the foremost Federal agency in hydrology. To do this he sought to enhance its already substantial scientific reputation and eminence by greatly strengthening the program components of hydrologic analysis, interpretation, and research, and to build up commensurately a cadre of leading research and practicing professionals in the science. Corollary to these efforts, he recognized the needs to restructure the Division to more effectively plan and execute multidiscipline hydrology programs and projects and to report the findings with timely, high-quality, and more problem-oriented publications. All these efforts were urged and supported by Director Nolan.

The organizational efforts which in reality began in the early 1950's (see Ferguson's Volume V), required all 9 years of Leopold's tenure, plus a little more, to accomplish the full transition sought—from a Branch line to a Division line-management structure. This section of Volume VI summarizes these years of change within the Division.

### Offices of the Division

#### At the Outset, 1957

In June 1956, almost a year before Carl G. Paulsen retired, the Survey approved and announced a reorganization of the Division, which provided for:

- Stronger Division roles and staff sections at Headquarters for planning and programming, publications, career development, foreign hydrology, radiohydrology, and administrative support.
- A field level of Division coordination and general oversight through Division Hydrologists, supported by Branch Area Chiefs, at each of the four field centers in Arlington, Va., Rolla, Mo., Denver, Colo., and Menlo Park, Calif.—the first step toward a full regional management structure.
- A stronger Division role in District-level programming and resource allocation through the Division Hydrologists in concert with the Branch Area Chiefs, as members of the Area committees, and the chairmen of District WRD Councils.

The reorganization plan was announced and described in detail in Paulsen's memorandum of June 14, 1956, (and the accompanying Departmental Manual Release 23, dated April 4, 1956). This action was a culmination of in-house studies going back to 1952, recommendations of the 1954 Van Pelt Commission, and staff work by Leopold and Nace, as principal assistants to Paulsen, to produce the 1956 plan. In the earlier deliberations from 1952 to 1954, George E. Ferguson and Douglas R. Woodward of the Director's staff exerted strong influence on the directions ultimately adopted, as did work of a Paulsen-appointed study committee of Warren W. Hastings, Harvey B. Kinnison, and Harold E. Thomas, who provided Division inputs to the Van Pelt Commission (see Ferguson's Volume V). The 1956 plan left the four operating Branches virtually intact as to their operational roles and organizational structure, except for changing the name of the Technical Coordination Branch to the General Hydrology Branch.

By the time Leopold became Chief Hydraulic Engineer in May 1957, the 1956 plan had been largely implemented as shown in figures III–1 and III–2 (reproductions of pages from the WRD Organization and Personnel Directory dated July 1, 1957). The organizational structure and stipulated duties of the six Division-level staff sections represented a significant first step toward centralizing within the Division line of command more direction and support of planning and programming, manpower, publications, and administrative support; and, to a lesser extent, the coordination and some operational functions of two major programs of that time—foreign hydrology and radiohydrology. These growing programs required multidisciplinary teams made up of personnel from two or more of the Branches, coordinated Bureau-level direction, and centralized logistical support.

At the time Leopold was appointed Division Chief, Raymond L. Nace held the position of Associate Chief, and Albert G. Fiedler, the position of Assistant Chief. Others assigned to the office of the Chief Hydraulic Engineer were Walter B. Langbein and Thomas Maddock, Jr., both serving as senior staff scientists and advisors. Charles V. Theis, Staff Scientist headquartered at Albuquerque, N. Mex., coordinated

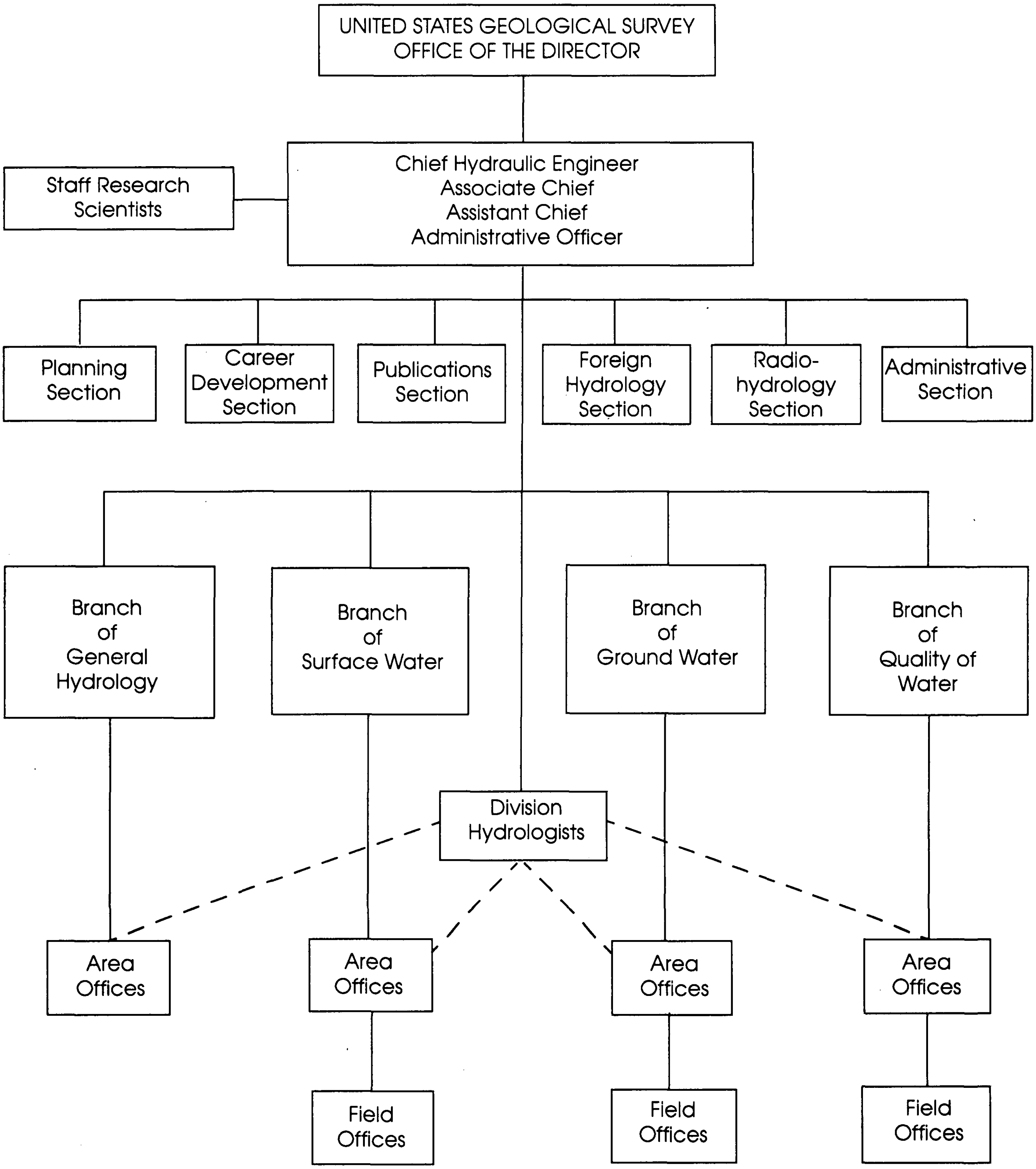



Figure III-1. Organization chart of the Water Resources Division, July 1, 1957.

WATER RESOURCES DIVISION

OFFICE OF THE CHIEF

WATER RESOURCES DIVISION

The Water Resources Division conducts investigations which provide basic water facts required for economical development and best use of the Nation's water resources, and which provide adequate hydrologic and geologic data for the effective control, prevention, or reduction of the harmful or destructive types of water. The Division is subdivided into four operating Branches.

PLANNING SECTION

Develops plans and long-range and annual programs of Division activities. Prepares statements defining the nature of the various classes of activities of the Division; prepares monetary breakdowns showing the program costs for each activity; reviews project proposals and cost estimates.

Prepares annual program justifications and descriptions of activities for submission to the Director, the Department, the Budget Bureau, and the Congress.

Studies methods of program development and control, and recommends improvements in planning and programming.

CAREER DEVELOPMENT SECTION

Advises, guides, and assists the Branches in the development and utilization of the most economical and effective means of manpower management practices.

Conducts, evaluates, and disseminates, for internal use in the Division, surveys of manpower utilization to assure proper placement of scientists and engineers.

Coordinates and supports the recruiting and training activities of the Branches.

PUBLICATIONS SECTION

Represents the Water Resources Division in all policy matters relating to publications and release of scientific reports prepared or reviewed within the Division; advises on priority, programming, and fiscal matters in relation to publications; keeps a status record of reports and scientific papers being prepared in the Division.

Studies the general problem of getting Division reports from author to public, including general trends and developments in the art of publication; recommends methods for increasing the efficiency and speed of processing reports.

FOREIGN HYDROLOGY SECTION

Arranges, assists, and directs that work of the Division which is part of the foreign-aid program of the U.S. Government to aid development of natural resources in foreign countries.

Arranges on-the-job training of foreign nationals under the supervision of USGS personnel assigned to work in various host countries, and similar training to foreign nationals on trainee assignments in the United States.

Assists the study of specialized problems relating to investigations in territories, possessions, and overseas areas not in the "Technical Assistance" category.

RADIOHYDROLOGY SECTION

Coordinates the work of the Branches for the Atomic Energy Commission, and the nationwide studies by the Branches of radioactivity and radioelements in natural waters.

Is the Division Security Officer. Becomes familiar with requirements of all legislation and orders having to do with national security aspects of the Division program; represents the Division on the Survey Relocation Committee. Initiates security clearance actions, and is custodian of the Division file of classified documents.

ADMINISTRATIVE SECTION

Provides centralized services for the Division and Branches in budget and finance, personnel, property and procurement, records management, and other fields of administration, business, and management.

Carries out Division policy and instructions relating to budgeting, financial planning, allocation of funds, personnel processing and records, spaces utilization, property records, procurement, mail, files, storage and disposal of records, and distribution.

Interprets and implements rules, orders, and procedures pertaining to the above fields.

Figure III-2. Structure and roles of Headquarters units of the Water Resources Division, July 1, 1957.

cooperative investigations with the Atomic Energy Commission (AEC) and Federal program activities relating to radioactivity of water resources. Paulsen continued to serve as Delaware River Master following his retirement and later, in August 1957, became Federal representative on the Arkansas River Compact Commission. May E. Theisen was secretary to Leopold, and Gertrude M. Winkle, Ruth L. Malone, and Dorothy M. Ireland were secretaries to Nace, Fiedler, and Langbein, respectively.

The Planning Section was headed by Kenneth B. Young, assisted by Hallard B. Kinnison, hydraulic engineer, and Natalia M. Armstrong, secretary; the Career Development Section by Roy E. Oltman assisted by Grace C. Andrews, secretary; the Publications Section by Erwin S. Asselstine; the Radiohydrology Section by Victor T. Stringfield assisted by Louisa I. McAnallen, clerk; and the Foreign Hydrology Section by Thomas E. Eakin assisted by Roy O. Jackson and Colene R. Bauer, geologists, Joan Ross, secretary, and Marylou I. Kelsey and Anne E. Leone, clerk typists.

Frank Barrick, Jr., as Administrative Officer, and Charles W. Morgan, Chief of the Administrative Section, and his assistant Marjorie E. Allen, oversaw a relatively large staff for general administrative and fiscal-management services. Frances W. Casey and Marjorie A. Shepard served as secretaries to Barrick and Morgan. Staff members included William J. DeVito, Chief, General Services Unit, assisted by Francis H. Collette, Verdell L. Henegan, Frances W. Murphy, Selma J. Nootenboom, Ralph V. Quarles, and Helen J. Thompson; and John D. Scopi, Chief, Fiscal Management Unit, assisted by Bettie F. Edney, John W. Elmore, Arthur E. Goucher, Kathleen E. Harte, James J. Snyder, and Margaret L. Youmans.

At mid-1957, four Division Hydrologists were on duty in their area centers: George E. Ferguson, Atlantic Coast Area (ACA), Arlington, Va.; Henry C. Beckman, Mid-Continent Area (MCA), Rolla, Mo.; Sherman K. Jackson, Rocky Mountain Area (RMA), Denver, Colo.; and Arthur M. Piper, Pacific Coast Area (PCA), Menlo Park, Calif. They served as area representatives of the Chief Hydraulic Engineer for all Division affairs and were to become increasingly involved in interagency regional planning and coordination of water-resources programs within their respective areas. They were charged to work with the District councils to guide and coordinate program planning, especially program design and selection of interpretive hydrologic studies funded in the cooperative programs. Branch representatives (titled "Branch Area Chief") on the Area committees were also on board in RMA: Francis M. Bell, SWB; Stanley W. Lohman, GWB; Frank C. Ames, QWB; and Harold V. Peterson, GHB; and in PCA: Harvey B. Kinnison, SWB; Harold E. Thomas, GWB; and William L. Lamar, QWB. Only Henry C. Barksdale, GWB, had been named in ACA; no one yet in MCA.

WRD District Councils, composed of District supervisors of the Branches and chaired by one of them, were expected to coordinate more effectively program development and operations, to collocate and centralize wherever possible their District offices and support services, and to speak with one voice in their negotiations with cooperating agencies.

By memorandum of November 27, 1957, Leopold spelled out his concepts and policies for organization and management of the Division. His overriding theme emphasized achieving unity and coherence in the Division's mission while adhering to functional (Branch) lines of authority and responsibility in program execution. Three paragraphs of that memorandum which highlighted his policy on roles and relationships were:

> Pooling of ideas, interchange of information, and joint participation in program development are among the means of achieving unification. Three organizational levels provide opportunities for such participation: (1) The Washington office group, consisting of Division and Branch Chiefs and their staffs; (2) the water-resources Area committees, consisting in each Area of the Division Hydrologist (permanent chairman) and the Branch Area Chiefs; (3) the State Council, usually consisting of District Chiefs and their elected chairman.
>
> It is the intent, in part, of the present memorandum to clarify and strengthen the position of Area Committees and State Councils in the organizational structure. It calls attention to the important work that can be performed by the Committees and Councils and places on record the intention to increase their influence.
>
> The principle is reiterated that the ultimate responsibility for program formulation lies with the Division and its officers. Program execution and operations are primarily Branch responsibilities, but Division representatives are concerned with these to whatever extent is necessary to assure that program execution is achieved, that operations are effective, and that future activities are programmed in orderly succession. Means for achieving coordination and joint exercise of responsibility are outlined below. These concern

only the requirements from the overall standpoint of the Division. Formulation of supplemental or additional requirements for internal Branch purposes is the responsibility of individual Branches.

This structure, designated roles, and staff in place at the outset provided the overall framework for management and operation of the Division through the intervening years of transition from a Branch-line organization in 1956 to a Division-line organization in late 1964.

### The Intervening Years, 1958–64

Though the organization as established in 1956–57 remained essentially unchanged in structure with only a few minor additions through these years, transitional changes in roles and staff gradually centered more leadership and decision-making and administrative support with the Division offices and units at Headquarters and Area levels. Program direction and balance, recruiting, training, and career development, and the primary control and allocation of funds and management of the reports-review process became increasingly centered in Division headquarters units and with the Area Committees. The Branches essentially retained full control over project execution, maintenance of technical standards, and advancement in methodology; and secondary control over funds and manpower resources. Research program activities, which were largely centered in the Branches throughout most of this period, were reassigned to the GHB, as the principal research arm of the Division late in the period.

#### *Division Headquarters*

In his monthly activity report to the Director dated January 14, 1959, Leopold announced a number of changes—some temporary, some permanent—in Division headquarters assignments. A. Nelson Sayre, who had headed the Ground Water Branch for 12 years (see "Ground Water Branch") was reassigned to a position of Staff Scientist in the Chief's office to write a book on ground-water principles and distribution, where he remained until his retirement in 1961. Nace was to move aside from his Associate position for a few months to prepare a manuscript on water problems of the United States, during which Joseph V.B. Wells, Chief of the SWB, served as Acting Associate Chief. S. Kenneth Love, Chief of the QWB, stepped aside temporarily to study "...certain administrative and technical problems" in the water-quality program area. These moves naturally required backup reassignments (described in the Branch sections of this volume). All of the temporary assignments were completed in the stipulated "4 to 5 months."

This overall maneuver was representative of Leopold's strong belief that such assignments were beneficial to the organization for the generation of new ideas and to the individual for career development. (Author's note: The "troops" may have outwardly discounted the operation as an exercise in "musical chairs" but in practice they respected and supported their temporary bosses.)

Indicative of Leopold's interest in career development and training of younger professionals in WRD, he invited the Branch Chiefs in a memorandum of April 16, 1958, to nominate a research assistant to work closely with him for a 2-year period. Robert M. Myrick, SWB, Columbus, Ohio, was selected and moved to the Chief's office in November 1958, as a first of a series of these training assignments.

Effective July 1, 1959, the WRD Equipment Development Laboratory at Columbus, Ohio, transferred responsibility for procuring, manufacturing, stocking, and selling of standard equipment to the Administrative Division in Silver Spring, Md. Instrument research and development, however, continued at the Columbus laboratory (see "Surface Water Branch").

In 1959, Lawrence E. Newcomb replaced Kinnison as staff member of the Planning Section.

The first formal change in the organization of the Division Chief's office came in early 1960 (announced in WRD memorandum dated December 28, 1959) when a second Assistant Division Chief position was established and filled by Joseph Wells. He and Albert Fiedler shared the increasing workload of ongoing management and operations, plus some tasks formerly handled by Nace. Indicative perhaps of his management style, Leopold apparently left it up to Wells and Fiedler to sort out their duties.

In June 1960, Roy Oltman was formally reassigned from Chief, Career Development Section, to the staff of the Chief Hydraulic Engineer as a technical advisor and consultant on specialized problems in hydrology and hydraulic engineering. He spent much of his time for some months before this formal reassignment and in the ensuing months on preparing information and reports on behalf of the Survey for the Senate Select Committee on National Water Resources (The "Kerr Committee"). John H. Adamson succeeded Oltman as Chief of the Career Development Section.

Stringfield, who had headed the Radiohydrology Section from its creation in 1956, was reassigned in July 1960 to the Office of the Associate Chief

Hydrologist as a scientific advisor and consultant on ground-water problems related to the development of nuclear energy. Harry E. LeGrand succeeded Stringfield in the Radiohydrology Section position. Also in July, George C. Taylor of Mineola, N.Y., GWB, succeeded Thomas Eakin as head of the Foreign Hydrology Section. Eakin returned to the GWB to undertake ground-water studies in the Nevada District.

In September 1960, Kenneth Young moved to Madison, Wis., as District Engineer, SWB. He was succeeded as Chief of the Planning Section by Irving E. Anderson, from the SWB.

By memorandum of July 12, 1960, the Chief Hydraulic Engineer spelled out Division and Branch responsibilities for programs and operations. What is to be done, and when, in the context of major program elements and fiscal years, was pronounced the responsibility of Division officers; operational scheduling and execution, the responsibility of Branch officers, but subject to review and concurrence by the Division. Thus, the scope of Division control over programming and scheduling was being extended increasingly toward a Division-line organization, and through Division Hydrologists and Council Chairmen, to the District level.

The year 1961 started on a sad note—the death of former Chief Hydraulic Engineer, Carl G. Paulsen, on January 30.

In April 1961, Leopold called upon Frank Barrick, Administrative Officer, to conduct a study of administrative management and associated problems within the Division. The purpose was "...to make our administrative management more effective and reduce the drain of administration on the time of supervisors" (memorandum dated April 21, 1961). Charles Morgan was named to serve as Acting Administrative Officer and Marjorie Allen, as Acting Chief, Administrative Section. In oral communication with the author on September 20, 1989, Barrick recalls having spent about a month during which he visited Districts and prepared a written report to Assistant Chief Fiedler, its principal recommendation being to consolidate administrative units at District level—a single unit to serve all Branches in a State.

The two Assistant Division Chiefs retired in 1961—Fiedler in March and Wells in May. Wells would continue part-time until 1975 as Delaware River Master. Fiedler found a second career in the private sector, working as a water-resources professional in the ground-water field for many years. Until these positions were filled, Irving E. Anderson served as an Acting Assistant Division Chief for a number of months.

Elwood R. Leeson, District Engineer, Topeka, Kans., SWB, was selected to fill one of the Assistant positions and moved to headquarters in September 1961. His position subsequently occupied the role of operational management. Later, in March 1962, Tyrus B. Dover moved into the second Assistant's position from the position of Division Hydrologist, MCA, St. Louis, and his role subsequently tended to focus on the personnel side of management including career development, recruitment, and training.

The number of professional staff positions in the Division sections of publications, radiohydrology, and foreign hydrology increased markedly during 1960 and 1961, undoubtedly reflecting increasing workloads and Division involvement in these activities. New names included Helene L. Baldwin, Glen F. Brown, Caroline A. Bush, Dagfin J. Cederstrom, Luther C. Davis, Russell L. McAvoy, Glennon N. Mesnier, Alan E. Peckham, David A. Phoenix, and Donald R. Wiesnet. William W. Emmett replaced Myrick as research assistant on the Division Chief's immediate staff.

The years 1962 and 1963 saw some enlargement of organizational structure and additional increases in staff within the Division headquarters offices. The Career Development Section was dissolved and in its place two new sections emerged, reflecting the high priority being given to recruiting, training, and professional career development of personnel, and a shift in manpower management from the Branches to the Division. These two sections were Manpower Utilization, headed by Edmund F. LeRoux, and Recruiting and Training, headed by Raymond O. Abrams. Staff totaled 10 persons in these new sections according to the January 1, 1964, directory as compared to a staff of two persons in the Career Development Section in January of 1962. New staff members included Naydean M. Baker, Caroline M. Metcalf and Robert A. Perry.

The Publications Section under Erwin Asselstine grew with the increasing reports-processing workload assumed by the Division, from five persons in January 1962 to 11 persons in January 1964. New staff members by the later date included Verda M. Dougherty, Margaret M. Griffin, Kathleen T. Iseri, Frances G. Thompson, and James C. Warman.

A new section, Special Reports, headed by Medford T. Thomson from the SWB, was from its creation in 1962 a large group of 20 persons or more who took over much of the technical review, editing, and manuscript preparation. This Section also was commissioned to prepare some special reports requested by management. By January 1964, the staff roster included professional and technical careerists Clarence W. Anderson, John M. Birdsall, Carolyn Browning, Edith B. Chase, Rodney Hart, Margaret P. Mahey, Glennon N. Mesnier, Eva M. Patton, Lois E. Randall, and others.

By January 1963, the Radiohydrology Section was headed by Paul H. Jones. Its professional staff included Alfred Clebsch, Jr., George D. DeBuchananne, Alan E. Peckham, and Eugene S. Simpson. By January 1964, however, the research activities and personnel had been reassigned to the much enlarged GHB.

In his memorandum of August 3, 1962, to District Chiefs and staff officials, the Chief Hydraulic Engineer rather clearly spelled out his plan to accomplish reorganization to a Division-line structure. He said:

> We are considering the possibilities and implications of transformation to a Division-line structure in which Branch headquarters would have staff functions. The Division line of supervision would extend directly through the Division Hydrologist to Division District Chiefs, each of whom would be responsible for the entire operation in his State. Division Hydrologists would be line supervisors for all States in their areas. Branch Area Chiefs would be staff for the Division Hydrologist.
>
> Regardless of whether the above-noted kind of change occurs it is necessary to revamp the headquarters sections of the Division in order to centralize certain administrative, management, and programming functions which are now dispersed in Branch sections. Much of this realinement can be achieved without change in the present basic organizational structure. Some initial steps have been taken and others will be taken shortly. When this revamping is sufficiently advanced to function properly the so-called change of command upon approval could be shifted readily from Branch to Division offices in Washington, in Area Centers, and at District headquarters. Assignment of Division Chiefs in the State would proceed in an orderly manner. Owing to local situations, in some cases there would be departures from a strictly sequential process of reorganization.
>
> It would be presumptuous to predict approval by the Survey or the Department of any reorganization planned before it is fully developed. However, we have the Director's approval for regrouping activities in the Division headquarters and for trial reorganization of responsibilities in certain field offices. G.F. Worts has been designated as District Chief for the State of Nevada with supervisory responsibility for the total Nevada Program. Inasmuch as we plan to learn by doing, not all administrative details of District organization and its relation to present administrative lines have been fully resolved.

Closely following, by memorandum of October 26, 1962, Leopold announced the Director's approval for two more "trial" Division-level Districts: Tennessee, to be headed by Joseph S. Cragwall and the Caribbean, by Dean B. Bogart. Even though he cautioned these actions were being taken to gain experience as to future appropriate organizational structure, it was evident that a major reorganization would come and that it was being supported in concept by the Director.

In this same period, Ernest L. Hendricks, then Chief of the SWB, was selected by Leopold to be Associate Division Chief, replacing Nace, who sought to return to research and writing and to devote more time to his international activities, particularly the upcoming International Hydrological Decade (IHD) and other UNESCO programs (see Part IV, "International Programs"). By February 1963, Hendricks was fully functioning as Associate Chief of the Division.

Also later in 1962, the Chief Hydraulic Engineer focused his interest and attention on organizing research activities, which until then had been mostly conducted separately by the branches. By memorandum of November 6, 1962, Leopold asked Rolland W. Carter, then Chief of the Research Section, SWB, to consult with Frank E. Clarke, Chief GHB, and Robert Schneider, Acting Chief, Research Section, GWB, to consider two questions: "What scope should the Division research activity encompass? What should be the organizational structure of the research group?"

As a consequence, by mid-1963, and adhering to the Director's limited permission, specified elements of the fundamental research program were concentrated in the GHB, resulting in a large number of personnel transfers from the other Branches, especially GWB (see "General Hydrology Branch"). This group of research hydrologists later were to become the core of the Division's research program following full reorganization. The strategy behind this clustering of fundamental research activities and associated personnel was undoubtedly related to Division efforts to obtain funding for and establishing a Water Resources Institute. (For more discussion of the Institute proposal, see Parts IV and V, "The Program" and "Budget and Appropriations" sections of this volume and Part VIII, "Water Resources Research Act of 1964.")

A significant step in reorganization was announced by Associate Chief Hendricks on March 21, 1963 to wit:

> The title of Chief of the Division has been changed to Chief Hydrologist. Effective immediately the title Chief Hydrologist shall be used in all correspondence addressed to Mr. Leopold and in all correspondence prepared for his signature.
>
> The broadening scope of Division activities has placed greater emphasis on hydrology as a new disciplinary science, combining many skills, including engineering, geology, chemistry, and others. The change in Mr. Leopold's title has been made as a National consequence of this emphasis on hydrology.

This change in title was the cornerstone to establishing the "hydrologist" classification series in the CSC and later to converting most WRD professional positions from engineer, geologist, chemist, and others to hydrologist (see Part VI, "Establishing the Hydrologist Series").

Though the Chief Hydrologist pressed the Director for permission to formally and fully reorganize the Division during mid-1963, approval was not forthcoming for a complete change. Hendricks related in his memorandum of April 23, 1963, to key officials that, "...the Director's reluctance grows directly out of the experiences of last year when there was a concerted move in the Department to pull the water activities out of the Survey and out of other bureaus to form a new Water Bureau in the Department. A second factor which is related to the first is the pending action of the so-called Anderson Bill (S–1). If the Anderson Bill should pass the Congress, the Department will be faced with a problem in organization to administer the Act..... He is quite unwilling, therefore, to muddy the water in any fashion by requesting the Department to approve reorganization of the Division at this time....."

Nevertheless, the Director did approve a number of lesser organizational changes in July and August of 1963 (WRD memorandums 64.09 and 64.14), including:

1. Transfer of the Soil and Moisture Conservation (S&MC) Program from the GHB to the Office of Division Hydrologist, RMA, with the program placed under the leadership of Kenneth R. Melin, project hydrologist.

2. Transfer of the Division's Radiohydrology Section to the GHB with its work there to concentrate fully on research. Operational elements of the program would continue to be placed with other units of the Division for more effective hands-on supervision.

3. Reassignment of a number of research projects of an interdisciplinary character and most ground-water research from Branch research sections to the GHB as mentioned earlier.

In July 1963, Lawrence E. Newcomb was appointed Chief of the Division's Planning Section where he had been acting since Irving E. Anderson's retirement in December 1962.

In June 1964, in further preparation for reorganization, three staff committees were named by Hendricks, who was spearheading the planning for the reorganization, as follows:

1. <u>Staff Branch Organization</u>: Chairman, Williams, SWB; Clarke, GHB; Love, QWB; and Hackett, GWB—to recommend initial organization of present operating Branches when they become staff branches.

2. <u>Operation Services</u>: Chairman, Horace M. Babcock (representing the field organization); Wallace T. Miller, SWB; Solomon M. Lang, GWB; Herbert A. Swenson, QWB; and Francis T. Schaefer, BAC-SWB, ACA—to consider which of the operational services now performed by the Branches should be moved to the Division headquarters or Area Centers.

3. <u>Overall Division Organization</u>: Chairman, Dover; Williams; Jackson; and the chairman of the Operation Services Committee (Babcock)—to give primary attention to the complete Division organization, with particular reference to the early months or years of operation under the revised organization.

On June 25, 1964, Hendricks similarly charged the Division Hydrologists to convene for several days at Headquarters to consider Area operations under reorganization.

By late July 1964, a draft of an overall Division reorganization was being informally reviewed in the Director's office. The formal proposal went forward to the Director by memorandum of September 3, 1964. The Chief Hydrologist announced by WRD Memorandum 64.41, December 3, 1964, that Director and Departmental approval of reorganization would be effective December 9, 1964. This multiyear effort to reorganize from a Branch to a Division-level management and operational mode had been accomplished, at least conceptually on paper, and in part by functional changes and demonstration through the six intervening years of planning and transition.

Assistant Division Chief Dover, at his own request, sought and accepted reassignment to the Office of the Area Hydrologist, Denver, in August of 1964 as Branch Area Chief, QWB, succeeding Frank Ames, who just previously had been reassigned to research in RMA. Frank E. Clarke succeeded to the Assistant Chief's position a few months later, leaving Joseph E. Upson as Acting Chief, GHB, at the close of the year.

A significant impact on the Division's structure, role, and staff occurred as a result of Circular A–67 issued by the Bureau of the Budget (BOB) in August of 1964 and the subsequent formation of the Office of Water Data Coordination (OWDC) in WRD. OWDC's organization, role, and staffing are recounted later in this volume in Part VIII, "Water Issues and Events."

#### *Area Offices*

The Atlantic Coast (ACA), Rocky Mountain (RMA), and Pacific Coast Area (PCA) offices were at or near full staff and operating as Area committees by 1957 or early 1958. It was in September 1960, however, before the Mid-Continent Area (MCA) office was established in St. Louis, Mo. Until then its members had served from their former duty stations.

Locations and senior-level staffing of the four Area offices for the intervening years 1958–64 are shown in figure III–3. The Area committee rosters remained relatively stable throughout the period in ACA, RMA, and PCA. MCA experienced a number of key personnel changes throughout the period, led by Division Hydrologist Beckman's retirement in early 1958.

The Division Hydrologists and Area Committees were extended increasingly more leadership and management responsibilities through these transitional years. From the very start in May 1957, Leopold charged the Division Hydrologists, with their Area Committees as a group (memorandum of May 21, 1957), to evaluate and recommend, for acceptance or rejection, cooperative program proposals. They were cautioned, however, to be sensitive to prior commitments to cooperators, to maintain good will with them, and to exercise fairness and consistency among the States.

The first meeting of Division Hydrologists on November 21 and 22, 1957, in Washington was concerned to a great extent with the programming process, identifying water problems as a rationale for selecting hydrologic studies and research, and other matters, such as personnel needs, lines of communication, and functions of the GHB. It was made clear that program formulation was the Division's responsibility, and program execution and operation, the Branches' responsibility. The Division Hydrologists responded positively to their new commissions.

This shifting of "powers of management and direction" was not taken lightly and without dissent by the Branches. A committee of Branch Chiefs, in a memorandum to the Chief Hydraulic Engineer dated February 5, 1960, petitioned for retention of executive authority as traditionally exercised by their Branches and called for coordination only, not direction at Council and Area levels, but the Chief stood firm.

As the intervening years passed, the Division Hydrologists and Area Committees were given greatly enlarged roles in management, not only in planning and programming, but in other areas as well. They exercised stronger voices in career development and training of personnel, in reviewing and approving of project proposals, in providing for technical assistance to Districts, in monitoring technical content and general acceptability of reports for publication, and in guiding and directing District Council activities, including, by 1963, the appointment of a permanent Council chairman. Just before reorganization in late 1964, the Division Hydrologists were delegated authority to approve professional-grade promotions and reassignments through grade GS–12.

Throughout 1961 to 1964, increasing numbers of technical-support positions, mostly Branch-attached personnel (see Branch sections, following), reported administratively to their Branch Area Chiefs but received technical direction from their Branch and Section Chiefs.

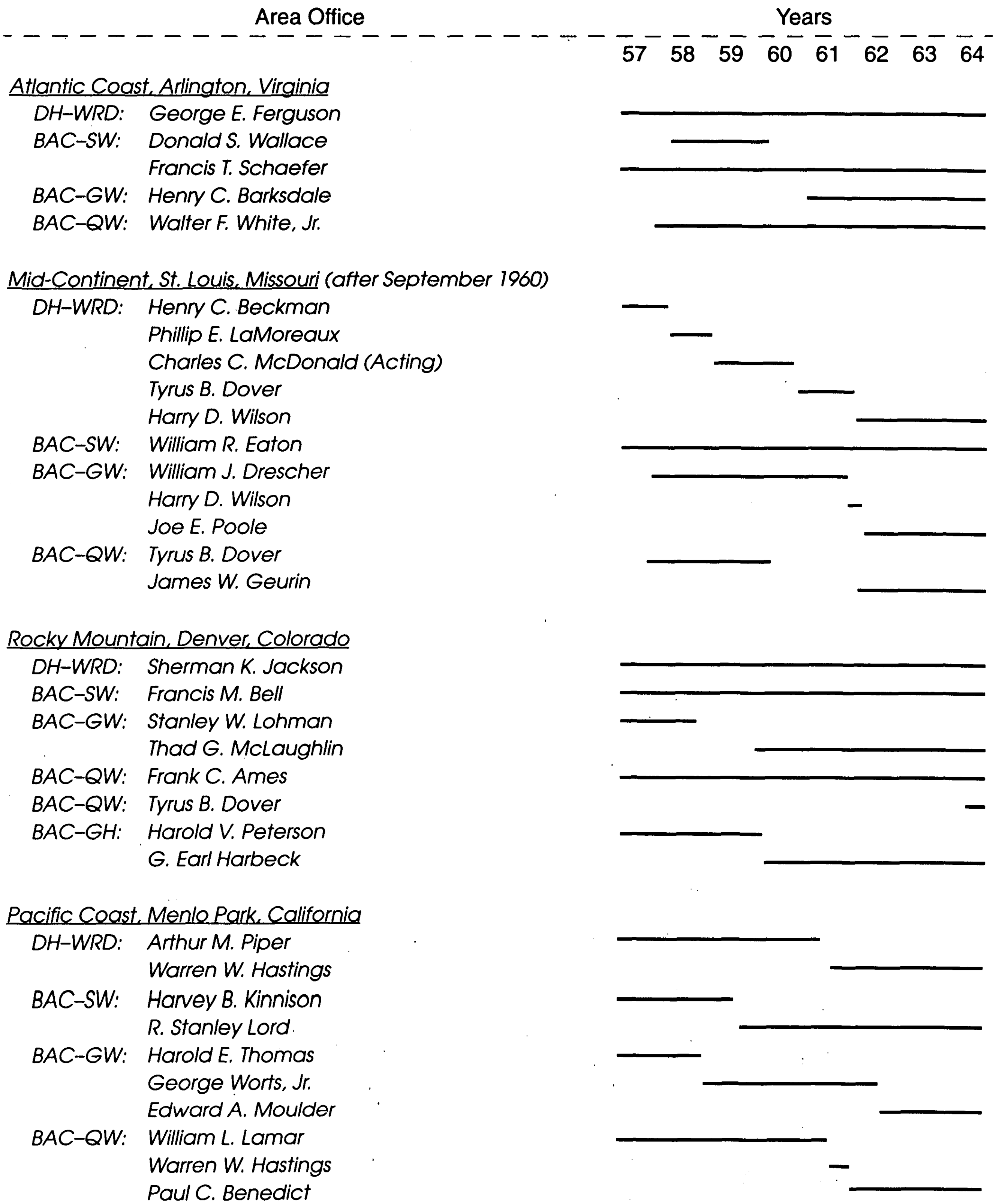
Secretarial and other nontechnical support personnel who served with the Area offices during these intervening years, 1958–64, included:

In ACA—Doris V. Clagett, Ines A. Gore, Cyreal W. Hoernemann, Betty L. Hudner, Katherine L. Jefferies, Edna W. Kalbfleisch, Norma J. McComas, Rebecca W. Perry, and Mary Jane Slane.

In MCA—Clara Ann Reeves, Decima S. Scott, and Marilyn S. Whittaker.

In RMA—Berniece R. Canzona, Joan A. Cecrle, Joy L. Charbonneau, Shirley B. Greene, Mary Helen Hawks, Jeannean W. Hayes, Lois M. Lingle, Betty R. Masin, Claudine S. O'Donnell, Irene Paulsen, Sharon L. Peterson, Bonnie J. Roadway, Phebe A. Turechek, Mary A. Wadge, Barbara T. Walton, and Wyn-Nelle L. White.

In PCA—Rita M. Christian, Mary E. Grisak, Constance E. Lamansky, Alice J. Larsen, Mildred P. Martin, Catherine A. Marvin, Helen M. McGraw, and Blanche A. Stinson.




*Note: After 1964, all BAC positions were reassigned as Division-level staff positions under the Division (Regional) Hydrologists.*

Figure III-3. Location and Senior Staffing of Area Offices, WRD, 1958–64.

By December 1964, when full reorganization was approved by the Director, the Area offices were, in reality, already more "line" than "staff."

### District Offices

The three Districts already mentioned—Nevada, Tennessee, and Puerto Rico-Virgin Islands (later renamed Caribbean District)—were assigned Division-level status during the intervening years, this action taken in late 1962 (see Part X, "District Activities" for details). The Arizona District formally became the fourth in February 1964 with Horace M. Babcock named as District Chief.

All Districts, however, during these years were increasingly exhorted to strengthen their council role in program planning and cooperator communications, and to improve their coordination in program execution, report review, administrative services, and all other possible ways. Centralizing office locations and facilities was encouraged and supported by the Division. Multidiscipline multi-Branch projects were encouraged and in many instances given funding priorities by the Area Committees, who also provided for or supplied technical assistance and training.

Although one cannot explicitly assess the success of these efforts—responsiveness was quite varied among the States—most Districts by the end of 1964 were indoctrinated in the inevitability of being changed to Division-level organizations, with all the work under the direction of a single District supervisor. Table III–1 lists the Council chairmen as of January 1, 1964, and to what extent locations and office facilities were collocated and administrative services centralized. The fact that 15 Districts with Branch headquarters still in different cities, and another 12 Districts with Branch offices not together in the same cities, was a measure of the logistical tasks that lay ahead. Moreover, 28 Districts still were without centralized administrative support units.

### Field Offices of the Division

Several field offices reported organizationally to the Office of the Division Chief.

Office of the Delaware River Master, Milford, Pa.—This office conducted the day-to-day operations of the Delaware River Master as mandated by the Supreme Court Decree of June 7, 1954. It was headed by W. Vaughn Iorns until 1958 when Iorns was succeeded by Robert E. Fish. Fish has recounted the activities and staffing in Part VIII of this volume, "Delaware River Master."

Representative and Project Office, Columbus, Ohio.—C. Vernon Youngquist, engineer (WAE), represented WRD in interdistrict water-resources programs for the Ohio River Basin. Youngquist, a former District Engineer for Ohio (SWB) and later a State water official, represented the Division throughout the period of this volume.

A project office was established in 1963, headed by Morris Deutsch, geologist, to prepare water-resources assessments of subbasins of the Great Lakes Basin, and later the Ohio River Basin, in support of major river-basin studies led by the U.S. Army Corps of Engineers. This office was continued throughout the period and beyond. Others attached to the project office were Paul R. Jordan, engineer, George D. Dove, geologist, Joe C. Wallace, physical science technician, Karen M. Erickson, cartographic aid, and Sue E. Lotte, clerk-stenographer. (See also Part X, "District Activities, Ohio.")

Field Unit, Menlo Park, Calif.—Upon relinquishing the position of Division Hydrologist, PCA, early in 1961, Arthur M. Piper returned to research and to a role as senior advisor not only to the Division Chief but to Survey and Interior officials as well. He continued in this capacity throughout the period, and afterwards until his retirement in 1968, assisted by Rita M. Christian, Secretary.

## Reorganization Implemented, 1965–66

Leopold served as Chief Hydrologist through 1965 and until mid-January 1966, when his requested reassignment to a senior research position was announced. His Associate, Hendricks, served thereafter as Acting Chief Hydrologist until formally named to the Chief's position June 19, 1966. As Associate Chief and then Acting Chief, Hendricks bore much of the brunt of effecting the necessary changes in structure, roles, and staff to implement the reorganization.

The reorganization announcement of December 3, 1964, cautioned that many changes were yet to be accomplished, but they would come slowly and deliberately. A second memorandum on December 3 to Branch Chiefs and Division Hydrologists spelled out lines of communication to be observed. Policy and overall program direction would be from Chief Hydrologist to Division Hydrologist to field officials; technical support and direction would be from Branch Chiefs to Branch Area Chiefs (a title soon to be dropped) to field offices or individuals, but with information copies to the Chief Hydrologist. Overall direction of research was to be retained by the Chief Hydrologist, acting through the GHB. In that second memorandum the Division Hydrologists were directed to designate

Table III–1. Council Chairmen and status of District facilities as of January 1, 1964

| State | Council chairman | Same city | Same location | Consolidated Administration |
|---|---|---|---|---|
| Alabama | Powell, William J. | Yes | Yes | Yes(?) |
| Alaska | Marsh, Ralph E. | No | No | No |
| Arizona | *Babcock, Horace M. | Yes | Yes | Yes |
| Arkansas | Yost, Ivan D. | Yes | Yes | Yes |
| California | Kunkel, Fred | No | No | No |
| Colorado | Odell, John W. | Yes | No | Yes |
| Connecticut | Horton, John | No | No | No |
| Delaware | See Maryland | -- | -- | -- |
| Washington, D.C. | See Maryland | -- | -- | -- |
| Florida | Patterson, A.O. | No | No | No |
| Georgia | Cameron, Albert N. | Yes | No | No |
| Hawaii | Miller, Merle M. | Yes | Yes | Yes |
| Idaho | Travis, Wayne I. | Yes | Yes | No |
| Illinois | Mitchell, William D. | No | No | No |
| Indiana | Hale, Malcolm D. | Yes | Yes | Yes |
| Iowa | Bennion, Vernal R. | Yes | No | No |
| Kansas | Kennedy, Edward J. | No | No | No |
| Kentucky | Schrader, Floyd F. | Yes | Yes | No |
| Louisiana | Kapustka, Stanley F. | Yes | No | No |
| Maine | Hayes, Gordon S. | Yes | Yes | No |
| Maryland | Forrest, William E. | No | No | No |
| Massachusetts | Knox, Charles E. | Yes | Yes | No |
| Michigan | Ash, Arlington D. | Yes | Yes | Yes |
| Minnesota | Brown, Richmond F. | Yes | No | No |
| Mississippi | Lang, Joe W. | Yes | Yes | No |
| Missouri | Homyk, Anthony, Jr. | Yes | No | No |
| Montana | Lane, Charles W. | No | No | No |
| Nebraska | LeFever, Floyd E. | Yes | Yes | Yes |
| Nevada | *Worts, George F., Jr. | Yes | Yes | Yes |
| New Hampshire | See Massachusetts | -- | -- | -- |
| New Jersey | Sinnott, Allen | Yes | Yes | Yes |
| New Mexico | West, Samuel W. | No | No | Yes |
| New York | Heath, Ralph C. | Yes | Yes | Yes |
| North Carolina | Wyrick, Granville G. | Yes | Yes | Yes |
| North Dakota | Erskine, Harlan M. | Yes | No | No |
| Ohio | Molloy, John J. | Yes | No | Yes |
| Oklahoma | Fischback, Alexander A. | Yes | No | No |
| Oregon | Sanderson, Roy B. | Yes | Yes | No |
| Pennsylvania | Steacy, Robert E. | No | No | No |
| Rhode Island | See Massachusetts | -- | -- | -- |
| South Carolina | Johnson, Albert E. | Yes | No | No |
| South Dakota | Powell, John E. | No | No | No |
| Tennessee | *Cragwall, Joseph S., Jr. | No | No | Yes |
| Texas | Twichell, Trigg | Yes | Yes | Yes |
| Utah | Arnow, Theodore | Yes | Yes | Yes |
| Vermont | See Massachusetts | -- | -- | -- |
| Virginia | Gambrell, James W. | No | No | No |
| Washington | Veatch, Fred M. | Yes | No | Yes |
| West Virginia | Griffin, William C. | No | No | No |
| Wisconsin | Young, Kenneth B. | Yes | No | No |
| Wyoming | Wiard, Leon A. | No | No | Yes |
| Puerto Rico | *Bogart, Dean B. | Yes | Yes | Yes |

*District Chief, WRD District

Source: January 1, 1964, WRD Organization and Personnel Directory.

deputies for research to serve as spokesmen and liaison officers for all research groups at each of the Area Centers.

Assistant Division Chief Leeson issued a memorandum on December 17, 1964, to the Branch Chiefs establishing an ad hoc committee of Branch representatives to consolidate program and operation files from the Branches to the Division. He named Horace G. Thomasson as Chairman, assisted by Louis P. Denis and Delmar W. Berry, to accomplish the task.

A DOI press release dated December 21, 1964, announced the reorganization plan for the Division and presented the rationale behind it as:

> "The immense growth of this country," said Secretary Udall, "has strained the Nation's water resources to the point that a community or industry seeking new or enlarged sources of water must consider a number of sources and the quantity and quality of the water from each source.
>
> "This change," he said, "has brought increasing inquiries to the Geological Survey's many field offices for answers to questions involving surface water, ground water, and water quality--engineering, geologic, and chemical information--all related to one another, and yet all traditionally separate. The reorganization of the Survey's Water Resources Division is designed to provide more effective and complete answers by blending previously fragmented individual skills of engineers, geologists, and chemists."

WRD memorandum 64.52, February 15, 1965, adopted the title "District Chief" for the person in charge of WRD District activities in a State and "Area Hydrologist" for the position formerly titled "Division Hydrologist."

On April 1, 1965, Hendricks provided Division, Branch, and other key officials with an initial draft of a statement on the functions of the Branches. This statement embodied 10 major areas of activity, all technical, and including such tasks as identifying water information and research needs, setting technical standards and controlling quality, maintaining a cadre of specialists and consultants, conducting special studies, and providing Divisional representatives on multiagency and professional-society committees.

In July 1965, Hendricks and Frank E. Clarke, Chief, GHB, analyzed and recommended supervisory patterns of research and Area staff positions which assigned the majority of research personnel to their Area Hydrologist through their Area Research Hydrologist (see "General Hydrology Branch"). Additionally, there were technical staff members reporting directly to the Area Hydrologists, a number of senior and younger scientists reporting directly to the Chief Hydrologist, and a relatively large technical staff, mostly associated with the radiohydrology program, reporting to the Chief, GHB. These arrangements were essentially confirmed by the January 1, 1966, WRD Organization and Personnel Directory and attest to the fact that most if not all of the research program, projects, and personnel had been reassigned by that time from the Branches to the Division. (See table III–2.)

During this same period the title of Branch Area Chief ceased to be used. Individuals in these former Branch positions became part of the Area management staff.

On August 3, 1965, by WRD memorandum 66.07, field officials were notified that the four QWB record-processing centers at Columbus, Lincoln, Rolla, and Sacramento were now organizationally part of those WRD Districts and under the direction of those District Chiefs.

By memorandum of August 9, 1965, the Chief Hydrologist named Raymond L. Nace as the Division's "Coordinator for Program Planning," the first of a long line of program officers to follow. It was presumed then, however, to be a part-time duty as Nace would continue to work as Research Hydrologist and as representative of the Chief Hydrologist in the international hydrologic community.

By January 1, 1966, according to the WRD Directory of that date, 27 of 47 Districts had been consolidated into Division Districts under the leadership of District Chiefs. The remaining Districts were reorganized in 1966 and 1967 (see table III–3).

In the midst of this eventful period for the Division, William T. Pecora, then Chief Geologist, became Director of the Survey, succeeding Thomas B. Nolan, who had served in the top position since 1956. It is interesting to note that Leopold's tenure as Chief of the WRD about equaled Nolan's tenure in duration and closely coincided with it in time.

By mid-1966, reorganization had been largely accomplished at Area and District levels but not at National Headquarters. Developing the new organizational structure, defining roles, and reassigning people came about only after much iteration of alternate proposals, strong but differing opinions about what Branches and Division roles should be, and genuine concern about maintenance of technical discipline, competence, and oversight in an emerging and growing multidiscipline program context. Branch officers seemed particularly concerned about their ability to maintain technical leadership and quality control with no line authority over project management.

Table III-2. Staff of WRD Headquarters, Area Offices, and Units, January 1, 1966

OFFICE OF THE DIVISION CHIEF
Leopold, Luna B., Chief Hydrologist
Thiesen, May E., Personal Assistant

OFFICE OF THE ASSOCIATE CHIEF
Hendricks, Ernest L., Associate Chief
Malone, Ruth L., Secretary (Steno)

OFFICE OF THE ASSISTANT CHIEFS
Leeson, Elwood R., Asst. Chief
Clarke, Frank E., Asst. Chief
Grube, Norma C., Secretary (Steno)
Merchant, Margaret G., Secretary (Steno)
Burks, Mary Jane, Secretary (Steno)

OFFICE OF DIVISION STAFF SCIENTISTS
Langbein, Walter B., Hydrologist
Nace, Raymond L., Hydrologist
O'Bryan, Deric, Social Scientist
Swenson, Herbert A., Hydrologist
McGuinness, Charles Lee, Geologist
Stringfield, Victor T., Geologist
Heindl, Leopold A., Hydrologist
Schneider, William J., Hydrologist
Pluhowski, Edward J., Hyd Engr
Horner, Lee, Botanist
Ireland, Dorothy M., Clerk (Steno)
Jennings, Eva R., Secretary (Steno)
Harrison, Lillian C., Clerk (Typing)
Scott, Kathy L., Clerk (Steno)

PLANNING SECTION
Daniels, Warren S., Chief, Hydrologist
Thomasson, Horace G., Jr., Hydrologist
Armstrong, Natalia M., ProgAnalAsst

MANPOWER SECTION
Abrams, Raymond O., Chief, SupvPersMgtSpec
Metcalf, Caroline N., PerStSp(Recruit)
Perry, Robert A., PersonnelMgtAsst
Phillips, Joan F., Personnel Clerk
Frank, Patricia E., Secy(Typing)
Johnson, Susan M., Clerk-Typist

PUBLICATIONS SECTION
Asselstine, Erwin S., Chief, Geol
McGovern, Harold E., Geol
Griffin, Margaret S., Geol
Dougherty, Verda M., Geol
Iseri, Kathleen T., Editor
Thompson, Frances G., Editor
Hillier, Donald E., CartoTech
Clark, Evelyn N., Clerk (Typing)
Thompson, Helen J., Clerk (Typing)
Altizer, Marlene H., Clerk-Typist
Heny, Michael, Jr., Publ-Clerk

WATER DATA COORDINATION
Hackett, O. Milton, Chief, Hydrologist
Whetstone, George W., SupvHydrol
Stewart, Herbert G., Jr., Hydrologist
Moore, Helen H., AdminAid
Madar, Joan A., Clerk-Steno

OFFICE OF THE DELAWARE RIVER MASTER
Wells, Joseph V.B., Engr

SPECIAL REPORTS SECTION
Mesnier, Glennon N., Acting Chief, Engr
Birdsall, John M., Geol
Randolph, James R., Geol
Walling, Faulkner, B., Chem
Hart, Rodney, EngrTech
Mahey, Margaret P., EngrTech
Chase, Edith Becker, TechPublWriter Ed
Anderson, Clarence W., EngrTech
Deike, Ruth G., Geol
Hoernemann, Cyreal W., Writer-Editor
Payne, Faith N., TechPublWriterEditor
Caston, Lois M., SupvEditClk
Browning, Carolyn, CartoTech
Patton, Eva M., CartoTech(Drfts)
Smith, Thelma, CartoTech(Drfts)
Fleshmon, Lois C., EditClk
Sparshott, Linwood H.,Jr., CartoTech
McConnell, Barbara D., EditClk
Sleeper, Douglas A., Clerk-Typist
Silcox, Mildred B., Secy(STeno)
Russell, Regina R., CorrespClk(Typ)
Wills, Clara G., Clerk
Ayres, Audrey, Clk-Typist
McClain, E. Louis, Clerk-Typist
Humphrey, Agatha P., Clk-Typist

OFFICE OF INTERNATIONAL ACTIVITIES
Taylor, George C., Jr., Chief, Hydrol
Jones, James R., Geol
Edelen, George W., Jr., Engr
Tibbetts, Gordon C., Jr., EngrTech
Kfoury, Simon H., CartoTech
Bradford, Gary M., CartoTech
Williams, Rebecca P., ForTraAsst

Table III–2. Staff of WRD Headquarters, Area Offices, and Units, January 1, 1966--Continued

Daniels, Alice C., Secy(Typ)
Dunbar, Mildred M., Secy(Typ)
McDonald, William H., Clerk
McClung, William V., Clerk-Typist

OFFICE OF THE ADMINISTRATIVE OFFICER
Barrick, Frank, Jr., AdmOfficer
Allen, Marjorie E., AdmAsst
Casey, Frances W., General Office Asst

ADMINISTRATIVE SECTION
Morgan, Charles W., Chief AdmOfficer
Snyder, James J., Adm Officer

General Services Unit
Devito, William J., Chief, AdmAsst
Collette, Francis H., AdmAsst
Quarles, Ralph V., Supply Clerk
Bokman, Delores M., Clerk(Typing)
Martinsky, Carol A., Clerk-Typist
Horton, Gladys M., Clerk-Typist

Fiscal Management Unit
Scopi, John D., Chief, AcctFisAsst
Goucher, Arthur E., AcctFisAsst
Elmore, John W., AcctFisAsst
Ellis, Myrtie M., AcctClerk
McQueeney, Bertha E., AcctFisClk
Youmans, Margaret L., AcctClerk

Note: Branch offices and staff are described in the Branch organization sections that follow.

OFFICE OF THE AREA HYDROLOGIST
ATLANTIC COAST AREA - ARLINGTON, VA.
Ferguson, George E., Area Hydrologist
Barksdale, Henry C., Engr
Schaefer, Francis T., Engr
White, Walter F., Jr., Chem
Stuart, Wilbur T., Engr
Back, William, Hydrol
Cederstrom, Dagfin J., Hydrol
DeBuchananne, George D.,Hydrol
Barnes, Harry H., Jr., Engr
Crooks, James W., Hydrol
Kimrey, Joel O., Hydrol
Swanson, Mary Jayne, ProgramAnal
Jeffries, Katherine L., Secy-Steno
Clagett, Doris V., Secy-Typing
Alatizer, Marlene H., Clerk-Typist
Outlaw, Lindabelle, Clerk-Typist

Research Projects Staff
Baltzer, Robert A., Engr
Bennett, Robert R., Geol
Billings, Richard, ElecTech
Bredehoeft, John D., Geol
Carlston, Charles W., Geol
Cory, Robert L., Oceanographer
Nauman, Jon W., Oceanographer
Eddy, James E., ElecDevTech
Edwards, Melvin D., Chem
Gambell, Arlo W., Meterol
Hanshaw, Bruce B., Geol
Jones, Blair, Geol
Matalas, Nicholas C., Engr
Papadopulos, I.S., ResHydrol
Lai, Chintu, Engr
Phipps, Richard L., Bot
Sigafoos, Robert S., Bot
Trainer, Frank W., Geol
Wolff, Roger G., Geol
Yotsukura, Nobuhiro, Engr
Gilroy, Edward J., Math
Appelgate, Edna, Clerk-Steno
Gore, Ines, Clerk-Steno
Lusby, Joan, Clerk-Steno
Rosson, June C., Secy-Steno
Wilcox, Joan R., Clerk-Steno
George, John R., Hydrol

Research Projects Staff
District of Columbia
Olsen, Harold W., Engr
Smith, William O., Phys
Emmett, William W., Engr
Williams, Garnett P., Geol
Parkes, John E., Engr

OFFICE OF THE AREA HYDROLOGIST
MID-CONTINENT AREA -ST. LOUIS, MO.
Wilson, Harry D., Jr., Area Hydrologist
Poole, Joe L., Hydrol
Geurin, James W., Hydrol
Eaton, William R., Hydrol
Robinove, Charles J., Hydrol
Tice, Richard H., Engr
Reeves, Clara Ann, AdminClk
Whittaker, Marilyn S., Secy
Burnham, Phyllis N., Clerk-Typist
Brice, James C., Geol

OFFICE OF THE AREA HYDROLOGIST
ROCKY MOUNTAIN AREA - DENVER, COLO.
Jackson, Sherman K., Area Hydrologist
Harbeck, G. Earl, Jr., Hydrol
Lohman, Stanley W., Geol
Bell, Francis M., Hydrol
Dover, Tyrus B., Hydrol
McLaughlin, Thad G., Hydrol
Ames, Frank C., Engr
Haynes, George L., Jr., Hydrol
Carroon, Lamar E., Engr
Hudson, Hugh H., Engr
LaRocque, George A., Jr., Engr
Matthai, Howard F., Engr
Meyers, J. Stuart, Engr
Petersen, Mervin S., Engr
Skougstad, Marvin W., Chem
Barnett, Paul R., Chem
Beetem, W. Arthur, Chem
Dennis, P. Eldon, Geol
Swenson, Frank A., Geol
Grove, David Bernard, ChemEngr
Edwards, Kenneth W., Chem
Janzer, Victor J., Chem
Robinson, Billy P., Chem
Kennedy, Vance C., Geol
Scott, Robert C., Geol
Bullard, Edwin R., Jr., Geophy
Jenne, Everett A., Soil Scientist
Fishman, Marvin J., Chem
Goldberg, Marvin C., Chem
Johnson, Jesse O., Chem
Mallory, Edward C., Jr., Chem
Wershaw, Robert L., Geol
Malcolm, Ronald L., Soil Scientist
Sturrock, Alex M., Jr., Physicist
Angelo, Clifford G., Chem
Burcar, Patricia Joan, Chem
Claassen, Hans C., Chem
Midgett, Maryland R., Chem
Dunton, Pauline, J., Chem
McCullough, Richard A., Math
Wollitz, Leonard E., ElctTech
Parshall, Ernest E., ElectDevTech
Dewar, Robert S., PhySciTech
Scarbro, George F., PhySciTech
Villasana, Edward, PhySciTech
Golden, Darwin, PhySciTech
McNutt, Margaret H., EngTech
Roscio, Paul K., EngrTech
Emerson, Robert L., PhySciTech
Kouba, Dorothy L., PhySciTech
Smith, James L., CartTech
Hayes, Jeannean W., EngrAid
Hubbard, Lawrence, EngrAid
Rickard, Marjorie S., PhySciAid
Snyder, Richard L., PhySciAid
Miller, Lawrence L., PhySciAid
Swartz, William M., PhySciAid
Hawks, Mary Helen, Secy(Steno)
Paulsen, Irene, Secy(Steno)
Turechek, Phebe A., Secy(Steno)
Lingle, Lois M., Clerk(Steno)
Charbonneau, Joy Lorene, Clerk(Steno)
Fosler, Avis W., ClkDictMachTrans
Gibson, Frances M., Clerk(Typ)
Masin, Betty R., Clerk(Typ)
Lull, Corinne A., Clk-Steno
Madigan, Eleanor L., Clerk-Typist
Booker, Sarah Eveline, Clerk-Typist
Beckham, Kenneth J., Chem
Warren, Charles Thomas, PhySciAid

Project Office -Denver
Parker, Garald G., Sr., Hydrol
Eisenlohr, William S., Jr., Hydrol
Koberg, Gordon E., Hydrol
Stallman, Robert W., Engr
Melin, Kenneth R., Engr
King, Norman J., Geol
Hadley, Richard F., Geol
Keys, Walter S., Geol
Schumm, Stanley A., Geol
Branson, Farrel A., Botanist
Voegeli, Paul. T., Hydrol
Lusby, Gregg C., Engr
Sammel, Edward A., Geol
Daum, Claude R., Physicist
McQueen, Irel S., Engr
Van Lewen, Melvin C., Engr
Kahn, Lloyd, Chem
Sloan, Charles E., Geol
Miller, Reuben F., SoilSci
Shown, Lynn M., SoilSci
Ghering, Garth E., ElecDevelTech
Osterkamp, Waite R., PhySciTech
Ratzlaff, Karl W., PhySciTech
Buller, William, PhySciTech
Kast, John A., ElecDevelTech
Jackson, Charlotte E., Secy(Steno)
Ensinger, Janet M., Clerk-Typist
Schnepf, Jo Ann, Clk(Steno)

Hydrologic Laboratory - Denver
Johnson, Arnold I., Engr-in-Chg
Lockwood, William N., Geol
Bingham, Donald L., HydEngr
Jones, Ronald Herseth, Hydrol
Bechtold, Virginia Lee, EditAsst
Pitchford, Frances R., Clerk-Typist

Hydrologic Equip and Service Unit - Denver
Shuter, Eugene, Tech-in-Chg
Ralston, Don A., EngrTech
Goemaat, Robert L., Engr Tech
Jones, Richard E., EngrTech
Springer, Donald K., EngrAid
Anderson, Grady B., EngrAid
Green, Stanley T., PhySciAid
Jordan, Lois A., Clerk-Typist

Field Unit - Fort Collins
Guy, Harold P., Engr
Richardson, Everett V., Engr
Chang, Fred Feng-Ming, Engr
Kilpatrick, Frederick A., Engr
Sayre, William W., Engr
Nordin, Carl F., Jr., Engr
Rathbun, Ronald E., ChemEngr
Brower, Beverly K.,Clerk-Typist
Simons, Daryl B., Engr
Albertson, Maurice L., Engr
Chamberlain, Adrian R., Engr
Plate, Erich J., Engr
Koloseus, Herman John, Engr

OFFICE OF THE AREA HYDROLOGIST
PACIFIC COAST AREA, MENLO PARK, CALIF.
Hastings, Warren W., Area Hydrologist
Benedict, Paul C., Hydrol
Lord, R. Stanley, Hydrol
Moulder, Edward A., Hydrol
Robinson, Thomas W., Hydrol
Hem, John D., Chem
Lamar, William L., Chem
Culbertson, Don M., Engr
Dawdy, David R., Engr
Young, Loren E., Engr
Feth, John H., Hydrol
Kunkel, Fred, Hydrol
Newcomb, Lawrence E., Hydrol
Barnes, Ivan K., Geol
Rubin, Jacob, SoilSci
Slack, Keith V., Biolog
Page, Harry G., Hydrol
Schoen, Robert, Hydrol
Goerlitz, Donald F., Chem
Ehrlich, Garry G., Chem
Poizer, Wilfred L., Chem
Roberson, Charles E., Chem
LaMarche, Valmore C., Jr., Geol
Ripple, Charles D., SoilSci
Donaldson, Donald E., Chem
Law, Leroy M., Chem
Janda, Richard J., Geol
Marvin, Catherine A., Secy
Stinson, Blanche A., Secy(Steno)
Grisak, Mary E., Clerk(Steno)
Perez, Robert P., Jr., Clerk(Typ)
Dick, Gertrude L., Clerk-Steno
Potts, Ingrid T., Clerk-Steno
Tanaka, Grace T., Clerk-Steno
Lamansky, Constance E., Clerk-Typist
Eldred, Karleen K., Clerk-Steno
Peterson, Harold V., Hydrol
Helley, Edward J., Geol

Project Office -Menlo Park
(Reports to the Area Hydrologist - Denver)
Snyder, Charles T., Hydrol
Lichty, Robert W., Hydrol
Zdenek, Ferdinand F., Hydrol
Smith, Ralph E., Geol
McGraw, Helen M., Clerk-Typist

Project Office -Sacramento
Poland, Joseph F., Geol
Lofgren, Ben E., Engr
Bull, William B., Geol
Riley, Francis S., Geol
Ireland, Richard L., EngrTech
Farmer, Margaret H., Secy(Steno)

Field Unit - Sacramento
Brown, Eugene, Chem
Nishioka, Yoshimi A., Chem

Table III–3. *The initial roster of WRD District Chiefs, their dates of entry, and discipline*

| State | District Chief | Date | Former branch | Discipline |
|---|---|---|---|---|
| Alabama | Broadhurst, William L. | 3/65 | GW | Geol. |
| Alaska | Hulsing, Harry | 12/64 | SW | Engr. |
| Arizona | Babcock, Horace M. | 2/64 | GW | Engr. |
| Arkansas | Sniegocki, Richard T. | 6/65 | GW | Geol. |
| California | Hofmann, Walter | 2/65 | SW | Engr. |
| Colorado | Moulder, Edward A. | 2/67 | GW | Engr. |
| Connecticut | Horton, John | 10/66 | SW | Engr. |
| Delaware | See Maryland | -- | -- | -- |
| Florida | Conover, Clyde S. | 2/65 | GW | Engr. |
| Georgia | Cameron, Albert N. | 7/65 | SW | Engr. |
| Hawaii | Miller, Merle M. | 2/66 | SW | Engr. |
| Idaho | Burnham, Willis L. | 7/66 | GW | Geol. |
| Illinois | Mitchell, William D. | 1/66 | SW | Engr. |
| Indiana | Hale, Malcolm D. | 2/65 | SW | Engr. |
| Iowa | Wiitala, Sulo W. | 2/67 | SW | Engr. |
| Kansas | Dingman, Robert J. | 11/66 | GW | Geol. |
| Kentucky | Schrader, Floyd F. | 2/67 | SW | Engr. |
| Louisiana | Meyer, Rex R. | 1/66 | GW | Geol. |
| Maine | Hayes, Gordon S. | 4/66 | SW | Engr. |
| Maryland | Wark, John W. | 12/64 | QW | Engr. |
| Massachusetts | Knox, Charles E. | 2/65 | SW | Engr. |
| Michigan | Ash, Arlington D. | 6/65 | SW | Engr. |
| Minnesota | Collier, Charles R. | 5/67 | QW | Engr. |
| Mississippi | Robinson, William H. | 2/65 | SW | Engr. |
| Missouri | Homyk, Anthony, Jr. | 1/67 | SW | Engr. |
| Montana | Lane, Charles W. | 4/66 | GW | Geol. |
| Nebraska | MacKichan, Kenneth A. | 7/65 | QW | Engr. |
| Nevada | Worts, George F., Jr. | 8/62 | GW | Geol. |
| New Hampshire | See Massachusetts | -- | -- | -- |
| New Jersey | McCall, John E. | 8/66 | SW | Engr. |
| New Mexico | Hale, William E. | 1/66 | GW | Engr. |
| New York | Heath, Ralph C. | 2/65 | GW | Geol. |
| North Carolina | Rice, Edward B. | 7/65 | SW | Engr. |
| North Dakota | Erskine, Harlan M. | 7/66 | SW | Engr. |
| Ohio | Molloy, John J. | 6/65 | SW | Engr. |
| Oklahoma | Odell, John W. | 7/67 | SW | Engr. |
| Oregon | Kapustka, Stanley F. | 9/66 | QW | Chem. |
| Pennsylvania | Bemer, Norman H. | 7/66 | QW | Chem. |
| Rhode Island | See Massachusetts | -- | -- | -- |
| South Carolina | Carter, Rolland W. | 1/66 | SW | Engr. |
| South Dakota | Powell, John E. | 7/66 | GW | Geol. |
| Tennessee | Cragwall, Joseph S., Jr. | 9/62 | SW | Engr. |
| Texas | Twichell, Trigg | 2/65 | SW | Engr. |
| Utah | Wilson, Milton T. | 7/65 | SW | Engr. |
| Vermont | See Massachusetts | -- | -- | -- |
| Virginia | Gambrell, James Wyatt | 7/66 | SW | Engr. |
| Washington | Laird, Lesley B. | 8/64 | QW | Chem. |
| West Virginia | Griffin, William C. | 4/66 | SW | Engr. |
| Wisconsin | Holt, Charles L.R., Jr. | 7/66 | GW | Geol. |
| Wyoming | Wiard, Leon A. | 1/67 | SW | Engr. |
| Puerto Rico | Bogart, Dean B. | 9/62 | SW | Engr. |

Leopold had invited Harry D. Wilson, Area Hydrologist, MCA, to spend time in headquarters during 1965 and 1966, as a moderator, facilitator, and consultant to Division and Branch officers on headquarters organization, and to draft a headquarters reorganization plan. Wilson, a self-avowed practitioner of participative management, listened patiently to all viewpoints, weighed all suggestions, and finally proposed what he considered to be a workable plan—one that would be generally acceptable to all viewpoints. He proposed a three-pronged staff arrangement, each headed by an Assistant Division Chief: one for information services (reports and data processing), one for administration and technical support services (operations), and one for technical oversight (Branch and research activities). His final proposals were presented to the Acting Chief Hydrologist in an internal report in May 1966, and were in essence implemented in the months following.

Although the reorganization efforts were not completed until some months after mid-1966, the resulting structure is best summarized by figure III-4, an organizational chart for the Division as of August 1966, and figure III-5, a configuration of regional boundaries.

After Hendricks' appointment as Chief Hydrologist in June 1966, Frank E. Clarke was named Associate Chief a few months later. Elwood R. Leeson became Assistant Chief for Administration and Technical Services. Before the end of the year, George W. Whetstone had been named Assistant Chief for Reports and Data Processing, and in 1967, Roy E. Oltman became Assistant Chief for Research and Technical Coordination with Joseph E. Upson as his deputy for research.

With the completion of final reorganization by mid-1967, the General Hydrology Branch was dissolved and the Branches of Surface Water, Ground

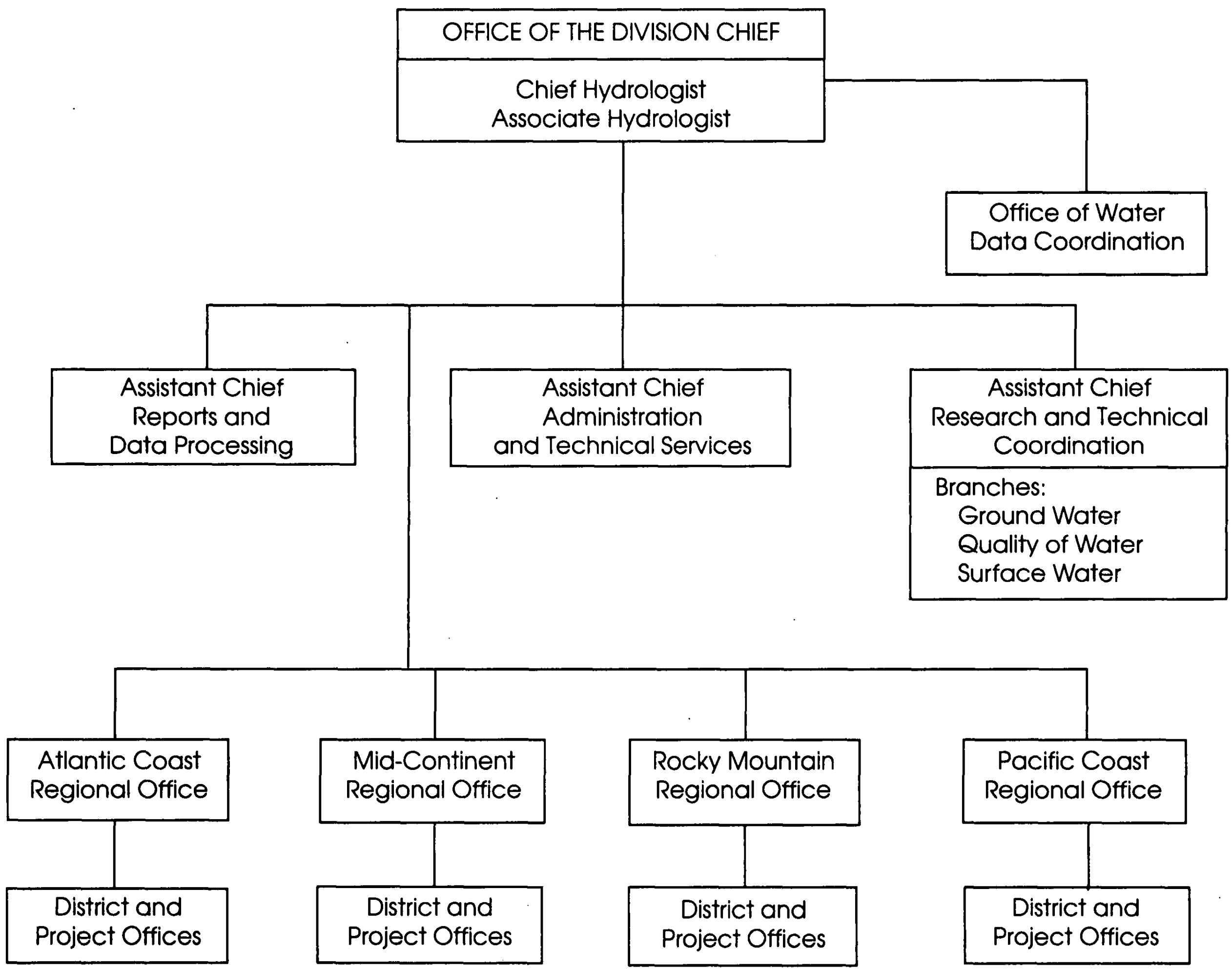



Figure III-4. Organization chart of the reorganized Water Resources Division, October 1966.

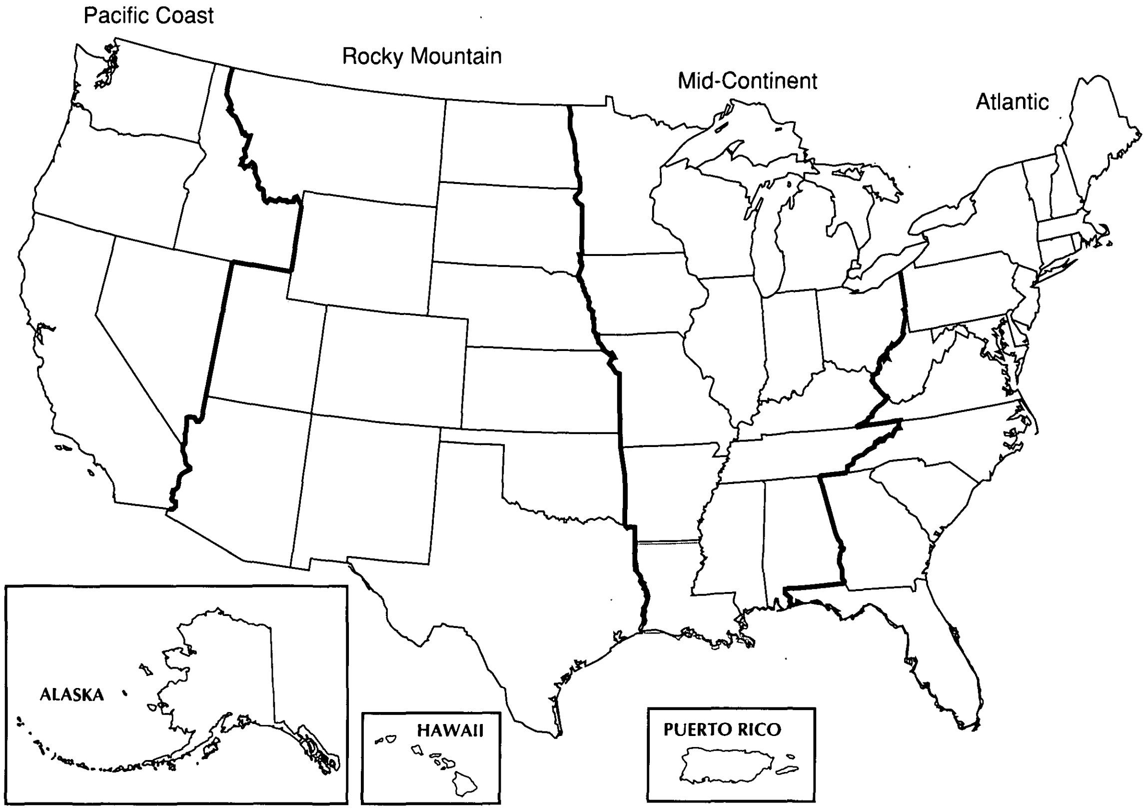



Figure III-5. Regional boundaries and offices, WRD, October 1966.

Water, and Quality-of-Water were in their roles as technical staff units of the Division. The Area (Regional) offices were fully operational as line managers of the Districts and of all other program activities including research within their areas. New titles of Regions and Regional Hydrologists had become official and all Districts had been converted to Division-level status.

The complete reorganization, which began in 1956, was finally accomplished a decade later.

## Surface Water Branch

*By* Donald M. Thomas *and* reviewed *by* Henry C. Riggs, Clayton H. Hardison, Francis J. Flynn, Charles R. Showen, Harry H. Barnes, *and* other vintage stream gagers

The Surface Water Branch (SWB), the oldest and largest of the operating Branches, reached a pinnacle of size, influence, and prominence during the years 1957 to 1966. Its staff operated in all States, Puerto Rico, and Guam, and gained national and international recognition for excellence and accomplishments. During the WRD reorganization, which began officially in 1964, most of the SWB activities and staff were transferred to Division-level administration. When the reorganization was completed in 1966, the SWB, like the other operating Branches, had been converted to a small headquarters unit with primarily quality-control and review responsibilities.

### National Overview

The SWB had grown rather steadily over the years and, by 1956, employed 1,062 people including 590 professionals—mostly engineers, 300 subprofessionals and 172 in administrative/clerical positions. In 1962, the latest year in which employees were assigned to a specific Branch in all field offices, the SWB staff numbered 1,270 with little change in personnel types. Ferguson (Volume V) noted the growth in numbers of subprofessional employees (there were only seven in 1941) and commented that the increasing numbers could be attributed to the success of using subprofessional personnel as stream gagers during the engineer-short World War II years. Following the war, when SWB programs were growing rapidly and government work and salaries were relatively unattractive to graduating engineers, the trend toward increased use of technicians continued.

The SWB staff in 1962 operated out of a headquarters office, four Area (Regional) offices, 20 field units that reported either to headquarters or to the Branch Area Chief (BAC-SWB), 46 District offices, 82 Subdistrict offices, and 63 field offices. Most of the District offices were located at State capitals to be near cooperating State agencies. The grass-roots locations of personnel had played a major role in the creation of the national stream-gaging program and the growth of WRD cooperative programs.

The primary objective and by far the most time-consuming activity of SWB was operating the national network of stream-gaging stations and publishing data from that network. Over the years, the number of stations showed a steady increase: 5,800 stations in 1947, 6,832 in 1957, and 8,340 in 1967. In addition to the complete-record stations for which the daily stage and (or) flow rate was determined and published, an increasing number of partial-record gaging stations had been established, about 9,700 by 1967, for which only annual maximum stages and discharges or minimum discharges were determined.

Collecting, processing, and publishing data was a gigantic endeavor accomplished by monumental, labor-intensive effort. For the usual stream gage, basic field observations were obtained by a continuous water-level recorder or from one or more daily gage readings by an observer, and by periodic measurement of the flow. In the office, the daily average discharge was computed from the flow-measurement-defined stage-discharge relation and the corresponding daily water level. Monthly and annual statistics were then computed using desk calculators from the listed daily flows. All listings and computations were closely checked for accuracy, and the decisions, judgments, and assumptions of the analysis were documented in an annual "station analysis." The listed stages, discharges and statistics along with the station analysis and a manuscript identifying the gage location, history, and other pertinent information were forwarded to the Basic Records Section staff at Headquarters, who reviewed the materials for accuracy and acceptability before typing for offset printing in the annual series of Water-Supply Papers (WSP). The problem of timely publication of data was complicated in the years 1945 to 1957 by the large backlog of unprocessed data that had accumulated during World War II.

SWB officials long had recognized that the data processing and publishing system was cumbersome, expensive, and slow, and they had begun investigations of many alternatives. The alternatives covered all phases of the streamflow-data program, including more accurate and cost-effective techniques for field-data collection, use of newly developing technology for machine processing of flow records, more timely and more useful publication formats, and evaluating networks to identify gaging stations of low-value or duplicate information that could be discontinued. (See Part IV, "Hydrologic Data Networks" and "Operations Research.")

Although operation and improvement in the streamflow-data program was the centerpiece of SWB activities, other work also was in progress at the beginning of this period. These activities included basic research into hydraulics of open-channel flows, development and improvement of indirect methods for determining flood peak-flow rates, improving instrumentation, and defining techniques for establishing the magnitude and frequency of both low flows and floods.

No statement on the background of the SWB could be complete without a description of the primary member of the staff—the stream gager who collected the field data and converted it into the streamflow-data reports. Usually, he was either a civil engineer or an engineering technician. The stream gager learned his skill through reading Water-Supply Paper 888 and on-the-job training because no academic institutions taught the techniques. He usually worked alone on field trips that commonly lasted a week or two. At a time when long-distance telephone calls were virtually never used, the stream gager was expected to handle unusual situations or emergencies in a prudent and effective manner without guidance from the office. In addition, he was on call for flood measurements at all times; every experienced stream gagers could cite numerous instances of late-night or holiday summonses to immediately travel through stormy weather to some distant gaging station for the high-water measurement needed to define the upper end of a rating curve. The successful stream gager obviously enjoyed the opportunity for unsupervised outdoor work and already possessed or soon developed the personal characteristics of independence, self reliance, pragmatism, dedication to duty, and, perhaps most important, the "feel for a river." In the office the stream gager was required to persevere through the repetitive and often tedious chore of converting recorder charts and measurement notes into streamflow records. All work was closely checked for accuracy and completeness. Avoiding the admonishment of checkers and reviewers required that the stream gager pay attention to details and consider the numerous alternative analytical options available—a training that developed a recognition of the reliability and the limitations of natural-resources data. Finally, the stream gager recognized early that the career ladder to increased salary and authority likely would include a transfer to another duty station, a career decision which broadened his experience, enhanced his dedication to the organization, and established a strong esprit de corps.

Virtually all of the 1957-to-1966 leaders of the SWB and many of the senior officials of the WRD came from a stream-gaging background. Of the 1957-to-1961 SWB staff at Headquarters, all but two (Alan V. Jopling, a geologist, and Vujica M. Yedjevich, an engineer) began as stream gagers. As the analytical and research efforts of SWB expanded, the needs for additional skills were recognized. Three of the first professionals with no stream-gaging experience joined the Headquarters staff in the fall of 1961, they were Donald I. Cahal, a physicist, and Nobuhiro Yotsukura and Chintu Lai, both engineers.

### Headquarters Organization, Functions, and Staff

A small Headquarters staff assisted by the staffs of the four Area offices directed and managed the widespread, field-oriented SWB organization. In 1956, the Headquarters staff consisted of 71 people and reached a maximum of 76 by 1962. By 1966, after reorganization had shifted many of the SWB functions and operations to Division units, the staff numbered only 17: 11 professionals, 1 statistical assistant, 1 engineering aid, and 4 clerk/typists.

The SWB headquarters staff in 1957 was organized into an Office of the Branch Chief and six Sections, each of which had the functions as listed in figure III–6. The Office of the Branch Chief and the Planning Section were located in the General Services Administration Building, north of the Interior Building in Washington, D.C. Because of a lack of adequate space in or near the Interior Building, the rest of the staff were housed in the Washington Building of the Arlington Towers apartment complex across the Potomac River in Arlington, Va.

Until after the WRD reorganization became effective in December 1964, the SWB structure and functions shown in figure III–6 remained reasonably applicable, except that the SWB Training Section duties were transferred to the WRD Career Development Section in 1962. There were, however, significant changes in specific duties and operating methods of the Sections, particularly during the SWB reorganizations of September 7, 1961 (SWB Memo 62.15) and June 21, 1963 (SWB Memo 63.67). Numerous personnel changes occurred. In addition to the common practice of rotating field people into headquarters positions for a 2-year or longer educational experience, experimenting and testing during the prereorganization period generated numerous temporary and short-term details of senior personnel into alternate positions resulting in a wealth of "Acting Chief" titles.

One of the functions that was common to all Sections of SWB was a responsibility for technology transfer—by consulting, teaching at training sessions, and, most important, by preparing or reviewing reports, handbooks, and manuals. In 1962, Thomas J. Buchanan of the Hydrologic Studies Section began updating Water-Supply Paper 888 with a new manual on stream gaging, and that manual was distributed to field offices in a loose-leaf format. Upon completion of Buchanan's manual in October 1963, it was decided that future manuals on techniques should be distributed as bound reports in a series of "Surface Water Techniques" reports (SWB Memo 64.53). Several chapters of Surface Water Techniques reports were prepared and distributed although the reports had no official status as USGS publications. This series of reports subsequently evolved into the formal publication series "Techniques of Water-Resources Investigations of the United States Geological Survey" (TWRI) that present techniques from all Branches of WRD.

#### *Office of the Branch Chief*

The Office of the Branch Chief was responsible for policies, plans, budgets and operations of all SWB field and headquarters offices. In addition to the Chief, Assistant Chief, from one to four staff professionals, and two or three secretaries, senior members of the SWB headquarters staff occasionally were assigned temporarily to the Office of the Branch Chief to assist with administrative and management tasks and on special assignments.

In 1957, the Branch Chief had a direct line authority to each District office. Communication was primarily by memorandum and infrequent long-distance phone calls. District Engineer visits to headquarters and occasional areal or national meetings of District Engineers provided guidelines and criteria for District operations, leaving the District Engineers wide latitude for planning and managing District programs.

Creation of the District Councils in the early 1950's and the Area offices in the mid-1950's provided for an increasing coordination and unification of

WATER RESOURCES DIVISION

OFFICE OF THE CHIEF

BRANCH OF SURFACE WATER
Code 4040 0001

The Branch of Surface Water collects, analyzes, and evaluates data relating to the rivers and other surface waters of the Nation. Determines sources, quantity, distribution, movement, and availability of surface waters. Engages in research, both basic and applied, including investigations in hydraulics of open channels and the hydrologic characteristics of watersheds as they relate to flow in surface streams, lakes, and reservoirs. Conducts investigations related to floods and droughts: their magnitude, frequency, and relation to climatic and physiographic factors.

RESEARCH SECTION
Code 4041 5402

Coordinates, integrates, and maintains continuity of the research activities of the staff sections and field offices of the Branch; actively performs research; provides consultation services to staff and field units to resolve problems of hydraulic technology and instrumentation.

Plans work estimates for research projects of all types which seem to offer possibilities for advancements or economies in the scientific theory, instrumentation, methods, or practices used in surface-water investigations; recommends priorities and assignments of projects to staff or field units.

Inspects progress and conformance with specifications of objectives, tests new theories, techniques, and instrumentation developed to assure reliability.

FLOOD SECTION
Code 4042 5402

Formulates plans, makes and coordinates investigations, and prepares reports related to flood flows in open channels. Recommends, conducts, and coordinates areal studies of the correlation between the magnitude and frequency of flood discharges and climatic and physiographic factors. Establishes a plan and maintains a core of supervisory engineers to direct field parties in studies of floods immediately after flood-producing storms.

Recommends and advises on research projects involving undefined principles and practical application of hydraulic-engineering and fluid mechanics to flood flows. Conducts research projects related to flood flows in coordination with the Research Station.

Develops procedures, guides, and instructions and establishes standards for the collection and analysis of flood data, and trains selected engineers as specialists in their work.

HYDROLOGIC STUDIES SECTION
Code 4043 5402

Formulates, conducts, and coordinates hydrologic investigations of low-flow and intermediate-flow characteristics of surface-water courses and related climatic and physiographic conditions.

Conducts research, coordinated by the Research Section, to advance the science of hydrology of low flows and intermediate flows and the evaluation, interpretation, and correlation of surface-water data with other factors.

Provides consultation services to staff and field units on practical and theoretical solutions to hydrologic problems, and trains specialists in statistical, analytical, and interpretive techniques developed.

Prepares reports dealing with nationwide or regionwide aspects of surface-water supply and application of hydrologic techniques.

BASIC RECORDS SECTION
Code 4044 5402

Reviews and compiles streamflow data and other surface-water records into annual or other compilation reports for publication.

Develops procedures, standards, and instructions for collection, computation, and review of surface-water records. Trains selected engineers in the advanced phases of this work.

Conducts studies of the effects of storage and other flow factors on the utilization and interpretation of surface-water data. Studies of this nature are coordinated with the Research Section.

TRAINING SECTION
Code 4046 5402

Interprets and applies Division personnel policy and practices in the Branch; coordinates the recruiting activities of the Branch; provides recruitment assistance to field officials, assists the Division Career Development Section as required; directs and coordinates the training of scientific and technical employees of the Surface Water Branch; sponsors and administers special courses to accelerate the training and advancement of engineers and technicians in the science of hydrology and in the highly specialized field of open-channel hydraulics.

Coordinates and provides assistance and continuity to on-the-job training; maintains and evaluates records of the educational and extracurricular accomplishments of each professional and technical employee.

PLANNING SECTION
Code 4045 0001

Formulates plans and recommends technical and administrative policies, to coordinate the activities of the Branch and to effectuate an adequate and comprehensive surface-water investigations program.

Reviews the current overall program and recommends adjustments, as determined by trends and the anticipated requirements for surface-water data.

Develops long-range and annual program plans to meet the Branch and Division objectives, with cost estimates, program descriptions, justifications, and tentative work schedules, and coordinates with the appropriate Branch and Division staff sections.

Provides information and criteria for determining priority of the various types of investigations and recommends allocations of appropriated funds. Takes necessary staff action for allocation of funds and setting firm work schedules for approved projects.

Figure III-6. Organizational units and functions of Surface Water Branch at Headquarters, July 1, 1957.

District programs and operations. Although the SWB Chief retained line authority, the District Council influenced District program content, and the Branch Area Chief SWB assumed the responsibility for reviewing and approving field personnel matters such as travel, promotions, and performance reviews (SWB Memo of May 19, 1958). The BAC-SWB in the Area Office was appointed by and served as the agent of the SWB Chief; nevertheless, in June 1959 (SWB Memo 59.80) the SWB Chief requested that each District Engineer visit Headquarters every 3 to 4 years to prevent eventual insulation of field people from Headquarters by Area Offices.

With the change of District offices from Branch to Division organizations beginning on a trial basis in 1962 and reaching full-scale implementation by 1966, the line authority to WRD field offices came from the Division Chief through the Division (Area) Hydrologist. The Branch Area Chiefs became staff to the Division Hydrologist. The Chief of the SWB retained responsibility only for technical support and quality assurance of surface-water activities in WRD Districts.

Joseph V. B. Wells, who had been Chief of SWB since 1946, was appointed to the position of Assistant Division Chief on December 28, 1959. He was a personable and persuasive leader, and Ferguson (Volume V) noted that "...he had the support of his District Chiefs [sic] despite the fact that many of them were considerably older."

Ernest L. Hendricks, who started his WRD career as a stream gager in Florida, succeeded Wells as SWB Chief on March 6, 1960, and continued in the position until he was appointed Acting Associate Division Chief on March 25, 1962. From October 3, 1962, through the remainder of this period Melvin R. Williams was Chief of the SWB.

Adrian H. Williams served as the Assistant Chief of the SWB from 1946 until his retirement on December 30, 1965, although he continued to work at other duties as a rehired annuitant through 1968. Williams had started his career as a stream gager in the Grand Canyon of Arizona and also worked in the Oregon and Montana Districts before becoming Assistant Chief of SWB. He seemed to easily bear the burden of providing balance and continuity to the operations of the Office of the Branch Chief during the turbulence of the 1960-to-1965 period of changing SWB Chiefs and Acting Chiefs. Williams had an excellent knowledge of SWB field people and an amazing ability to recall names of people with whom he had limited contact—an ability that may have been enhanced by a "little black book" that was meticulously updated with information on an individual's career highlights, names of wife and children, and various other bits and pieces. The position of Assistant Branch Chief was not filled on a permanent basis after Williams retired.

Staff of the Office of the Branch Chief undertook various analytical activities. One staff endeavor of note was the Operations Research Project initiated in 1957 by Irving E. Anderson and Charles W. Reck, which identified water-resources problems, determined the data needs and data-accuracy requirements to address those problems, and proposed appropriate data formats (See Part IV, "Operations Research"). While assigned to the Office of the Branch Chief, Clayton H. Hardison defined a technique for analyzing carry-over storage potentials of large reservoirs, and Rolland W. Carter prepared reports on hydraulic techniques for determining the effects of bridges, culverts, and other channel constrictions on water-surface elevations.

Other career employees who worked in the Office of the Branch Chief during the 1957–66 decade included Daniel G. Anderson, Benita V. Belden, Tate Dalrymple, Kathleen A. Hazelton, Bernis B. Linkins, Eric L. Meyer, Roy E. Oltman, Roy B. Sanderson, Donald M. Thomas, and Medford T. Thomson.

#### *Research Section*

The SWB Research Section, activated in 1951, was staffed only at field locations until 1955 when Rolland W. Carter transferred from the SWB research project at Georgia Institute of Technology to take charge of a new Research Section at Headquarters. Under Carter's direction and with increased funding, the Research Section staff and activities expanded dramatically. In 1957 the Headquarters staff of the Research Section consisted of 9 professionals, 3 technicians, and 3 clerk-typists, with an additional 19 professionals, 3 technicians, and 2 clerk-typists at 5 field locations. By 1963 the staff numbered 14 professionals, 1 technician, and 3 clerk-typists at Headquarters and 26 professionals, 2 technicians, and 3 clerk-typists at 10 field locations.

The objective of the Research Section was to plan, conduct, coordinate, and monitor research activities of SWB. The Headquarters staff actively performed research work, but in addition was responsible for consulting with researchers working on other projects and for inspecting progress and conformance with specified objectives for each project.

A SWB Research Council was created in 1956 to identify, prioritize, and recommend worthwhile research projects. The Council was chaired by Carter and staffed by four field engineers, Douglas D. Lewis (Nebraska), William D. Mitchell (Illinois), Thomas R. Newell (Idaho), and Melvin R. Williams (Alabama).

During 1957 to 1966, SWB research projects covered a wide scope of activities. During the early years of the period, most projects were aimed at improving the efficiency of streamflow-data processing and at increasing the reliability of data through broadened understanding of open-channel flow mechanics and by using improved measuring instruments. Later, the scope of work broadened to address such subjects as effects of vegetation on runoff, use of tree rings as indices of climatic trends, and relation of flow indices to geomorphological characteristics.

Results of Research Section activities during 1957 to 1966 contributed significantly to establishing national and international leadership of SWB in surface-water hydrology and open-channel hydraulics. Details on the people and products of the research work are provided in Part IV, but cited here are some of the research products during these years. Laboratory studies of the mechanics of flow in open channels undertaken at Georgia Institute of Technology defined techniques and coefficients for hydraulic analyses of bridges, culverts, and other channel constrictions. These results soon became standards for many engineering applications. At the SWB Equipment Development Unit in Columbus, Ohio, instruments were developed or adapted for automatic processing of streamflow records, a "bubble gage" system was designed to allow collecting a stage record without constructing a costly stilling well, and an acoustic velocity meter was designed and tested that could provide a temporal record of the changes in average velocity of flow in a channel. At Headquarters, computer programs were developed to compute discharge rates from stage records on rivers and along tidal reaches and to determine flood peak discharge rates from channel surveys and high-water marks. Statistical studies provided a firm technical basis for forming estimates of streamflow characteristics at ungaged sites. Radioactive and dye tracers were tested and techniques defined to use tracers for measuring dispersion, time-of-travel, and discharge rates.

Rolland W. Carter filled the position of Research Section Chief intermittently until he became the Chief of the new Hydraulics (formerly Floods) Section in June 1963. During the period June 9 to September 26, 1958, Carter was on a special assignment at Leopold's request to study research needs in hydraulics and sedimentation, and during the period July 6, 1959, to March 27, 1961, he was assigned to an SWB staff position to satisfy his desire for technical and scientific pursuits. An academic in both appearance and conduct, Carter's scholarly approach and decisive and productive actions earned the respect of colleagues and subordinates and enabled him to create a superior research team.

During Carter's absences, Melvin R. Williams filled in as Acting Chief during June to September 1958 and served as Chief from July 6, 1959, to March 27, 1961.

When Carter became Chief of the Hydraulics Section in June 1963, five of the SWB Research Section projects were transferred to the GHB as a part of the WRD reorganization plan. No one was designated to replace Carter as Research Section Chief during June 1963 to April 22, 1964; then Robert A. Baltzer, a member of the Research Section stationed at the University of Michigan, transferred to headquarters as Acting Chief. Baltzer earlier had resigned from a streamgaging position in the Michigan District to attend graduate school and had been rehired by Carter for a position in the Research Section after receiving his Ph.D.

A March 25, 1965, memorandum from the Chief Hydrologist officially transferred remaining SWB Research Section projects to the offices of the Area Hydrologists; however, George F. Smoot and Donald I. Cahal lingered on in SWB research activities through the remainder of this period to provide expertise and guidance on high-tech instrumentation.

Other career members of the SWB Research Section at headquarters during 1957 to 1966 included Daniel G. Anderson, Manuel A. Benson, Bertha A. Brown, Mark W. Busby, Daniel Y. Chen, William J. Conover, John R. Crippen, Jacob Davidian, David R. Dawdy, Margery O. Drilleau, Richard G. Godfrey, Ennio V. Guisti, Kathleen A. Hazelton, William L. Isherwood, Barbara S. Jacobs, Alan V. Jopling, Chintu Lai, Solomon M. Lang, Nicholas C. Matalas, Henry C. Riggs, June C. Rossen, William J. Schneider, Ruth M. Shaver, John Shen, Hubert J. Tracey, Regina S. Wilkinson, Vujica Yedjevich, and Nobuhiro Yotsukura.

### *Floods Section*

The Floods Section, which had been known as the Technical Standards Section until December 1957, became the Hydraulics Section in June 1963. The Section was responsible for three major functions: (1) technical standards and support for field operations, (2) reports assistance, and (3) management of national programs on flood hydrology and channel hydraulics.

The technical standards work included maintaining a corps of "Flood Specialists" (later renamed "Hydraulics Specialists") at field locations, preparing manuals and handbooks on hydraulic and indirect-measurement techniques, and providing consulting services, coordination, and technical review of flood-documentation and flood-frequency reports. The flood specialists, a group of from four to seven hydraulic engineers specially trained in indirect-measurement methods, were located in Districts or Area (Regional) offices and could rapidly mobilize qualified manpower and necessary equipment to document extreme floods. During 1957 to 1966, the Flood Specialists not only continued their outstanding work with floods but also assumed additional responsibilities, including reviewing all indirect measurements, training, advising on and reviewing highway-program work, and participating in work on the national program of flood-frequency studies.

To maintain and improve their capabilities, the Flood Specialists were frequently detailed to Headquarters for short technical assignments. However, irregularly scheduled (often annual) conferences of flood specialists were the principal means of information exchange. Minutes of the conferences were eagerly read by most engineers and technicians and they served, in effect, as manuals or handbooks.

Floods Section personnel also prepared annual Water-Supply Papers that summarized significant floods each year, reviewed and processed for publication reports and flood maps that documented extreme events, and reviewed and processed analytical flood reports. In the SWB reorganization of June 21, 1963, the report functions of the Floods Section along with the personnel responsible for that function (A. Rice Green, Julian O. Rostvedt, and George W. Edelen) were transferred to the Reports Section.

Three national programs were coordinated and managed by the Section: The highway program, a Soil Conservation Service (SCS) sponsored investigation, and the nationwide flood-frequency study.

The highway program was a conglomeration of District investigations of small-stream floods and/or bridge sites that were cooperatively funded primarily with State highway departments. The earliest programs, which began in the late 1940's in Alabama, Georgia, Louisiana, Missouri, Virginia, and Washington, included 18 States by 1957 and 41 by 1966.

Because little information had been collected on flood characteristics of small streams, these programs had a broad appeal. In addition to the highway departments, 27 Federal, State, and local agencies entered into similar studies so that by 1966 a total of 46 States had small-stream flood-investigation programs. The passage of the Interstate Highway Act of 1963 provided research funds to the States and significantly increased participation in the programs.

Although all of the highway investigations had as the primary objective the collection of data to define the magnitude and frequency of small-stream floods, the programs differed in approach and design. Some utilized crest-stage gages only, some concurrently recorded storm rainfall and runoff with SWB-developed stage-rainfall (S-R) or dual-digital recorders, and some used gages of both types. The programs differed because of improving data-collection techniques, expanding analytical capabilities, and cooperator desires. During 1957 to 1966, small-stream flood data were used to prepare flood-estimating relations for 18 States. The Floods Section participated in the small-stream flood programs by acting as advisor and technical consultant to the Districts, and coordinating with officials of the U.S. Bureau of Public Roads.

The SCS program, which began as an interagency agreement signed on December 14, 1954, had three parts: (1) tabulating flood-peak flow rates and concurrent rainfall data for 797 gaging stations with drainage areas of less than 400 square miles; (2) tabulating flood peaks and runoff volumes; and (3) collecting basic data at SCS project sites to study effects of ponds on peak flows. Funds provided by SCS was $20,000 for FY 1955, $40,000 for FY 1956 and about $50,000 for FY 1957. Results for all three parts were provided to SCS, but only results of the first part were published by USGS (WSP 1813, 1965).

A federally funded program managed by the Floods Section produced Water-Supply Papers 1671 to 1689 (1964 to 1968) on the "Magnitude and Frequency of Floods in the United States." These reports provided techniques for estimating the magnitudes of flood-peak flows having recurrence intervals of up to 50 or 100 years at nearly any natural stream site in the Nation. The results of these studies gained wide acceptance by planners, engineers, and designers and demonstrated the value of the mass of available streamflow data to engineering applications (see Part IV, "Regional Flood-Frequency Studies").

Tate Dalrymple was Chief of the Floods Section from 1951 until the SWB reorganization of June 21, 1963, when he became a member of the Branch Chief's staff. He previously had been a stream gager in Texas and acting District Engineer in Ohio. Dalrymple's stern countenance covered a devilish and mischievous sense of humor that was either admired by or intimidating to colleagues. A teller of tall Texas tales, Dalrymple's story could go on indefinitely if he sensed a listener's growing uneasiness at having to leave to catch a carpool. Dalrymple used his unique communication skills to expand the SWB activities from simple stream gaging to data analysis and interpretation. He was largely responsible for initiating the Highway Programs, the SCS program, SWB flood reports, and flood-mapping activities. He was able to convince other Federal agencies of the value of SWB analyses and to see that worthwhile products were delivered.

Dalrymple's first principal assistant was Manuel A. Benson, a cherubic, cigar-smoking stream gager from the New England and Indiana Districts who transferred to Headquarters in 1949. While working, Benson commonly laid his ever-present cigar in an ashtray; each cigar usually requiring relighting several times during its useful life. Benson managed the indirect-measurement and flood-frequency portions of the Section's work until September 1956, then joined the Research Section and subsequently the Hydrologic Studies Section where he had a significant national influence on methods of flood-frequency analyses.

Joseph S. Cragwall, Jr., a Lyndon B. Johnson look-alike and a member of the Headquarters staff since May 1952, replaced Benson as Dalrymple's principal assistant in July 1957. He worked mostly on the cooperative highway programs, spending considerable time developing new programs in the Districts. In July 1958 he became the District Engineer in Tennessee, the second District integrated into a unified WRD field organization. Cragwall later returned to Headquarters to become Chief Hydrologist and then Associate Director—the most senior USGS position ever held by a stream gager.

William P. Somers, formerly a New England and Utah stream gager, replaced Cragwall as principal assistant to the Section Chief and remained in the position until he transferred to the new Federal Water Pollution Control Administration on December 4, 1966.

Rolland W. Carter served as Chief of the newly named Hydraulics Section from June 21, 1963, to January 21, 1966, when he moved to South Carolina as WRD District Chief. Harry H. Barnes, formerly of the Mississippi District, the Research Section at Georgia Tech, and a Hydraulic Specialist in both Atlanta, Ga., and in the ACA headquarters in Arlington, Va., was named Chief of the Hydraulics Section on April 19, 1966.

Other members of the Floods Section staff at Headquarters during 1956 to 1966 included James F. Bailey, Thomas J. Buchanan, Jack R. Carter, Ernest D. Cobb, Jacob Davidian, George W. Edelen, Jr., Charles R. Gamble, A. Rice Green, E. Robert Hedman, Belle C. Jacomet, Karl Jetter, Mary A. Kelley, Jane L. Lynch, Kyle D. Medina, Hazel J. Paulucci, Herman A. Ray, Julian O. Rostvedt, Eileen R. Smith, and Mack R. Stewart.

Those who had served as Flood (Hydraulic) Specialists prior to 1967 were G. Lawrence Bodhaine at Tacoma, Wash., and Denver, Colo.; Dean B. Bogart at Albany, N.Y.; Seth D. Breeding at Austin, Texas; Rolland W. Carter at Atlanta, Ga.; Albert B. Goodwin at Raleigh, N.C.; Walter Hofmann at Los Angeles, Calif.; Harry Hulsing at Menlo Park, Calif.; Howard F. Matthai at Sacramento, Calif., Denver, Colo., and Menlo Park, Calif.; Roy E. Oltman at Lincoln, Nebr.; Mervin S. Petersen at Rolla, Mo., and Denver, Colo.; Henry C. Riggs at Raleigh, N.C.; William P. Somers at Salt Lake City, Utah; Jack Terry at Denver, Colo.; and Richard H. Tice at Charlottesville, Va., Trenton, N.J., and St. Louis, Mo.

#### *Hydrologic Studies Section*

The Special Reports and Investigations Section became the Hydrologic Studies Section in 1957 with an expanded scope of work. Functions and responsibilities of the Section included answering requests for information, utilizing newly developed processes and research results to recommend technical procedures for hydrologic analyses, transfer of the technical recommendations to District-level investigators and analysts, technical review of all analytical (except flood) reports, and maintenance of the SWB library.

The nature of the work led to a series of short-term projects in areas of expertise for various staff members. The projects usually ended with a published report, manual, or handbook intended for guidance of field office analysts, and the staff members were available for consulting and for teaching at training sessions. The subjects addressed by the Hydrologic Studies Section during 1957 to 1966 included these:

Clayton H. Hardison and Robert O.R. Martin proposed a "pivot-station" method for estimating low-flow characteristics of ungaged sites based on a few low-flow discharge measurements.

Mark W. Busby mapped the nationwide variations from normal of annual streamflows during the newly defined standard meteorological period 1930 to 1960.

George A. Kirkpatrick established a technique for using the newly available "datatron" statistical outputs to define flood-volume duration-frequency estimates.

Manuel A. Benson and Donald M. Thomas used computer techniques to establish regression relations between numerous streamflow indices and the physical and climatic characteristics of contributing drainage areas.

Richard G. Godfrey and James F. Wilson demonstrated use of radioactive and dye tracers for measuring flow rate, time-of-travel, and dispersion.

Henry C. Riggs studied base-flow-recession curves, storage-frequency relations, and techniques for evaluating regional resources from miscellaneous flow measurements.

To assist in coordinating work with field offices, Howard Matthai in the Denver Regional Office was designated as a field representative of the Section in the June 21, 1963, SWB reorganization.

Clayton H. Hardison, who had been the Chief of the Hydrologic Studies Section and its predecessor Section since 1954, transferred to the Office of the Branch Chief in the SWB reorganization of September 7, 1961. An enthusiastic and energetic man who had started as a stream gager in New England and then worked in Alabama and Kansas, Hardison obviously enjoyed consulting with and guiding young analysts.

Roy E. Oltman replaced Hardison as Section Chief in September 1961 and served until March 23, 1965, when he accepted a staff position with DOI's new Office of Water Resouces Research. He had previously been a technical consultant on the staff of the Chief Hydraulic Engineer and the Chief of the Career Development Section, WRD. (See Part II, "Leadership.")

Henry C. Riggs was the Assistant Chief from September 7, 1961, to March 23, 1965, then Acting Chief until March 1966, when he became Chief. Another quiet and thoughtful man, he continually amazed people with his endurance and stamina during field expeditions. Riggs had started his USGS career as a stream gager in Washington State and had managed the Highway Program in North Carolina before transferring to Headquarters in July 1956.

Conrad D. Bue, a Montana stream gager who had transferred into the Special Reports and Investigations Section in 1948, continued to direct the editing and processing work with the assistance of Margaret P. Mahey, Kathleen T. Iseri, and other members of the staff as needed. During the reorganization of September 7, 1961, responsibilities for editing and processing of reports was transferred from the Hydrologic Studies Section to the newly named Reports Section (formerly the Basic Records Section) and Bue, Mahey, and Iseri were transferred to report-processing duties in various other units.

Other members of the Hydrologic Studies Section staff during 1957 to 1966 were Thomas J. Buchanan, Charles W. Carlston, Patrick B. Cawood, Jean M. Crain, John R. Crippen, Luther C. Davis, Harold G. Golden, Sarah E. Graham, Ronald L. Hanson, Joan Hilker Hofmann, William L. Isherwood, John R. Kreider, Kyle D. Medina, Vivian R. Martini, Glennon N. Mesnier, Donald O. Moore, James K. Searcy, Rose M. Smith, and Carl C. Yonker.

### Basic Records Section

The Basic Records Section during 1957 to 1966 underwent more redirection and significant changes in functions than any of the other SWB sections. The Section, which had been named the Annual Reports Section in 1956, became the Basic Records Section until September 7, 1961, when it became the Reports Section, and then again became the Basic Records Section June 21, 1963.

After 37 years of service, Barney J. Peterson, Section Chief since 1924 retired on December 31, 1957. Francis J. Flynn was named as Peterson's successor on January 26, 1958, and remained in the position until he transferred to the FPC on April 8, 1967. Flynn started his SWB career in the New England District and transferred to the Section in April 1944. William C. Griffin, who had worked in the Alabama and Washington Districts, transferred into the Section as Flynn's principal assistant on February 14, 1958, and remained until he became District Engineer in West Virginia on November 5, 1962.

The primary function of the Section during early years of this 1957 to 1966 period was to review streamflow records prior to publication annually in Water-Supply Papers. The Section also was very active in headquarters training of field personnel and preparing training materials and technical memoranda for field-office guidance. In addition, the Section managed the nationwide project of compiling all streamflow records available through 1960 into a readily accessible and usable format (see Part IV, "Compilation of surface-water records"). Also, during part of this period, the Section was responsible for converting all flow records into machine-readable format for computer processing, storage, and retrieval.

Publication of the annual Water-Supply Papers required reviewing gaging-station records submitted by field offices, typing of daily flow values and other information, and then collating typed records into a downstream order for photo-offset printing. Because Water-Supply Papers grouped records on a drainage-basin basis while records were prepared in the field on a State basis, efficiency of operations required a detailed scheduling for delivery of data from field offices to the Section. Reviewing submitted records was accomplished primarily by detailees from field offices. Details commonly lasted for four months, and about half of the detailees' time was in training on streamflow-records production under the guidance of the Basic Records Section staff and the other half on various hydrologic and hydraulic subjects taught by the staffs of other Sections. Typing and collating of records utilized a pool of about 20 clerk-typists at the start of this period, but the typing pool decreased significantly as a result of creating a Denver Basic Records Unit, and because of changes in methods of processing and publishing surface-water data.

Primarily because office space was more readily available at the Denver Federal Center, a Denver Unit of the Basic Records Section was created in July 1957. Bennie A. Anderson transferred from Headquarters and directed the Denver Unit until he returned to Headquarters in 1963. Harold P. Eisenhuth assisted by George E. Philipsen managed the Denver Unit for the remainder of the period. Detailees from field offices also performed the review work in Denver, but then traveled to Headquarters for training.

The expanding magnitude of data collecting complicated preparing the annual reports. To assist in collating records in downstream order, but primarily to aid in forthcoming machine storage and retrieval of flow records, a system for identifying each gaging site with a unique identification number in downstream order was needed (see Part IV, "Hydrologic Data Networks"). Instructions for establishing the number system were issued to the field offices on April 18, 1957, and the numbers were satisfactorily established for all complete-record sites by early 1959 (SWB Memo 59.69) and for all partial-record sites in mid-1960 (SWB Memo 61.11). These identification numbers were used for the first time in the 1958 water-year reports.

Printing of Water-Supply Papers commonly occurred 3 or more years after the close of the water year and the delay had been a constant source of concern. Operations Research reports by Anderson and Reck (SWB Memos 59.61 and 60.11) noted the tremendous effort required to provide prepublished records for cooperators and data requests, questioned the need for annual publications in the WSP series, and suggested that formal 5-year WSP publications with annual Statewide data reports could be adequate (see Part IV, "Operations Research"). A January 5, 1960, letter from the Chief Hydraulic Engineer to the new SWB Chief Hendricks recommended accepting the Anderson-Reck suggestion. On June 15, 1960, (SWB Memo 60.75), Hendricks announced that informal publication of streamflow records would begin on a State basis with water year 1961. Section personnel prepared instructions to the field offices for preparing and printing the annual reports and also for submitting data for formal publication in 5-year Water-Supply Papers. Formal publications of surface-water information in WSP's occurred for the water years 1961 to 1965 and 1966 to 1970 and were then discontinued in favor of the State-level data reports.

Alteration of the Basic Records Section functions and operations also resulted from changing from a manual to a machine mode for preparing flow records. A significant but unsuccessful effort at automating data processing attempted to develop, beginning in 1952, a machine (dubbed the "SURWAC") to read a graphic recorder trace, convert it into a gage height, and then into a discharge record. SURWAC was unsuccessful because of the variable quality of recorder chart traces and because of the problems of maintaining a one-of-a-kind computer. The project, managed by William L. Isherwood, was abandoned in 1958 in favor of a digital recorder being developed under a contract with the Fischer-Porter Company (see Part IV, "Instrumentation").

By 1963, a practical digital recorder had been developed and field tested at 268 sites, machines for translating the digital recorder tapes for computer input had been developed, computer programs for producing a "primary" and "final" listing of flow data had been written, and a data-handling process between field and headquarters had been adopted. (See Part IV, "Computer Applications in Hydrology.") A work group of SWB and Administrative Division personnel chaired by Rolland W. Carter reviewed reliability, economy and practicality of the proposed automatic processing system and published their findings in Circular 474 (1963). The work group found the automated system worthwhile and recommended converting about 1,000 stations to digital-recorder operation each year beginning in 1964. The conversion began immediately but was constrained by cost and availability of recorders. To manage the conversion, Headquarters purchased recorders and rented them to Districts.

The change to State-level data publications and to automatic processing of streamflow records removed the opportunity for prepublication review of the records by the Basic Records Section. To provide desired quality control, an in-district review procedure was announced in SWB Memo 62.56 dated April 2, 1962. The in-district reviews allowed more comprehensive evaluations of field office operations than previously had been possible.

SWB Memo 60.81 (June 17, 1960) announced the creation of the Automatic Data Processing Unit within the Basic Records Section with Charles Showen, an ex-West Virginia stream gager, in charge. That memo also advised of the transfer from the Research Section to the ADP Unit of the Basic Records Section, the responsibilities for converting available flow records to computer inputs for the "Datatron" statistical summaries. Margery O. Drilleau and Regina S. Wilkinson, who had worked on the Datatron project for Isherwood in the Research and Hydrologic Studies Sections, moved to the ADP Unit.

The SWB reorganization of September 1961 shifted the responsibilities of the Hydrologic Studies Section for processing SWB analytical reports and for the SWB library to the newly named Reports Section.

The Reports Section then had three subsections: the ADP Unit, the Basic Data Unit, and the Analytical Reports Unit. The SWB reorganization of June 21, 1963, changed the name back to the Basic Records Section and transferred responsibilities of the Floods Section for review of flood reports to the Analytical Reports Unit of the Basic Records Section. That reorganization also moved the ADP Unit to the Plans and Operations Section.

Other career employees (except those in the typing pool) who worked in the Basic Records Section at Headquarters during 1957 to 1966 were Conrad D. Bue, Robert M Comegys, Mildred M. Dunbar, A. Rice Green, George W. Edelen, Cavis B. Ham, Edward B. Hodges, Kathleen T. Iseri, Margaret P. Mahey, Vivian R. Martini, Donald O. Moore, and Julian O. Rostvedt.

The typing pool consisted of a staff of editor-clerks and clerk-typists that prepared the discharge records for publication in Water-Supply Papers. As the needs for typing diminished during the 1957-to-1966 period, many members of the typing pool moved to other editorial, clerical or secretarial positions. Members of the typing pool during 1957 to 1966 included Alice P. Alberts, Arnold B. Barr, Tillie D. Barrows, Helen L. Britt, Marcia U. Byrd, Doris V. Clagett, Hellena D. Collins, Donald A. Dove, Margery Drilleau, Rita M. Fones, Barbara A. Gascon, Carolyn M. Hardin, Barbara B. Head, Nancy R. Inman, Belle C. Jacomet, Lois M. Jefferson, Chris G. Jensen, Myron L. Lenkin, Ethel K. Logan, Beulah A. Miller, Lucy M. Miller, Marion M. Miller, Shirley Peltin, Eunice M. Princ, Mildred M. Reed, Libby Reniere, Helen M. Robertson, Hilda Rosenbaum, Johanna Smey, Hazel L. Smith, R. Eileen Smith, Richard B. Speaker, Saundra L. Spivak, Evelyn A. Stidham, Elizabeth A. Taylor, Nancy C. Taylor, Virginia Warhurst, and Gladys A. Wills.

### *Career Development Section*

The Training Section, which was created in 1956 to train employees in advanced techniques of hydrologic analyses, was changed to the Career Development Section in the reorganization of September 7, 1961 "...to better reflect the responsibility of the section..." (SWB Memo 62.15).

Functions of the Section included career development, recruiting, interpreting and applying criteria and specifications on personnel practices, and assisting the WRD Career Development Section as required (see Part VI, "Hydrology and Professional Development"). Career-development activities addressed both staff placement and training. Records of accomplishments, skills, training, and other attributes of all SWB individuals were kept to assist in locating appropriate people to fill staff vacancies. In-house training was a major effort. The Section staff organized and scheduled short courses for professionals and technicians, arranged and managed correspondence courses, and administered programs for formal university training, performance awards, and other personnel-related tasks. The Section coordinated and participated in SWB and WRD recruiting of university graduates. To increase awareness of SWB personnel needs, the Section staff presented numerous demonstrations and lectures to university groups.

Roy E. Oltman, who was the first Section Chief, became Chief of the WRD Career Development Section in early 1957. James J. Ligner, a stream gager from the Washington and Connecticut Districts, directed the Section until he transferred to the Arizona District on October 15, 1960. On November 14, 1960, Medford T. Thomson was named Section Chief.

In 1962, functions of the SWB Career Development Section were transferred to two new WRD Sections, the Manpower Utilization Section and the Recruiting and Training Section. Thomson and Raymond O. Abrams, a Virginia stream gager who had transferred to the Section in January 1959, became respectively the Chief of the WRD Special Reports Section and Chief of the WRD Recruiting and Training Section.

Members of the SWB Career Development Section during the years 1957 to 1962 included Emilia F. Bello, Evelyn A. Brown, Helen V. Costello, Patricia E. Frank, Barbara L. Hickman, and Joan C. Skoff.

### *Planning Section*

Created in 1956 with John E. McCall, a former Kentucky stream gager as Chief, the Planning Section was the only SWB Section physically located with the Office of the Branch Chief in the General Services Administration Building in Washington.

Planning and coordinating programs and allocating funds were the primary functions of the Section. Its work involved managing and allocating Federal funds and other Federal agency contributions and monitoring District budgets and fiscal operations. Managing the SWB share of the Washington Office Technical Service Charge (WOTSC) was a Section function closely watched by field officers, many of whom considered the "rake-off" a "rip-off."

A task that expanded greatly during 1957 to 1966 was that of organizing and preparing materials for Congressional hearings. The Section also was responsible for documenting progress on Federally funded projects.

As a part of the responsibility for reviewing program effectiveness and for recommending adjustments, the Section administered and coordinated a nationwide analysis of the stream-gaging program. Completed in 1957, the work determined for each gaging station the need for and the use of the data and identified redundancies in the program (see Part IV, "Hydrologic Data Networks").

During the SWB reorganization of June 21, 1963, the Section name changed to the Plans and Operations Section and the scope of responsibilities expanded. The ADP Unit from the Basic Records Section was transferred into the new Section, as was the administration of the Equipment Development Unit in Columbus, Ohio, which was formerly directed by the SWB Research Section.

Section Chief McCall became District Engineer in New Jersey in August 1958 and was succeeded by Albert N. Cameron, a stream gager from Georgia. In September 1961, Cameron was appointed District Engineer, Georgia, and Wallace T. Miller, the District Engineer in Colorado and formerly a stream gager in Oregon and New Mexico, became Section Chief.

Other career employees who worked in the Planning Section during 1957 to 1966 included Dolores K. Barnes, Robert M. Beall, Justin A. Bettendorf, Kenneth W. Causseaux, Louis P. Denis, Margery O. Drilleau, Anna A. Hook, Martin R. Hum, Lucille T. Heilprin, Norman E. Hutchison, Dolores C. Kennedy, Dorothy L. Koziski, Thomas H. Meredith, Alvin F. Pendleton, Herman A. Ray, Charles W. Reck, Roy B. Sanderson, Charles R. Showen, Nathan C. Thomas, James F. Wilson, and Regina S. Wilkerson.

## Surface Water Branch Field Units

As previously noted, SWB personnel were located in four Area (Regional) offices and in various other field units that reported to SWB headquarters or to Branch Area Chiefs, SWB.

The SWB personnel who served on foreign assignments during 1957 to 1966 are identified in Part IV, "International Programs."

### *Area Offices*

Functions and activities of the Area Offices previously have been described in detail. SWB personnel who served in those offices until reassigned to the Division in 1965 included:

#### *Atlantic Coast Area, Arlington, Va.*

Donald S. Wallace, BAC February 26, 1958, to February 28, 1960; Francis T. Schaefer, BAC August 1,1960, to end of period; Harry H. Barnes and Betty L. Hudner.

#### *Mid-Continent Area, St. Louis, Mo.*

William R. Eaton, BAC July 1, 1958, to end of period; Richard H. Tice and Marilyn S. Whittaker.

#### *Rocky Mountain Area, Denver, Colo.*

Francis M. Bell, BAC March 12, 1957, to end of period; G. Lawrence Bodhaine; Evelyn M. Carlsen; Lorene E. Giddings; Howard F. Matthai; Claudine S. O'Donnell; Joyce M. Owens; and Mervin S. Petersen.

#### *Pacific Coast Area, Menlo Park, Calif.*

Harvey B. Kinnison, BAC March 12, 1957, to March 14, 1959, R. Stanley Lord, BAC April 16, 1959, to end of period; David R. Dawdy; Harry Hulsing; Helen M. McGraw; Terrence O'Donnell; and Arvi O. Waananen.

### *Georgia Tech Hydraulics Laboratory, Atlanta, Ga.*

Close cooperation between the staffs of the SWB and the Georgia Tech hydraulics laboratory continued during 1957 to 1966 (See Ferguson, Volume V). The scope of laboratory work increased to cover many aspects of open-channel flow (see Part IV, "Surface water research"). Hubert J. Tracy was engineer-in-charge of the SWB staff working at the laboratory under technical guidance of Professor Carl Kindsvater. The arrangement was mutually beneficial because several SWB personnel were able to advance their education and several Georgia Tech students became SWB employees. (See Part X, "Georgia.") SWB staff working at the hydraulics laboratory during 1957 to 1966 included William E. Andress, Harry H. Barnes, Philip H. Carrigan, B.C. Christopher, Sara D. Collins, Russell W. Cruff, William W. Emmett, Celene W. Harmon, Dan B. Jones, Frederick A. Kilpatrick, Gerald M. Leigh, Carl M. Lester, Paul G. Mayer, Lottie H. Pamplin, Frederick H. Ruggles, Paul E. Spieks, John R. Turner, James R. Wallace, and Robert R. Wright.

### *Equipment Development Laboratory, Columbus, Ohio*

The Columbus Equipment Development Laboratory, started as a SWB unit in 1948 under the guidance of Arthur H. Frazier, was transferred from SWB to WRD administration in 1954. Functions of the laboratory included procuring, warehousing, and distributing standard equipment to WRD offices, as well as researching, developing, and testing improved equipment. In July 1954, Edgar Edward G. Barron, a stream gager who had worked in New Jersey, North Carolina, Illinois, and Kentucky, transferred to the laboratory as a representative of the SWB Research Section to work primarily on the development of a manometer system or "bubble gage" that could sense changes in water-surface elevation of a stream without the need for an expensive stilling well. Barron soon became engineer-in-charge of a small SWB unit at the Laboratory. In July 1959, when the responsibility for procuring, manufacturing, stocking, and distributing standard equipment was transferred from the Columbus Laboratory to the Survey's Administrative Division facilities in Silver Spring, Md., personnel of the WRD Columbus Laboratory were absorbed into the field unit of the SWB Research Section. The SWB unit developed a practical bubble gage in 1957 and researched, developed, and tested a variety of new items of equipment, including battery-powered cable cars for measuring discharge from the long cableways spanning the Columbia River, digital stage recorders and digital tape translators, a small stage-rainfall (S-R) recorder that provided a trace of stream stage and concurrent rainfall intensities on a single chart, "hot-wire" and other current meters, and a water-surface follower. The Columbus unit assisted District offices with installing and operating new equipment and aided field-office personnel in developing new ideas through the temporary assignment of district staff to the Laboratory or by reviewing and commenting on proposals from the field.

Barron retired in November 1965 and Harold O. Wires assumed the leadership role. Other SWB employees in the Columbus Equipment Development Laboratory during 1957 to 1966 were Donald I. Cahal, Harold E. Cox, William A. Hess, Lawrence C. Jeffers, Thomas W. Kollar, Jerry E. Mayles, Leon G. McLaughlin, Duane M. Preble, George F. Smoot, Michael Stahl, Samuel E. Rickley, and Alexander B. Willis.

#### *Current Records Center, Portland, Oreg.*

Creation of the Northwest Power Pool after World War II altered or potentially altered the way that hydropower operations affected streamflow and reservoir storage throughout the Columbia River Basin and the coastal drainages of Washington and Oregon. Irrigators, fisheries managers, and other water users were vitally interested in current information on surface-water flows. The Current Records Center was established in Portland, Oreg., in 1952 to provide up-to-date streamflow information to interested cooperators, agencies, and individuals. Based primarily on telephoned and mailed data, the Center staff prepared weekly reports on daily flows at selected gaging stations, monthly tables on the inflow, outflow and storage of key reservoirs, and monthly summaries of streamflow and reservoir conditions. The Center also served as a clearinghouse for inquiries about flows, storage and water temperatures. In April 1959, the Center distributed 282 mimeographed copies of the weekly flow reports, 315 copies of the monthly reservoir tables, and 527 copies of summaries of streamflow and storage information.

Hollis M. Orem, formerly of FPC, was the engineer-in-charge from the start of the unit in 1952 until he retired in April 1966. Albert M. Moore from the Portland SWB District replaced Orem. Others who worked in the Current Records Center were Daisy P. Chapelle, Camilla A. Gaylor, Robert W. Harper, Suzanne J. Matzke, Edith M. Moore, George E. Philipsen, Joan G. Prue, Margaret L. Smith, Edward H. Stolte, Allan S. Sollid, and E. Barbara Wolfe.

#### *Basic Records Unit (Surface Water Branch Basic Records Section), Denver, Colo.*

Those who worked with Bennie A. Anderson, Harold P. Eisenhuth, and George E. Philipsen in the Denver Basic Records Unit were Delores N. Abeyta, Merrily Arnold, Margaret A. Cornell, Rowena Y. Cox, Frances A. Flatt, Lois L. Gordon, Peggy M. Magee, Grace M. McDuff, Barbara J. Miller, Ella B. Montoya, Ida Price, Sea C. Shipley, Barbara M. Toepfer, Judith A. Tucker, Frances M. VanMeter, and Bonnie B. Warner.

#### *Other Surface Water Branch Field Units*

Other SWB personnel worked at locations listed below. Most were involved in research or regional assessments; others were working as water masters, on River Basin Compacts, detailed to university staff, or working on the compilation reports. Several were temporarily assigned to SWB from other Branches for administrative reasons. All were listed in the Personnel Directories as reporting either to the Chief or the Branch Area Chief, SWB.

Phoenix, Ariz.—David R. Dawdy, Marie B. Glenney, and John Shen.

Tucson, Ariz.—Michael R. Collings, Richard C. Culler, Henry B. Dalms, Nicholas C. Matalas, Robert M. Myrick, and Alfonso Wilson.

Yuma, Ariz.—Allen G. Hely and Gilbert H. Hughes.

Denver and Fort Collins, Colo.—Donald L. Bingham, Adrian R. Chamberlain, Ruth Czerner, Claude R. Daum, Helen E. Jenkins, John A. Kast, Frederick A. Kilpatrick, Gordon E. Koberg, Herman J. Koloseus, Betty R. Masin, J. Stuart Meyers, Everett V. Richardson, R.R. Robertson, Fred R. Steputis, Alex M. Sturrock, Jerry D. Tiff, and Barbara T. Walton.

Ft. Wayne, Ind.—John F. Ficke.

Iowa City, Iowa.—Leon E. Betts, Jacob Davidian, and Elaine A. Gockle, Herman J. Koloseus, George R. Kunkle, and Ernest C. Pogge.

Baltimore, Md.—John C. Goodlet.

Cambridge, Mass.—Myron B. Fiering, Alan V. Jopling, and Nicholas C. Matalas.

Lansing, Mich.—Robert A. Baltzer and Harold R. Henry.

Asheville, N.C.—Albert B. Goodwin.

Philadelphia, Pa.—Herman K. Wiskind.

Chattanooga, Tenn.—Bernard J. Frederick, Annis M. Harris, Alma J. Jefferies, Martha A. Mason, Jeanne M. Morgan, Paul R. Speer, and Marilyn S. Wert.

Oak Ridge, Tenn.—Bernard J. Frederick and Shirley A. Wilson.

Austin, Texas.—Frank W. Kennon.

Logan, Utah (Bear River Compact).—Glenn C. Anderson, Edith Duersch, Evelyn S. Fullmer, Richard B. Garrett, Louise S. Hammond, Judy Hansen, Albert B. Harris, Wallace N. Jibson, and Budd S. Robison.

Salt Lake City, Utah (Upper Colorado River Basin study).—Godfrey L. Oakland.

Tacoma, Wash.—Patricia L. Anderson, Earl G. Bailey, Henry C. Broom, Carl H. Helms, Mark W. Ritchey, and Wilbur D. Simons.

### Program Size

Table III–4 shows the source of and total funds for SWB activities and the total WRD funds for each fiscal year from 1957 through 1963. No SWB funding figures are available for fiscal years 1964 through 1966. The steady rate of increase in SWB funds from each source exceeded the annual rate of inflation and indicated a growing program. The SWB share of total WRD funds decreased from over 54 percent in 1957 to less than 52 percent in 1963. This decrease resulted from a smaller part of the Federal funds being used in SWB activities, and reflects the Chief Hydrologist's success in broadening the scope of investigations and increasing research in other disciplines.

Funds for operating the SWB headquarters came primarily from the Federal program and from the Washington Office Technical Service Charge (WOTSC). Limited information is available as to how funds were distributed to headquarters activities. From partial data for fiscal years 1961 and 1962, the distribution of Federal funds for selected projects was:

| | |
|---|---|
| Nationwide flood frequency | $55,000 |
| Nationwide compilation of streamflow data | 5,000 |
| Hydraulic research | 154,000 |
| Flood inundation maps | 10,000 |
| Instrument development | 96,000 |
| Data processing and analysis | 61,000 |
| Current Records Center, Portland, Oreg. | 36,000 |
| New scientific projects | 49,000 |
| Graduate student support | 7,000 |
| Bench-mark gages | 27,000 |
| Collection of basic records | 944,000 |

Table III–4. Sources and totals of Surface Water Branch and Water Resources Division funding, fiscal Year 1957 to fiscal year 1963

[In thousands of dollars; Coop, cooperative program; OFA, other Federal agencies; FPC, Federal Power Commission]

| Fund source | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 |
|---|---|---|---|---|---|---|---|
| Coop | 5,738 | 6,402 | 7,563 | 8,068 | 8,649 | 9,393 | 9,878 |
| OFA | 2,139 | 2,276 | 2,444 | 2,649 | 2,934 | 2,999 | 3,352 |
| Federal | 1,711 | 2,096 | 2,081 | 1,848 | 2,020 | 2,531 | 2,821 |
| FPC | 149 | 215 | 210 | 230 | 303 | 306 | 342 |
| Surface Water Branch Total | 9,738 | 10,990 | 12,299 | 12,796 | 13,906 | 15,229 | 16,394 |
| WRD Total | 17,906 | 21,068 | 22,938 | 24,307 | 26,553 | 29,189 | 31,734 |

These data are provided only as examples of annual allocations to SWB from Federal funds. WOTSC monies were used to fund technical oversight and support activities.

### After Division Reorganization

The WRD reorganization became effective in December 1964 and was completed in mid-1966, although changes to test and facilitate the reorganization began much earlier. A similar pattern of transitional activity occurred within the SWB headquarters. By 1962, the SWB Training Section function had been transferred into a WRD unit. By June 1963, several SWB research projects had been transferred into the GHB and the Flood (Hydraulics) Specialists had become administratively attached to the offices of the Division (Area) Hydrologists. Larger changes occurred during 1965—all the remaining SWB research projects became the responsibility of the Division (Area) Hydrologists, and the staffs and functions of the SWB Basic Records Section and the SWB Plans and Operations Section were incorporated into WRD units.

Table III–5. Organization and staff, Surface Water Branch, July 1, 1967

| |
|---|
| Office of the Branch Chief |
| Melvin R. Williams, Chief |
| Clayton H. Hardison, Research Hydrologic Engineer |
| June C. Rosson, Section Stenographer |
| Conrad D. Bue, Hydrologic Engineer |
| Hydraulics Section |
| Harry H. Barnes, Chief |
| Jacob Davidian, Hydrologic Engineer |
| Ernest D. Cobb, Hydrologic Engineer |
| Belle C. Jacomet, Section Typist |
| Eileen R. Smith, Clerk Stenographer |
| Hydrologic Studies Section |
| Henry C. Riggs, Chief |
| Harold G. Golden, Hydrologist |
| Donald M. Thomas, Hydrologist |
| Ronald M. Hanson, Hydrologic Engineer |
| Lyle D. Medina, Hydrologic Engineer |
| Joan A. Barnes, Statistician Assistant |
| Glenn R. Golden, Section Stenographer |
| Phillip A. Somers, Engineer Aid WAE |

When the reorganization was completed in mid-1966, the SWB staff consisted of 15 full-time and two part-time employees who were organized into three units: Office of the Branch Chief, Hydraulics Section, and Hydrologic Studies Section. Table III-5 shows the organization and staff as reported in the July 1, 1967, Personnel Directory. Responsibilities of the SWB were limited to technical concerns and included:

1. Evaluation of research needs and assessment of research products.
2. Establishing technical standards for surface-water investigations.
3. Quality control of WRD surface-water activities, reports, and products.
4. Maintaining a qualified staff of specialists and consultants.
5. Conducting special investigations.
6. Providing qualified WRD representatives for participation on interagency or technical-society committees and working groups.

## Ground Water Branch

*By* Gerald Meyer *and* reviewed *by* A. Ivan Johnson

### Overview

*By* O. Milton Hackett

At the onset, under the direction of A. Nelson Sayre, Branch Chief, and Clyde S. Conover, Assistant Chief, the Ground Water Branch (GWB) was about recovered from the growing pains associated with its rapid expansion after World War II. The many recruits from the earlier decade had been assimilated and trained. Staff support sections had been established at headquarters for Research, Operations, Planning, Personnel and Training, and Report Review. A federally funded research program to advance the science was underway under the direction of Robert R. Bennett. An in-house training program was in place, and a hydrologic laboratory and equipment pool for field support was operating in Denver, Colo. Supervision of field activities had been delegated to the Branch Area Chiefs, one for each of the four Regions (then called "Areas").

To improve Branch program planning and execution, nine senior scientists of the field organization had earlier (in 1951 and 1952) been designated regional staff geologists or engineers who were to provide technical and administrative liaison with the District offices and headquarters as well as to conduct self-chosen personal investigations and writings. They included Henry C. Barksdale, Hilton H. Cooper, John G. Ferris (later succeeded by William J. Drescher), Stanley W. Lohman, Raymond L. Nace, Joseph F. Poland, George H. Taylor, Charles V. Theis, and Harold E. Thomas. Assignment as Branch Area Chiefs logically followed for several of these regional leaders. The slogan of the day was "put numbers on the geology," signaling the swing from qualitative and descriptive ground-water studies to emphasis on quantitative and analytical investigations.

In January 1959, Sayre returned to his research and writing activities and Philip E. LaMoreaux, who had served as District Geologist in Alabama and then as Mid-Continent Division Hydrologist, took over as Branch Chief, assisted by Conover. In the succeeding 2 years LaMoreaux emphasized goal setting for the program of the GWB, the improvement of the planning and operation of field projects, and the timely completion of reports. To assist with the last of these he substantially strengthened the Report Review Section and made Federal funds available to complete "old-dog" reports. Stressed as a goal for ground-water studies was their usefulness for the management of water resources. The cooperative program of ground-water investigations was healthy and growing, and the number of federally funded areal ground-water basin studies, such as the Lower Colorado River Basin investigation led by Charles C. McDonald and the Mississippi Embayment project led by Elliott M. Cushing, was on the increase.

In May 1961 LaMoreaux resigned to return to Alabama as State Geologist. At that time the staff leadership positions were occupied by Conover, Assistant Branch Chief; Russell H. Brown, Chief, Research Section (headquarters at Arlington Towers); Horace M. Babcock, Chief, Operations Section; Horace G. Thomasson, Chief, Planning Section; Delmar W. Berry, Chief, Personnel and Training Section; and Charles L. McGuinness, Chief, Reports Section. Harry E. Legrand was coordinator of Branch input to studies for the AEC. A. Ivan Johnson headed the hydrologic laboratory and equipment pool at Denver, Colo. Research was carried out at the three Area Centers (Mid-Continent not yet activated), and at dispersed locations in the field—most notably at Phoenix under the direction of Herbert E. Skibitzke. James E. Eddy, at Arlington Towers, designed and developed special equipment in support of field studies and research. The Denver hydrologic laboratory also conducted a number of research projects and developed ground-water equipment. The Branch Area Chiefs, line officers responsible for field operations, were Henry C. Barksdale, ACA; William J. Drescher, MCA; Thad G. McLaughlin, RMA; and George F. Worts, PCA. All were stationed at their Area headquarters except Drescher, who was stationed at Madison, Wis.

LaMoreaux was succeeded as Branch Chief in 1961 by O. Milton Hackett, who had been District Geologist for the Boston District, and later in that year there was some shuffling of positions and modest reorganization within the Branch. A new position of Associate Branch Chief was established to share duties of the Branch Chief, with special attention to technical areas. Joseph T. Callahan, District Geologist, Georgia, was brought in for this job, but first served briefly as Assistant Branch Chief following Conover's return to the field program as District Engineer, Florida District. Babcock was reassigned from Operations to the post of Assistant Branch Chief, with primary responsibility for Branch operations. The duties of the Planning and Operations Section were merged under Thomasson. In the MCA, Drescher was reassigned to work on a study of deep sedimentary basins as candidate waste repositories. His replacement as Branch Area Chief, stationed at the new Area headquarters at St. Louis, Mo., was Harry D. Wilson, Jr., who had been District Engineer for the California District. Wilson, almost immediately reassigned as Division Hydrologist, was soon followed by Joe L. Poole, formerly District Geologist, Tennessee. In the PCA, Worts was reassigned in 1962 to be Chief of the newly consolidated Nevada District of the WRD. His replacement was Edward A. Moulder, who had been District Engineer of the Colorado District.

During the ensuing few years, as the leadership of the Division asserted increased program control, tasks traditionally carried out by the Branch in support of its functions were slowly winnowed away, some to be consolidated at Division level with similar tasks from the other Branches. These included personnel and training, and program planning. In some instances personnel were reassigned to the Division staff and in others they were reassigned within the Branch; of the key personnel, Berry went to the Branch Operations Section to assist Charles J. Robinove, Thomasson went to the Division Planning Section, and Edmund F. LeRoux from Thomasson's staff took over leadership of the Division Manpower Utilization Section. Report review was eliminated as a Headquarters function, and other duties of the Reports Section, such as reports handling and special reports, were shifted into new Division sections of Publications and Special Reports along with personnel involved—including such longtimers as Frances G. Thompson, John M. Birdsall, James R. Randolph, and Margaret M. Griffin. The report review staff was dispersed. Charles L. McGuinness, the Section Chief, went on loan to the DOI to help start the new Office of Water Resources Research and George H. Davis was assigned to the staff of the Survey's newly established scientific journal "Annual Review."

Edwin W. Reed, who had been acting Chief for many months while McGuinness was writing his comprehensive report on ground water in the United States (WSP 1800, 1963), transferred to the National Park Service. William D.E. Cardwell was reassigned to the Colorado District and Leopold A. Heindl to the staff of the Area Hydrologist, ACA. In August 1963 Babcock moved to Tucson to become, later, the Division District Chief in Arizona, and Gerald Meyer, formerly District Geologist for West Virginia, replaced him in July 1964 as Assistant Branch Chief. At Denver, by January 1964, the equipment pool and the Hydrologic Laboratory had been split, with Johnson retaining management of the Laboratory and Eugene Shuter taking over management of the equipment pool.

In spite of the organizational turmoil, the years 1961 to 1964 saw substantial advances in ground-water activity, both at field level and at headquarters. Much notable research was accomplished, including contributions to ground-water mathematics and flow hydraulics, such as the work of Akio Ogata, Jose A. da Costa, and others; advances in understanding of ground-water geochemistry, including the work of William Back, Bruce B. Hanshaw, and Ivan K. Barnes as well as others; mining hydrology, including the work of Wilbur T. Stuart; and land subsidence related to ground-water withdrawals, most particularly the research work of Joseph F. Poland. An aggressive recruiting effort brought to the research program during 1961 to 1965 a group of young Ph.D's oriented specifically to the needs of the program. These included John D. Bredehoeft, I. Stavros Papadopulos, George Pinder, Bruce B. Hanshaw, Harold W. Olsen, and Peter Trescott--all to make names for themselves in the earth-science world. Still others are cited throughout this Branch history.

The emphasis in the GWB was on the analysis of ground-water systems. This was made possible by the development in the research program of new hydrologic modeling techniques, first by use of the analog model, but leading toward the increased use of mathematical models as the digital computer became available. The fledgling Analog Model Unit at Phoenix, first under Skibitzke conjunctively with his modeling research, then under Boris J. Bermes, subsequently was given additional support under Eugene P. Patten. The usefulness of borehole geophysical methods, long promoted by Robert R. Bennett, Paul H. Jones, and Raymond L. Nace, in particular, was underlined by the recruitment of W. Scott Keys from the AEC for research on these methods. Automatic data processing was coming into vogue, and essential steps for use of ADP in the GWB were taken when for the first time a national system for numbering of wells and boreholes was adopted and a new form for the cataloging of subsurface data, developed under the leadership of Solomon M. Lang, was placed in field service. The hydrologic atlas, less time consuming to prepare than written reports, came into widespread use as a way to expedite the release of results from some kinds of field studies. The potential of the vast pool of existing data and local reports as a source for synthesis and presentation of useful information at national scale was reaffirmed by way of McGuinness' WSP 1800, "The role of ground water in the National water situation" and John H. Feth's HA-199 showing the extent of saline ground water in the conterminous United States. Ground-water contamination was given special attention by the assignment of Harry E. LeGrand to write several reports on this subject.

The year 1964 saw the last chapter in the official role of the GWB as a line unit. By then most routine tasks formerly carried out by the Branch staff were being conducted at Division level, leaving a small cadre of professionals to concentrate mostly on support for operations, technical quality assurance, and special studies. Included in this group were Berry, McGuinness, Davis, William W. Doyel, Lang, and James H. Irwin, the last three newly added to the Headquarters staff. Robinove had been reassigned, in 1963, to the MCA. That summer a substantial appropriation for new ground-water research became available for the new fiscal year. Initially the new research was slated for direction by the GWB, but instead it was placed in the GHB, then was reoriented to become the Division's principal research arm. Consequently, to avoid problems stemming from split responsibility for ground-water research, Hackett, GWB Chief, relinquished the ongoing program of ground-water research to the GHB. Joseph E. Upson, McGuinness, and Hilton Cooper, who had been tabbed to spearhead the new research effort, also were shifted to the GHB.

As of January 1965, Hackett was reassigned to head the Division's new activities under BOB Circular A-67, and pending selection of a new Branch Chief, Callahan served as acting Chief, an assignment that lasted for nearly a year. The year was pivotal in the reorganization of the Division. Berry moved to head the Division's new Operations Section, Doyel joined the Division's team in Chile, and Irwin moved to Oklahoma to serve as District Geologist. Callahan, Meyer, and their small staff faced the onerous task of assuring smooth turnover of Branch line functions to the Division and establishing the Branch in its new role as a staff arm of the Division. Callahan requested reassignment to the international program and in February 1966 was sent to Korea. McGuinness was appointed Branch Chief in June 1966 and Meyer continued as Assistant Branch Chief. By this time the old era, in which the

GWB carried substantial direct responsibility for ground-water activities of the U.S. Geological Survey, was ended.

The Branch's functions in the closing years of this history, 1965 and 1966, were increasingly confined to advisory technical, staffing, and training services for the Division headquarters and Area and District offices; design and conduct of training programs; technical oversight of Division and Area projects relating to ground water; technical quality control of ground-water practices throughout the Division; and planning, programming, and other staff functions concerning the Division's ground-water research and investigations. The Division's commitment to a continuing role of scientific leadership in ground-water hydrology was evidenced by the appointment by the Division Chief in 1966 of a committee of senior ground-water scientists to reexamine definitions of fundamental terms used in the science and to set forth revised terminology and quantitative units as deemed necessary. The committee, chaired by Lohman, included Bennett, Theis, Cooper, Johnson, McGuinness, and Brown. Their findings and conclusions were published in WSP 1988 in 1972.

## Introduction

Recognition of changing public and governmental requirements for water information stimulated broad organizational changes in the Water Resources Division during the period of this history to ensure maximum possible utility of its data, research, field studies, and services. These fundamental modifications affected all elements of the Division, including the GWB and its activities, in many profound ways, as reflected in the foregoing Overview.

Indeed, the Branch's many technical and scientific contributions documented in this section may well be overshadowed in history by the curtailment of the Branch's headquarters leadership role in ground-water geology and hydrology accompanying the reorganization and redistribution of research and investigative responsibilities, a notable happening in the hydrologic community.

It was no coincidence that integration of the Division's technical disciplines for improved water-wide study occurred during the nationwide rise to prominence of environmental and ecological issues in the 1950's and 1960's. These emerging governmental and public concerns needed new, interdisciplinary support only thinly available at that time. Solutions depended heavily on the earth sciences and, in particular, on products of the Water Resources Division. Water-quality deterioration and radioactive and toxic wastes were growing concerns among ecological and environmental problems recognized at the time.

As the period evolved, the emerging waste and contamination concerns commanded an increasing share of the Branch's investigative and research efforts, with corresponding influences on ground-water planning, programming, and training. Geochemical and biological aspects of hydrologic studies attuned to environmental and ecological problems necessitated modifications to the staff of scientists as well.

Understandably proud of its pioneer role and acknowledged preeminence in ground-water hydrology, and staffed with employees firmly dedicated to the science and to its applications to public water problems, Branch members nevertheless recognized the virtues of the newly integrated organization and that its time had arrived. Environmental, ecological, waste-management, and water-contamination problems signaled the need to widen the bounds of ground-water investigation to include interrelated elements of the environment and to increase interdisciplinary collaboration. Though some members of the GWB understandably were leery of radical departures from its past proven organization and operations, Branch personnel by and large actively supported the Division restructuring and energetically contributed to its implementation.

### Organization and Personnel

In the years 1957 to 1960, the Branch progressively strengthened its Headquarters, Regional, and District operations and programs, extending the era of rapid growth begun at the close of World War II. In the years 1961 to 1964, expansion continued, including consolidating past gains as well as further strengthening research and field programs. However, realignment of line responsibilities began to take form during that time, and during 1965 and 1966, the GWB and its three sister Branches were converted fully to staff arms of the Division.

#### *Branch Headquarters Structure and Responsibilities*

As documented in George Ferguson's history of the previous 10 years, in the post-World War II years the Branch experienced rapid expansion, including major increases in funds, personnel, and programs. By the start of this period of the history, the many new professionals enlisted during the previous decade were trained and positioned among the Districts and in research. The Branch headquarters at Washington had evolved into a sizeable organization with Sections established with responsibility for Research, Operations, Planning, and Training, each headed by an experienced ground-water geologist or engineer. A federally funded research program to advance the science and to aid field studies was under way, and a comprehensive in-house training program led by Branch senior scientists was well established. A hydrologic laboratory and equipment pool for support of field studies was providing nationwide services from its base quarters in Denver, Colo.

The Branch's expanding national program led to delegation of the supervision of field programs to Branch Area Chiefs, one appointed for each of the Division's four regions, at that time called "areas." Further, nine senior scientists were designated regional geologists or engineers to provide technical guidance to the field programs, to furnish consultation and technical assistance to Area offices and Branch headquarters, and to engage in personal self-chosen research. Along with growing requirements for geochemical and biological knowledge in support of environmental problems, quantitative hydrologic analysis was beginning to supersede less intensive qualitative and descriptive studies, which already covered much of the developed parts of the Nation.

Table III—6. Organization and staff, Ground Water Branch, 1957, 1960, 1963, and 1966

| 1957 | 1960 |
|---|---|
| BRANCH OF GW | BRANCH OF GW |
| A.N. Sayre, Chief | P.E. LaMoreaux, Chief |
| Planning Section | Planning Section |
| H.G. Thomasson, Chief | H.G. Thomasson, Chief |
| Operations Section | Operations Section |
| H.M. Babcock, Chief | H.M. Babcock, Chief |
| Training Section | Training Section |
| D.W. Berry, Chief | D.W. Berry, Chief |
| Research Section | Research Section |
| R.R. Bennett, Chief | R.H. Brown, Acting Chief |
| Reports Section | Reports Section |
| C.L. McGuinness, Chief | C. L. McGuinness, Chief |
| **1963** | **1966** |
| BRANCH OF GW | BRANCH OF GW |
| O.M. Hackett, Chief | C.L. McGuinness, Chief |
| Planning Section | Plans & Operations Section |
| H.G. Thomasson, Chief | D.W. Berry, Chief |
| Operations Section | |
| C.J. Robinove, Acting Chief | |
| Research Section | |
| Robert Schneider, Acting Chief | |

Longstanding responsibilities of the Branch for ensuring technical competence and authoritative research and investigation of ground water, and its important technical advisory role remained intact. In a 1964 record in the Branch files, the Branch Chief characterized its new mission as "a staff arm of the Division, as one to advise and assist the Division on all technical matters pertaining to ground-water hydrology. Specifically, the Branch [was] to provide technical leadership, participate in developing and establishing technical standards, and to exercise surveillance with respect to maintaining technical standards."

Table III–6 lists organizational units and key personnel of the Branch headquarters at the earliest, intermediate, and last years of the period, and officers in charge of those units. The table illustrates the fully developed Branch line organization in the early years and the successive decline in management sections and headquarters staff with the narrowing of responsibilities in later years.

#### *Branch Staff*

Substantial personnel adjustments took place throughout the period at Branch headquarters and among Branch units in Area and District offices as a result of the Division reorganization. Representative changes in senior personnel at GWB headquarters are reflected above in table III–6. Whereas long periods of service in senior positions characterized the Branch senior headquarters staff of earlier years, the fast-changing organization precipitated relatively rapid turnover of officers during the period of this history. The position of Branch Chief was held by A. Nelson Sayre from 1947 to 1959 (12 years), and by Oscar E. Meinzer for 35 years previously. Albert G. Fiedler held the Assistant Branch Chief's position from 1924 to 1959, a span of 35 years. In contrast, during the 10-year interval from 1957 to 1966, four men served as Branch Chief: Sayre, 1957 to 1958; LaMoreaux, 1959 to 1960; Hackett, 1961 to 1965; and McGuinness, 1966 (continuing to 1972). Callahan served in the newly established post of Associate Branch Chief from 1962 to 1965. And four men served as Assistant Branch Chief: Fiedler, 1957 to 1959; Conover, 1960 to 1961; Babcock, 1962 to 1963; Callahan, October 1961 to May 1962; and Meyer, 1964 (continuing to 1973).

Branch Area Chiefs were stationed at the four Area centers with responsibility for supervision of GWB programs at regional and District levels. In the series of changes in Division alignment described earlier, BAC's were gradually reassigned to the staffs of Area Division Hydrologists as part of the reorganization. Occupants of the BAC positions spanning the period are listed earlier in figure III–3; they include three in the PCA, two in the RMA, and three in the MCA. Only one BAC served throughout the period of this history, Henry Barksdale of the ACA. Lohman, Barksdale, and Drescher had previously served as regional staff geologists or engineers, posts that logically led to the BAC assignments. Changes of personnel at District level attributable to the reorganization were comparatively moderate and are discussed in Part X.

The full Branch complement in 1957, including Washington, Area, and District personnel, totaled 722, consisting of 396 professionals, 214 subprofessionals, and 115 clerical employees; 102 of these worked less than full time. In the next 2 years, professional personnel continued to grow in numbers, numbering 414 in 1959, with subprofessional personnel declining to 177 and clerical personnel rising to 117. The staff totaled 708 in 1959, of whom 76 were part-time employees.

Branch records indicate a similar staffing level for the next 2 years, with 430 professionals and 320 support personnel totaling 750 people in 1961.

In subsequent years the staff declined in numbers with the transfer in 1964 of a dozen or so research personnel to the newly created GHB, reassignment of regional research staffs to Area headquarters, and the reduction in Branch headquarters management personnel.

In January 1961, the Branch headquarters staff, including some at Arlington Towers, totaled 49. It declined to 20 in January 1963, to 11 in 1964, and to six in 1966. According to a 1963 record in the GWB files, the Branch reduced its headquarters staff during the previous 2 years in preparation for the impending reorganization from line units to technical staff units. The record notes that the Branch found itself in the difficult position of continuing as an operating Branch with only a skeleton staff.

Employees intensely dedicated to public service in the pursuit of ground-water knowledge explain the Branch's successes. The many dedicated employees who served during the period of this history, or part of it, are identified below. Excluded from that listing to avoid repetition are the senior Branch officers cited in the paragraphs above and in table III–6; Federal Program project leaders cited in table III–8; and the research project leaders identified in the Ground Water Research subsection of Part IV.

Branch members included John A. Adamson, Dorothy M. Albright, Jane L. Andreason, William Back, Anne V. Baker, Clara E. Benson, Joan D. Berry, Gilmora J. Biddle, Paul P. Bieber, Katherine Berrall, John M. Birdsall, Reginald R. Blankenship, Richmond F. Brown, Geraldine T. Buhl, Lee C. Burton, William D.E. Cardwell, Charles W. Carlston, Donald J. Casey, Evelyn N. Clark, Mabel C. Damon, Jose A. DaCosta, George H. Davis, George D. DeBuchananne, Julia A. Dorsey, Verda M. Dougherty, William W. Doyel, Caroline J. Eble, Dianne M. Ellis, John G. Ferris, Irene A. Foley, Ines A. Gore, Charles J. Gose, and Elizabeth H. Grayson.

And continuing, Gertrude W. Griffin, Margaret S. Griffin, Rodney Hart, Leopold A. Heindl, Catherine S. Hubbard, Agatha P. Humphrey, Mollie S. Jablow, Eva R. Jennings, Paul M. Johnston, Caroline B. Jorgensen, Edna W. Kalbfleisch, William W. Kephart, Solomon M. Lang, Harry E. LeGrand, Edmund F. LeRoux, Robert W. Maclay, Irene E. Magyar, Joan O. Marshall, Elizabeth E. Messick, Carol N. Metcalf, Mary F. Montgomery, Helen H. Moore, Joan V. Mouer, Harold W. Olsen, Joan F. Phillips, James R. Randolph, Edwin W. Reed, Audrey R. Reniere, Audrey K. Rigdon, Mary A. Ryall, Robert Schneider, Eugene S. Simpson, Thomas A. Simpson, William O. Smith, Robert W. Stallman, Wilbur T. Stuart, Nancy C. Taylor, Frances G. Thompson, John B. Thompson, Joan R. Wilcox, John R. Williams, Irene A. Wood, and Mary A. Zimmerman.

#### *Other Principal Leaders*

In addition to the senior Branch staff headquartered at Washington and identified above, or in Part II "Leadership," other principal leaders stationed throughout the Nation in Area and District headquarters offices are recognized as contributing a highly significant share of Branch leadership. They include Branch Area Chiefs, Senior Scientists, and certain other senior officers who served in the area or District offices within the period of this history.

Some are omitted here because they are covered in sections of the history appropriate to their principal services. Branch research program leaders, for example, are included in the Part IV, "Ground Water Research." As in most organizations, many experienced hands gave of their wisdom and counsel to younger colleagues even in the absence of official license. Listing those many behind-the-scenes leaders would not be practicable.

Henry C. Barksdale.—Barksdale entering on duty with the SWB and GWB (serving them jointly) as an engineer in Trenton, N.J., in 1923, completed over three decades of significant service by the time this period of history began. From 1952 to 1957, he served as GWB Staff Engineer for the Middle Atlantic Area, one of nine such Branch senior staff scientists designated throughout the Nation, and continued in charge of the New Jersey District ground-water program as well. From 1957 to the end of the period of this history and beyond, he served as Branch Area Chief of the GWB for the Atlantic Coast Area with headquarters in Arlington, Va.

Russell H. Brown.—Brown entered on full-time duty with the SWB in 1939, as a Junior Hydraulic Engineer in Boston, Mass., and transferred to the GWB the following year. Following progressively challenging field and headquarters assignments, he was transferred to the Branch's Research Section in Arlington, Va., in 1956 and was appointed Chief of the Section in 1960. In 1962, he transferred to the Branch's research office in Phoenix, Ariz., to conduct personal research and to continue participation in important technical committees and commissions, all the while honoring requests for his services on staff details to Washington headquarters. Brown remained in Phoenix to the end of this period of history and beyond.

Joseph T. Callahan, Jr.—Callahan's full-time career with the Survey started in 1951 with appointment as a geologist in the Arizona District. He was the Branch's District Geologist for Georgia from 1955 to 1961, with headquarters in Atlanta. In 1961, he transferred to Washington, D.C., to serve first as Assistant Chief for the Branch and then as Associate Chief. In 1966, Callahan accepted a 5-year assignment as Technical Advisor to USAID in Korea.

William J. Drescher.—Drescher entered on duty as a Hydraulic Engineer in Florida in 1941 and became Branch District supervisor in Wisconsin in 1951. In 1956, he was appointed Branch Staff Scientist for the nine northern States of the Mid-Continent Area, and in 1957, he was designated Branch Area Chief for the Area. He continued in that capacity until 1961, when he undertook research on the hydrodynamics of deep geologic basins and their capacity for storage of radioactive wastes. From 1964 to 1966, he coordinated a program of comprehensive river-basin studies throughout the Mid-Continent Region, and during 1965 and 1966, compiled and analyzed research on the Great Lakes.

John G. Ferris.—Ferris joined the Branch as an engineer in the New York District in 1938. He served as District supervisor in Indiana and then in Michigan, with a contemporaneous career of teaching and lecturing on ground-water hydraulics throughout the Nation and in other countries. During 1952 to 1957, he served as the Branch's Staff Engineer for the northern tier of mid-continent Districts. He transferred to Branch headquarters in 1957 as a Staff Research Engineer, and then in 1959, to the University of Arizona at Tucson, Ariz., to serve as advisor and principal lecturer for a new curriculum in hydrology initiated jointly by the USGS and the University. He returned to Washington in 1965 to serve as a member of the Branch technical staff, continuing in that capacity beyond the period of this history.

A. Ivan Johnson.—Johnson entered on duty in 1948 with the Branch's Hydrologic Laboratory, at Lincoln, Nebr., a regional office of the Missouri River Basin program. In 1954, the Laboratory was moved to Denver, assigned nationwide responsibilities, and Johnson was designated its Chief. In 1956, the Special Purpose Equipment Unit was established as part of the Laboratory services. He continued as supervisor of the Laboratory throughout the remainder of the period and beyond. His career during the period included preparation of a number of important technical reports, active participation in training activities, and details to headquarters as well as overseas technical-assistance visits.

Stanley W. Lohman.—Lohman entered on duty in 1930, and proceeded to compile an impressive record of scientific accomplishments in geology and hydrology well before the period of this history. During 1957 to 1959, he served as Branch Area Chief for the GWB in the Rocky Mountain Area, participated in the ground-water short courses and advanced ground-water seminars of the Branch as advisor and lecturer, and continued his hydraulic and geologic writings. In 1959, he was designated a GWB Staff Geologist, with relief from administrative duties and freedom to pursue research and to provide technical assistance to project personnel. Through the end of this period of history and beyond, he wrote important reports on geology and hydrology, participated in technical committees, and continued inhouse teaching and lecturing in this country and overseas.

Thad G. McLaughlin.—McLaughlin joined the Survey and Branch in 1942 as a geologist in the Kansas District, moved to Colorado 3 years later, and in 1951, was appointed District Geologist for Colorado. He continued in that post until 1959 when he was designated Branch Area Chief, Rocky Mountain Area. In 1965 and after Division reorganization, he was converted to Staff Hydrologist of the Rocky Mountain Region. He undertook a number of short-term technical-assistance assignments to Middle East countries and Greece during this period. In 1967, he was designated Regional Hydrologist for the Rocky Mountain Region.

Edward A. Moulder.—Moulder, an engineer, joined the Michigan District of the Branch in 1946. Subsequently he assumed increasing responsibilities, first in the MRB program in Montana and Wyoming and then in the Texas District, In 1959, he transferred to Colorado as District Engineer, GWB. In 1963, he was appointed Branch Area Chief, GWB, for the Pacific Coast Area, reassigned to Staff Hydrologist under the reorganized Division, and remained in that post until 1967 when he was appointed District Chief for the newly integrated Colorado District.

Joe L. Poole.—Poole, a geologist, joined the GWB in Carson City, Nev., in 1949. He served in the Branch District in Baton Rouge, La., from 1957 to 1959, then in Sacramento, Calif., from 1959 to 1960, and was assigned to the position of District Geologist for the Tennessee District from 1960 to 1962. In 1962, Poole was appointed Area Chief, GWB, in the Mid-Continent Area with headquarters at St. Louis, and he continued in that position until 1965, when he was converted to Staff Hydrologist, Mid-Continent Area, under the new Division organizational structure.

Matthew I. Rorabaugh.—Rorabaugh is one of the few WRD employees who worked in three Branches during their careers, reflecting his versatility in hydrology. His Survey employment started in 1938 in the Harrisburg, Pa., SWB District. He worked in the Water Utilization Branch in Washington, D.C., during World War II and was named GWB District Engineer in Louisville, Ky., in 1945. In 1954, he was placed in charge of the GWB District Office in Tallahassee, Fla., and remained there until 1962 when he undertook leadership of the Hungry Horse Reservoir bank-storage project in Montana. In 1966, he became Area Research Hydrologist, Mid-Continent Area, in St. Louis, Mo.

George H. Taylor.—Taylor, an engineer, joined the Branch in California in 1926. Among his technical and managerial contributions, he is perhaps best known for his leadership in the Missouri River Basin program (see Part IV, "Missouri River Basin Program"). In 1946, he was placed in charge of the ground-water part of the program. By 1958, when most of the immediate program objectives had been achieved, he was designated a Senior Staff Engineer and subsequently Operations Research Engineer for the GWB, remaining in that post until he retired in 1961 (see Part IV, "Operations Research").

Harold E. Thomas.—Thomas entered on duty as a Junior Geologist in the California District Office in 1931, the start of a remarkable career in ground-water hydrology. By the beginning of this period of history, he had developed a reputation as a national and international authority on water law, the conservation of ground water, and the hydrology of arid zones of the world. After serving for several years as District Geologist in Utah, he transferred to Menlo Park, Calif., in 1956 as Senior Staff Geologist and then Branch Area Chief for the Pacific Coast Area. In 1959 to 1961, he served as an invited Technical Advisor to Tunisia, and in 1965, as advisor to the government of Kuwait. He returned to Menlo Park in December 1965 as a Research Hydrologist and in 1966, accepted an assignment for long-range planning in the Office of the Division Chief in Washington, D.C.

George F. Worts.—Worts, a geologist, started his career with the Survey and Branch in 1940 in Long Beach, Calif. Following assignments in California and Minnesota, he was appointed District Geologist for California in 1956. In 1958, he was promoted to Branch Area Chief, Pacific Coast Area, in Menlo Park, Calif. In 1962, he was reassigned to Carson City, Nev., as the first Division District Chief for Nevada. He remained in Carson City through the end of this period of history. Throughout his career Worts always found time to provide technical assistance to water-resources agencies in other countries.

#### *Special Services Units*

The Branch maintained special services units at appropriate locations in order to provide technical assistance and services to field studies and research. Principal among these were the Hydrologic Laboratory and Equipment Unit at Denver, Colo., the research-oriented Equipment Development Unit in Arlington, Va., and the Analog Model Unit at Phoenix, Ariz. All of these units were within the ACA and RMA and they reported to those Area offices after the Division realignment, although Branch technical oversight continued.

Hydrologic Laboratory.—The Laboratory, initially in Lincoln, Nebr., was moved to Denver, Colo., in 1954, with A. Ivan Johnson in charge. The Laboratory provided hydraulic analyses and other mechanical and hydrologic tests of earth materials and guidance to field personnel in collecting materials for testing, including rental of the necessary field equipment. It conducted experiments requested by field and research units, carried out its own research, and maintained an equipment pool for the use of field offices. Francis C. Koopman developed new ground-water equipment for the Laboratory. Field centers maintained at Washington, D.C., Little Rock, Ark., Louisville, Ky., Idaho Falls, Idaho, and Sacramento, Calif., at various times during the period made equipment and limited laboratory assistance more accessible.

The main laboratory tests performed on samples of earth materials were permeability, specific yield, and particle size, which constituted about 95 percent of the laboratory determinations. Starting in 1954, soil-moisture tension, Atterburg limits, and capillarity tests were added as their value to field studies were more fully recognized and requests for those tests grew. Other analyses and tests were added to provide new services during the period.

The Laboratory's annual budget increased from about $5,000 in 1948 to about $200,000 in each of the years 1960 and 1961, reflecting long-term growth of its services to Branch units throughout the Nation. Most of the Laboratory's costs were met through repay for its services and rental of its equipment. Of its total funds of $194,000 in 1960, for example, repay of $85,000 was for laboratory services and equipment rental, $21,000 was for laboratory analyses, and $88,000 was for experiments and testing for special projects, including some of its own.

Johnson served as Chief of the Hydrologic Laboratory throughout the period of this history and was largely responsible for expansion of its services and staff. In 1957 the staff consisted of only three full-time persons; by 1963 it numbered about 24. In addition to Johnson, key full-time technical personnel during parts of the period included James A. Basler, Donald L. Bingham, Robert L. Goematt (also in Idaho Falls, Idaho, field unit, 1962 and 1963), Herbert Hopkins, Gerald E. Idler (also in Kentucky field unit), Richard E. Jones, Ronald H. Jones, Francis C. Koopman, Willis K. Kulp, Augustine H. Ludwig, William N. Lockwood, William H. Lohman, Marvin L. Milgate, Donald A. Morris, Robert P. Moston, James D. Orner, Wilbur N. Palmquist, Jr., Robert D. Penley (in Kentucky field unit), Robert C. Prill, Don A. Ralston (in Idaho Falls, Idaho, field unit), Eugene Shuter, Robert A. Speirer, Richard E. Taylor, Warren E. Teasdale (also in Sacramento, Calif. field unit, 1962 and 1963), Stanley Versaw, and Norman Yabe.

Other supporting technical and clerical personnel included Virginia L. Bechtold, Norma L. Benson, Irene M. Bloomgren, Joy L. Charbonneau, Carol R. Jones, Richard M. Kanawyer, William N. Lawless, Jr., Lois M. Lingle, Charles R. Martin, Joan J. Olsen, Carol L. Ramstetter, Lois A. Schilling, Louise K. Taylor, and Grace R. Woodring.

<u>Ground-Water Equipment Unit.</u>—Growth in demands for services and equipment of the Hydrologic Laboratory continued until 1963 when a separate unit was established with Eugene Shuter as Technician-in-Charge of a staff made up largely of technicians and drillers. The pool of drilling and sampling equipment was made available to district project leaders and researchers on a rental basis, generally with operators but in some instances for operation by field personnel.

The pool of equipment continued to expand in subsequent years to include better drilling and sampling apparatus, geophysical logging facilities, and various other pieces of sampling and exploratory equipment. In 1967, the staff totaled nine persons under the able leadership of Shuter. They included Grady E. Anderson, Wayne A. George, Stanley T. Green, David R. Humpherys, Richard E. Jones, Lois A. Jordan, Don A. Ralston, and Robert R. Pemberton.

<u>Equipment Development Unit.</u>—The Branch, and subsequently the ACA headquarters, maintained a one-person project in Arlington to design and develop special equipment, largely electronic in nature, in support of field studies and research. James E. Eddy, with informal guidance and assistance by Bennett and other ground-water research personnel, filled the position throughout the period. Products included a magnetic switch and counter for deep-well current meters, equipment for measuring head differentials in aquifers using pressure-sensitive transducers, and an angle-measuring device to determine the direction of current flow in electrical analog models by use of potentiometers.

<u>Analog Model Unit.</u>—During 1960, the Analog Model Unit in Phoenix, Ariz., formerly operated as a component of analog research, was established as an operational unit to provide modeling services to field offices on a reimbursable basis, as described in GWB memorandum no. 60.56. During its first several years, developmental costs were supported with Federal program funds. It analyzed selected ground-water flow problems in representative areas of the Nation and assisted field offices in utilizing electric-analog methods to solve complex hydrologic problems.

Herbert E. Skibitzke, in Phoenix, served as the first Chief of the research and service analog unit in conjunction with his other activities. He was succeeded in 1961 by Boris J. Bermes, and subsequently, in 1963, by Eugene P. Patten, Jr., at which time the units were combined. Demand for the services of the units grew rapidly, and at the time they came under the wing of the RMA in 1965, electrical analog modeling was rapidly, becoming a standard analytical technique among ground-water hydrologists.

Members of the Analog Model Unit serving within the period, in addition to Skibitzki, Bermes, and Patten, included William F. Bruns, James M. Cahill, Frank C. Caruso, Michael L. Field, Garth E. Ghering, Chester J. Kordylas, Stanley M. Longwill, Mary G. Magness, Dolores M. Meyer, Sylvia J. Quail, Joseph W. Reid, Robert D. Penley, and Dolores M. Wachtell.

Digital computers were becoming available to Division personnel at this time, and interest in mathematical modeling was beginning to rise among ground-water investigators. Over the next decade or so, digital computer modeling replaced all but a few specialized electric analog modeling needs of the Division.

### *Education and Training*

The diversity of disciplines among professional ground-water personnel expanded throughout the period of this history in response to the technical and interdisciplinary requirements of the 1960's. In 1961, for example, the professional staff was composed of 330 geologists, 89 engineers, 5 geophysicists, 3 mathematicians, 2 soil scientists, and 1 physicist. Forty-five percent of these scientists held advanced degrees, including 37 with Ph.D's.

In addition to academic preparation, however, supplementary training within the Branch was necessary. In fact, until the 1960's, the special skills needed for the Branch's work were not offered by universities. Much of the training was conducted by informal on-the-job supervision and instruction during the course of project work.

A formal in-house training program in ground-water hydrology was started in 1951 and continued through this period. Intermediate and advanced short courses of several weeks' duration provided intensive basic training to 550 Branch professionals and advanced training to 138 professionals. Branch senior scientists and experts in specific subjects were instructors and seminar leaders, and the innovative, effective short courses attracted both national and international respect. Principals among several dozen or more session leaders during this period included Back, Bennett, Ferris, Hanshaw, John D. Hem (of the QWB), Keys, Lohman, Patten, Shuter, Stallman, Skibitzke, and Theis. From time to time hydrologists from other WRD Branches and from cooperating State agencies were admitted to the courses.

A corollary program of foreign training consisted of the assignment of Branch personnel to ground-water studies in foreign countries and the training of foreign nationals in Branch facilities in the United States. The program started in 1950 under the Bilateral Technical Assistance Program and through the United Nations. Johnson, Ferris, Lohman, and others facilitated the foreign training effort through leadership of the program and service as instructors both in the domestic program and in schools conducted in other countries. Lohman, for example, taught ground-water hydraulics at a 2-week training session in Adelaide, Australia. Lacking a suitable textbook, he wrote one for class use. He later expanded it into the volume "Ground-water hydraulics" which was published in 1972 as USGS Professional Paper 708 and used worldwide as a university textbook and translated into Spanish.

## Programs and Funds

As an operating unit of the Division during the early and middle years of this history, the GWB continued its goals to determine and describe the occurrence, quantity, and quality characteristics of the Nation's ground water and to provide scientific understanding and technology sufficient to enable informed development and management of that water. Those broad goals encompassed the following specific objectives:

1. Reconnaissance investigations covering the Nation with descriptions of general geologic settings and ground-water hydrologic and chemical conditions.
2. Quantitative studies of the sources, movement, and discharge of ground water, including the effects of extractions by pumping, and variations in quantity and quality spatially with time.
3. Fundamental and applied research to develop geologic and hydrologic principles and techniques of investigation and analysis.
4. Definitions of the role of ground water in the total water realm and as one component of the Nation's total water supply.
5. Quantitative accounting of extractions and utilization of ground water and effects of its development on the Nation's hydrologic regimen. Investigation also of the response characteristics of ground-water systems as a means to predict the effects of water development and usage.
6. Prompt publication of findings and research to meet public and governmental needs.

### Program Content

In the early 1960's, the total program directed toward fulfilling these objectives consisted of the following five program elements: basic records (water records), areal hydrology and geology (areal hydrology), research (hydrologic principles), techniques, and support.

#### *Basic Records*

This program element constituted about 15 percent of the Branch program in the early 1960's. It included all projects for collecting, compiling, and reworking of hydrologic data for publication as statistical records. The scope of the category was broader than the systematic measurement of water levels in wells nationwide, although that was one principal component. It included collecting additional basic records such as chemical quality and temperature of ground water, withdrawals for use or drainage, lithologic and geophysical well logs, determinations of physical and hydrologic properties of materials, and other less common records appropriate to the program element.

The relatively small effort in manpower and funds devoted to basic records was considered to be inadequate to meet foreseen needs, particularly in support of the "benchmark" monitoring activity of the Division and advancing computer analysis of aquifer systems.

#### *Areal Hydrology and Geology*

This component, the largest activity during the period of this history, constituted 70 percent of the total Branch program in the early 1960's. Major effort focused on systematic investigation of the ground-water hydrology and ground-water resources of the Nation, through projects covering geographic areas ranging from counties to major ground-water or river basins to regions and to the Nation at large. Generally established hydrologic, hydraulic, and geologic principles were employed, but improved and new methodologies were devised during the course of the investigations where necessary and feasible.

Areal projects of these kinds were the principal ground-water investigations in the Federal-State Cooperative program, the Federal program, and the Other Federal Agency (OFA) program. These programs are described in some detail in Parts IV and X of this volume. Projects ranged in intensity from reconnaissance level through detailed descriptive investigations to intensive interpretive studies involving complex analyses and predictions of the effects of development and management practices.

#### *Research*

Ground-water research was viewed as a common denominator that provided linkage and support to all investigational work of the Branch. Centers of research activity were mainly in the regional and headquarters centers, but research projects could be identified and undertaken anywhere in the program of the Branch. For example, the Branch supported selected research projects at District level, often conducted in conjunction with field studies of the cooperative program.

The Branch supported 21 formal research projects in 1960 with funding of $475,000, or 37 percent of its available Federal funds. Allocation of such a significant portion of Federal program funds reflects the importance assigned to ground-water research at that time, when the complexities of problems related to the resource were becoming more fully recognized along with recognition of the deficiencies in hydrologic knowledge required to address those problems.

The primary challenge was to define ground-water systems with sufficient thoroughness and precision to predict the hydraulic and chemical responses to man's cultural developments and disturbances. Acknowledging that each problem could not be given individual attention, it was a practice of the Branch to conduct surveys to identify the nature of the many problems and the gaps in basic knowledge of ground water, and to design the research program accordingly.

The overall effort of the Branch during the early and middle years of the period concentrated on five categories of research: the unsaturated zone, the saturated zone, properties of reservoirs and porous materials, chemical hydrology, and geologic terranes. The first four were basic research and the last, applied research.

#### *Techniques*

Applied research projects seeking to develop new or improved field and laboratory procedures and instruments were grouped in the program element "Techniques." These projects included continuing research and development for analog-computer modeling, improved design of borehole geophysical equipment, down-hole current meters, and other investigational equipment.

Bennett built the Branch's first research borehole logger for water studies during 1947 to 1949 in Baltimore, Md. In 1963 a formal research project for development of improved logging equipment was initiated in Denver, Colo., with Keys as project chief. This research work was coordinated closely with the field-project logging services of the Equipment Pool.

The theory and design of electrical analog models for ground-water study was developed in the early 1950's by Skibitzke and Bennett. Bermes and Stallman were also active developers of analog modeling methods during this early stage. During 1957 to 1966, research focused on expanding the versatility of the technology and adapting the technique to real field problems. For example, application to leaky artesian aquifer systems was undertaken, beginning in 1961, especially with regard to permissible limits of mathematical and hydrological simulation in terms of margins of error allowable for given field situations. Research and service analog units worked in close association.

### *Support*

This category covered a small but important group of projects serving particular scientific, staff, or administrative purposes. They included, for example, ground-water texts and treatises written by Branch staff, the manuscript editing and revising function of the Branch, and other such activities that did not fall readily into the above four program categories.

## Program Funds and Sources

Branch records indicate that operating funds increased from about $5.5 million in fiscal year 1957 to about $7.7 million in fiscal year 1960, an increase of about $2.2 million or 40 percent. The increase maintained a 12-year interval of increasing funds, amounting to a fourfold increase from 1948 to 1960.

Those increases in funds notwithstanding, insufficient financing of Branch work was an ever-present handicap, even more so than shortages of professional personnel. A 1961 draft memorandum, retained in the Branch files, compared growth of program funds with the increase in number of professional employees during 1950 to 1961. It noted that funds increased at a rate of about 15 percent a year (from $2.65 million to $7.9 million), whereas numbers of professional personnel increased only about 6 percent a year (from 256 to 430). The memorandum concluded that the growth in funds merely reflected inflation and the increased costs of doing work, and that Branch capacity to meet accelerating demands for information was inhibited by lack of funds as much as or more than lack of personnel.

Table III–7 summarizes distribution of Branch funds among programs and numbers of projects in FY 1960, a somewhat representative year for the segment of this history prior to reorganization. The data were extracted from a program statement distributed with GWB memorandum no. 61.37, dated December 19, 1960.

Table III–7. Ground Water Branch program elements, distribution of funds, and number of projects, fiscal year 1960

| Program element | Total funds ($) | Percent of funds | Number of projects |
|---|---|---|---|
| Basic Records | 1,110,700 | 15.5 | 87 |
| Areal Hydrology and Geology | 5,035,000 | 70.5 | 432 |
| Research | 790,100 | 11.1 | 37 |
| Techniques | 123,500 | 1.7 | 11 |
| Support | 82,500 | 1.2 | 5 |
| Totals | 7,141,800 | 100 | 572 |

The table shows that on the basis of either funds or number of projects, about three-fourths of the Branch program consisted of areal hydrology and geology, 15 percent for basic records, only about 12 percent for principles and techniques, and a small amount for support activities. The table does not include $185,000 of nonproject Federal funds or ICA money for work in other countries made available to the Branch. Including those dollars, operating funds for 1960 totaled $7.4 million.

Branch project funds during the period of this history, and for several decades earlier, were from three sources—the Federal-State Cooperative program, the (OFA) program, and the Federal program. These programs were Divisionwide and are discussed in more detail in Part IV.

Comparison of the magnitude of funding from these three programs reveals the dominant significance of the Federal-State Cooperative program to the Branch effort. Two-thirds of the gross increase cited above for the 13-year period was in the Federal-State Cooperative program, with the remainder split between the OFA and Federal programs. The three sources provided Branch funds in about that same ratio during the early years of this history, 1957 to 1960, with continued growth from each source for the next several years, until 1965 when funds ceased to be allocated on a Branch basis.

### *Federal-State Cooperative Program*

This nationwide program was the mainstay of the Branch. Approximately 300 State and local resource agencies throughout the Nation cooperated financially by contributing one-half the cost of investigations, collaborating in program planning, and infrequently participating in the conduct of the field studies.

The joint effort assured a program aimed at real water problems, designed locally where the elements of the problems could be most clearly identified, yet supplemented with the national perspective derived from experience with water problems over the entire country and internationally. Priority among projects and the scope of investigation were influenced strongly by urgency of need and availability of funds. Specific criteria for development of work included (1) pertinence to State and local water problems, (2) compatibility with the authority and mission of the Survey and with Division and Branch goals, (3) anticipated contribution to hydrologic knowledge and its relevance to other work of the Branch, Division, and Survey, and (4) adequacy of available financing.

Cooperative-program funding for ground-water work rose steadily to $5.2 million in 1960, reflecting the growing need for ground-water information throughout the Nation. In 1960 three-fourths of cooperative funds were devoted to the Branch program element Areal Hydrology and Geology ($3.9 million); about 19 percent ($1 million) for Basic Records; 7 percent ($0.38 million) for Research; and minor amounts for "Techniques" and "Support."

The pressing need for information shortened the length of many cooperative-program field investigations, limiting the time for collecting and studying all of the data needed. The quality of interpretive reports produced under hurried conditions reflects credit on Branch personnel. Preparing reports to acceptable Branch standards delayed release of some reports beyond scheduled completion dates, creating consternation among some State cooperators who were impatient with prolonged delays.

#### *Other Federal Agencies (OFA) Program*

Branch studies for other Federal agencies varied widely in nature, purpose, and scope. They ranged from simple well-site locations for water development on Federal installations to complex investigations requiring several years and substantial manpower and funding.

Work for other Federal agencies was subject to the same general criteria as stipulated for the Cooperative program. Although OFA work was geared primarily to the special requirements of the other agencies, projects conducted under the program constituted a valued segment of the Branch program and often had broader applications than those of the requesting agency alone.

The OFA segment of the Branch program grew slowly but steadily over the years, reaching $1.13 million by 1960. In 1960, almost 90 percent of OFA work was in the program element Areal Hydrology and Geology ($0.9 million); 76 of the 92 OFA projects were in that category. Only about 5 percent of OFA funds was devoted each to Basic Records and Hydrologic and Geologic Principles and a much smaller amount to "Techniques" and "Support." Overseas work, a modest but valued segment of GWB activity, was included in this category, amounting to $271,000 in 1960.

#### *Federal Program*

The Branch's Federal-program projects were directed to studies that added to knowledge of hydrologic principles and the application of those principles as techniques that contributed to the solution of water problems. The studies generally were of large areas and, therefore, the investigations had regional or national significance.

Projects undertaken were those that addressed serious deficiencies in water information; competition for Federal funds was intense within the Branch and with other units of the Division. Criteria for selection included (1) pertinence to present or anticipated water problems and compatibility with Branch and Division goals, (2) expected contributions to hydrology, (3) compatibility with other programs of the Branch and other Division programs, and (4) availability of qualified personnel to do the work. Occasionally regional studies were mandated by the Congress. (See Part IV, "Mississippi Embayment Project.")

Distribution of effort among the program elements for the Federal program was considerably different from that of the other two program segments. Emphasis in the Federal program was on research, regional-scale studies, and support work. In 1960, for example, basic records and areal hydrology made up only 32 percent of the Federal program, as compared to 93 percent for these categories jointly in each of the other two programs. Research on principles and techniques and support projects made up 68 percent of the Federal program. The Federal program increased during the period reaching $1.27 million by 1961.

Table III–8 lists Federal Program projects of the Branch for fiscal year 1961. The table also identifies project leaders and funds allocated that year to each project.

In the succeeding years—1962 to relinquishment of Branch responsibility for the Federal program in 1964—increasing efforts were directed to areal and regional ground-water systems studies. A temporary committee on ground-water research, appointed by the Chief Hydraulic Engineer in 1962 and chaired by McGuinness, recommended in a memorandum dated June 5, 1963, additional systems studies in ground water. It resulted in expansion of studies of the geology and hydraulic systems of the Atlantic Coastal Plain by Philip M. Brown, aided by James A. Miller and others. Their work set the stage for systems studies of the geologically more complex Gulf Coastal Plain and Western interior regions of older sedimentary basins.

### Post-Reorganization Years

Branch authority for programs and operations officially ceased in December 1964, but the transition of responsibilities to the Division continued informally throughout the remainder of the period of this history. Cooperative (Coop) programs, OFA projects, and Federal-program projects with some exceptions, accrued to the four Area Headquarters. GWB research that was

Table III-8. Ground Water Branch Federal Program, fiscal year 1961

| Project | Project Chief | Funding |
|---|---|---|
| | **Water Records** | |
| Nationwide collection of basic records | District personnel | $34,650 |
| Raft River Basin water records | M.J. Mundorff | $5,250 |
| | **Areal Hydrology and Geology** | |
| Lower Colorado River project | C.C. McDonald | $210,000 |
| Mississippi Embayment project | E.M. Cushing | $105,000 |
| Trent Marl | Paul Brown and Steve Herrick | $4,725 |
| Ground water in Alaska | R.M. Waller | $18,585 |
| Management of ground water | W.J. Drescher and R.W. Sundstrom | $21,000 |
| Hydrology of Columbia River Basalt | R.C. Newcomb | $16,800 |
| Hydrology of limestone terranes | W.J. Powell | $21,000 |
| Relation of permafrost to ground water | J.R. Williams | $15,750 |
| Late glacial substages in New England and New York | J.E. Upson | $5,565 |
| Mining Hydrology | W.T. Stuart | $24,675 |
| Artificial recharge through wells | R.T. Sniegocki | $21,000 |
| | **Hydrologic Principles** | |
| Spatial distribution of chemical constituents in ground water | W. Back | $19,425 |
| Tritium studies | C.W. Carlston | $55,650 |
| Graduate-school research | C.E. Shaw | $1,575 |
| Origin of salty ground water in the Netherlands | J.E. Upson | $14,910 |
| Unsaturated flow | W.O. Smith | $13,860 |
| Transient flow | W.O. Smith | $17,010 |
| Theory of unsaturated flow | H.E. Skibitzke | $8,925 |
| Analog modeling of unsaturated flow | H.E. Skibitzke | $13,650 |
| Mechanics of flow through granular media | A. Ogata | $10,500 |
| Mechanics of diffusion, salt and fresh water | H.H. Cooper | $24,150 |
| Multiphase flow theory and applications | R.W. Stallman | $23,100 |
| Liquid movement in clays | H.W. Olsen | $26,250 |
| Mineral constituents in ground water | J.H. Feth | $51,660 |
| Mechanics of aquifers | J.F. Poland | $3,000 |
| Flow effects of heterogeneity | H.E. Skibitzke | $5,250 |
| Petrofabrics; directional permeability of marine sandstones | R.R. Bennett and Jose da Costa | $20,000 |
| Hydrologic environmental study | J.N. Payne | |
| | **Techniques** | |
| Electronic equipment development | J.E. Eddy | $9,030 |
| Analog computer research | B.J. Bermes | $10,185 |
| Analog computer service unit | B.J. Bermes | $21,000 |
| Training manual, ground water | S.W. Lohman | $14,175 |
| Operations research | G.H. Taylor | $18,900 |
| | **Support** | |
| Report on ground-water situation in the United States | C.L. McGuinness | $10,500 |
| Preparatory work for treatise on ground-water mechanics | J.G. Ferris | $21,000 |
| Hydrology of New Mexico, almanac | W.E. Hale | $9,450 |
| Geology and hydrology of Colorado National Monument, lay reader report | S.W. Lohman | $4,775 |
| Manuscript revision | Branchwide | $23,100 |
| Hydrologic and physical properties of soils and rocks, report | D.A. Morris and A.I. Johnson | $12,495 |

transferred to the GHB in 1964 was reassigned by mid-1966 to the four Area Headquarters with termination of the GHB. The Federal program of basic ground-water records continued as a Branch function.

Callahan and Meyer served in acting capacities in the first half of 1966 until McGuinness was appointed Branch Chief in June 1966. Primary Branch responsibilities by then included technical quality assurance, report-quality surveillance, operations support, and conduct or supervision of special technical or administrative studies.

## Quality of Water Branch

*By* Walton H. Durum *and* reviewed *by* W. Finch White, S. Kenneth Love, *and* R. Hal Langford, *and* with typing assistance *by* Winifred Durum.

Note: Much of the material initially submitted for this section was researched and presented by the author in 1978 in "Historical profile of quality-of-water laboratories and activities, 1879–1973," U.S. Geological Survey Open-File Report 78–432. The reader is referred to that publication for a more detailed history of the Branch.

### Introduction

For the Quality of Water Branch nothing had gone on before to match the excitement of the challenges and changes that took place in from 1957 to 1966. Many frank and constructive discussions were held between Division and Branch officers to determine the extent of the problems faced, the actions needed, and position papers to be prepared for developing these changes. This period has been aptly referred to as the "Golden Years" for water-quality specialists as the Branch and field support units emerged into a broadly based, highly trained group of professional and technical specialists, prepared to cope with the rapidly changing needs for sophisticated data, information, and supporting research.

For many years, the Division's water-quality work in many parts of the Nation consisted almost exclusively of the determination of inorganic chemical parameters. These determinations were essential to orderly developing of water-management projects; evaluating the suitability of surface water for impoundment for municipal, industrial, or irrigation use; determining the source and magnitude of saline pollution, both natural and manmade; measuring the effects of impoundment on water quality; and inventorying the chemical quality of water in wells as part of ground-water studies.

As public awareness and concern over the environment began to intensify in the United States, indeed worldwide, Federal and State agencies began to request a much broader range of basic chemical and biological information than before in order to meet their regulatory responsibilities in public health and environmental management. The enactment of the Water Quality Act of 1965 (Public Law 89-234) focused increasing national attention on water-quality problems and the need to deal with them.

During the years 1957 to 1966, Branch officers were approached by knowledgeable scientists in the Federal sector with the inquiry, "We know that Geological Survey, Federal Water Quality Administration, State agencies and others have extensive water-resources information gathering programs. But what assurance is there that a catastrophic event such as an accidental or deliberate spill of an unknown toxic substance will be detected before reaching the intake of a metropolitan water supply?" Another major question was, "What technical design of a water-quality observational network will best serve the expanding requirements for data in the public sector?"

Concurrently the Branch addressed another major question. "What system of laboratory facilities could best serve the Division's requirements?" Capital costs of new, sophisticated equipment would be excessive for small, District-level laboratories. Additionally, more stringent requirements for timely water-quality information was needed to assist enforcement agencies in routine activities.

Luna B. Leopold developed a keen interest in water-quality activities. He shored up research essential to an understanding of the principles of basic water science more nearly comparable with that of other hydrologic fields, and he participated in and counseled field investigations of water quality, thus strengthening the Division's program support for water-quality activities.

The Honorable Stewart Udall, Secretary of the Interior from 1961 to 1968, maintained a lively personal interest in water-resources and water-quality activities of the Survey. On more than one occasion he referred to the Survey as his "technical arm," and he and members of his staff called on the Division for information and technical advice about the highly visible water-quality problems of the Potomac River and Rock Creek in the Nation's capital. (Author's note: Such direct and increasingly frequent contacts dismayed Director Nolan, who viewed those contacts, initiated by a political appointee, with considerable apprehension.)

On one occasion the Secretary invited Langbein and Durum to a luncheon discussion with a small group of Department planners. "The Potomac River and Rock Creek are paper tigers," he said. "We must clean up these historical streams in the Nation's capital as an example for the rest of the country. Rock Creek looks like a chocolate malted whenever it rains. How long will it take to do this job?"

"At least 10 years," was the reply. "Too long," said the Secretary, a political pragmatist, "I won't be around then."

### Headquarters Units, Functions, and People

In the organization and management responsibilities for programs and operations of the WRD as outlined in a June 1960 memorandum, the function of scheduling projects, including allocating project funds was assigned to Branch officers, subject to review and concurrence by the Division. Project execution was wholly a responsibility of Branch officers.

The organization chart of the QWB, Office of the Branch Chief, July 1, 1957 (fig. III–7), included the Research Section, Planning Section, Training Section, Reports Section, and Evaluation Section. The latter section was never formally activated; its functions were assumed by the Branch Chief's staff. The Training Section was not activated until 1961 when it was formed as the Career Development Section.

That organization remained essentially unchanged through 1961. By January 1, 1962, as transitional reorganization measures were taking place, the Planning Section had been dissolved and its duties assumed, at least in part, by Division staff. By January 1, 1963, training and career-development functions had been assumed by the Division. Thereafter, the Branch organization remained essentially intact through 1966.

S. Kenneth Love served as Branch Chief during the entire period. Warren W. Hastings (1957 to 1960) and Herbert A. Swenson (1961 to 1964) were the Assistant Branch Chiefs. The assistant's position was left vacant for remainder of the period.

Raymond B. Vice headed the Planning Section, newly formed in April 1957, and W. Finch White moved to the Research Section that year for a short time until selected as Branch Area Chief, ACA, in September. Paul C. Benedict was Chief, Research Section (1957 to 1962), then was reassigned to the Menlo Park office as Branch Area Chief, QWB. He was succeeded by Frank E. Clarke (1962 to 1963). Clarke was followed by Walton H. Durum, who was reassigned from Chief, Reports Section.

Principal QWB staff in Washington during all or parts of the period and their assignments are charted in table III–9.

Martha Keith was principal secretary to the Branch during the period and for many years prior to it. Kathleen T. Iseri, Fredericka S. Bowman, Hazel L. Smith, and Anita B. Flack were the principal editorial staff.

Blair F. Jones (1960 to 1964), Ivan K. Barnes (1960 to 1962), Naydean M. Baker (1960 to 1962), Roger G. Wolff (1962 to 1964), Donald W. Fisher (1963), and Harry Messinger (1963) served in the Research Section.

Charles N. Durfor (1961 to 1962), DeForrest E. Weaver (1961 to 1962), Billy P. Robinson (1961 to 1964), Faulkner B. Walling (1962), Arlo W. Gambell (1962 to 1964), and Raymond T. Kiser (1959) were assigned to the Reports Section during the indicated periods.

Keith V. Slack (1961 to 1964), John J. Musser (1966 and 1967), and James F. Blakey (1966 and 1967) were assigned to the office of the Branch Chief during the indicated periods. David W. Moody entered on duty in 1964 in the office of the Branch Chief.

Russell H. Langford, who had been assigned to the Director's staff in 1959, was transferred to the Office of the Branch Chief in April 1961 and served for several months as his special assistant on management and control functions before transferring to the field in August.

Russell M. McAvoy headed the Career Development Section during its brief existence; then, in 1962, that function was assumed by the Division.

Granville A. Billingsley was named to head the Automation and Data Management Section when it was created in 1963. In 1966, he was succeeded by Deforrest E. Weaver.

The Washington, D.C., laboratory, a special services and research unit, reported to the Branch Chief. It was headed by DeForrest E. Weaver from 1957 to 1960 and by Herman R. Feltz for the remainder of the period. Others assigned to the D.C. laboratory at time during the period included Hans J. Crump-Wiesner, Donald W. Fisher, C. Michael Hoffman, Robert K. Reaves, Shirley L. Rettig, Leonard Siu, Myron M. Smith, Jr., Gordon L. Stewart, Robert M. Teates, Donald A. Turney, and Theodore A. Wyerman.

Others who served in QWB headquarters included Virginia K. Blatcher, Elizabeth S. Burchill, Amos D. Faux-Burhans, Anita B. Flack, Frances M. Foltz, Margaret M. Merchant, Harriet P. Potter, Frances L. Rosenbaum, Hazel L. Smith, and Janet S. Wolly.

On July 1, 1957, the Headquarters staff consisted of 11 professional and 11 other employees not includ-

WATER RESOURCES DIVISION

OFFICE OF THE CHIEF

QUALITY OF WATER BRANCH

The Quality of Water Branch collects, compiles, and evaluates basic data relating to determination and appraisal of the chemical and physical quality of water resources and the relation of water quality and suspended-sediment load to various parts of the hydrologic cycle. Does research on and investigates chemical, physical, geochemical, radiochemical, and cultural factors that affect the chemical characteristics of water and sediment movement and deposition.

RESEARCH SECTION

Plans, directs, conducts, and reports on research on fundamental chemical and physical forces that affect the distribution and movement of solutes and sediments in water and on the application of new principles and procedures to the solution of research and investigative problems.

Investigates and develops techniques, equipment, and methods; maintains and operates research facilities, and maintains liaison with the other institutions and individual scientists doing similar or related work; advises field offices of the Branch on techniques, procedures, and standards in quality-of-water investigations.

PLANNING SECITON

Formulates plans and programs and recommends technical and administrative policies and measures to coordinate activities of the Branch.

Develops, in collaboration with other Sections and with Branch Area Chiefs, annual and long-range programs and determines priorities therein.

Reviews current overall programs and recommends adjustments; reviews progress and rates of expenditures in current programs and recommends appropriate adjustment in plans.

*TRAINING SECTION

Directs and coordinates training of Branch employees (activated as Career Development Section in 1961) in special schools, by correspondence courses, and on-the-job training.

Evaluates the qualifications and training of personnel of the Branch to facilitate their proper placement.

Coordinates recruitment activities of the Branch with those of the other Branches and of the Division.

*Activated as Career Development Section in 1961.

REPORTS SECTION

Coordinates preparation and reviews reports resulting from investigations by the Branch; develops methods and systems to improve the form and quality of reports.

Prepares reports on nationwide studies of quality of water, annual reports on quality of surface water, and reports on industrial utility of public water supplies.

*EVALUATION SECTION

Coordinates and integrates special studies concerned with the evaluation, interpretation, and correlation of chemical quality and sediment data with other factors.

Engages in review, coordination, and consultation, and offers advice to Branch field offices on techniques of study and procedures for evaluation and use of chemical-quality and sediment records; assists in the training of specialists in statistical, analytical, and interpretive techniques.

*Never formally activated; functions assumed by Branch Chief's staff.

Figure III-7. Organizational units and functions of Quality of Water Branch at Headquarters, July 1, 1957.

Table III–9. Quality of Water Branch Headquarters Staff, 1957–66

| | | |
|---|---|---|
| S. Kenneth Love | Chief | (1957–66) |
| Warren W. Hastings | Assistant Chief | (1957–60); |
| Herbert A. Swenson | QWB Chief's staff | (1959–60); |
| | Assistant Chief | (1961–64) |
| W. Finch White | Chief, Research Section | (1957); |
| | BAC, ACA | (1957–) |
| Raymond B. Vice | Chief, Chief Planning Section | (1957–60); |
| | QWB Chief's Staff | (1961–66) |
| Paul C. Benedict | Chief, Research Section | (1957–62); |
| | BAC, PCA | (1962–) |
| Walton H. Durum | Chief, Reports Section | (1957–60); |
| | QWB Chief's Staff | (1961–63); |
| | Chief, Research Section | (1964–66) |
| Frank E. Clarke | Research Section | (1962); |
| | Chief, Research Section | (1963) |
| Edwin W. Lohr | Reports Section | (1957–60, retired) |
| Frank H. Rainwater | Research Section | (1957); |
| | QWB Chief's staff | (1958–61) (resigned) |
| Leland L. Thatcher | Research Section | (1957) |
| Harold P. Guy | Research Section | (1957–62) |
| Sumner G. Heidel | Reports Section | (1959–60); |
| | Chief, Reports Section | (1961–62) |

ing the D.C. laboratory with 8 chemists and 5 support personnel (Ferguson, vol. V). By January 1, 1962, as reorganization began to take effect, the staff numbered 19 professionals and 11 other employees. On July 1, 1967, a much reduced staff of six professional and three secretaries carried out the Branch staff functions following reassignments of other staff members to units of the reorganized Water Resources Division.

### Offices of the Branch Area Chiefs, Functions, People, and Highlights

William L. Lamar was designated Branch Area Chief, PCA, Menlo Park, Calif., August 12, 1957, and served in that position until 1961. He was succeeded first by Hastings for a few months, then by Benedict. Tyrus B. Dover, from Oklahoma City, served as BAC, MCA, between December 1958 and September 1960, when he moved to St. Louis as Division Hydrologist. James W. Guerin succeeded him as BAC in 1961, with headquarters in St. Louis. Frank C. Ames was designated BAC, RMA, Denver, Colo., in 1957, and remained in that position until 1964 when he was succeeded by Dover. Walter Finch White, Jr., served as BAC, ACA, for the period after September 1957.

With the four QWB Area Chiefs in place and functioning by 1957 or early 1958, administrative and technical direction of QWB programs in each area began to take shape. Although the scope of activities in each area varied widely, the BAC was a key individual in counseling program managers at a time when projects were growing rapidly both in size and technical complexity.

As the Division's research program grew, guidelines for administering, operating, and reporting research activities early in the period were made available to QWB District supervisors and staff officials (QWB memorandum, November 18, 1957). The activation of the Research Section, in July 1957, as a staff unit within the Office of the Branch Chief provided the necessary coordination and review of research activities carried on independently by the Branch and jointly with other Branches, the Division, and other governmental agencies. Research projects normally were under the administative supervision of the BAC for those projects that were Branch or multi-Branch in scope in order to allow the project chiefs to devote their efforts mainly to technical concerns rather than administrative details.

The QWB Area Chiefs and the Headquarters staffs of the Branch and Division met April 29 to May 1, 1958, to review long-range programs and technical and administative problems. The participants identified improved planning procedures applicable to future activities of the Branch (WRD memorandum, May 15, 1958). A similar meeting was held on April 1 to 2, 1959, to discuss program objectives in relation to Division policies and goals (WRD memorandum, May 15, 1959).

QWB memorandum 60.22 (December 16, 1959) outlined the responsibilities of the BAC as a key individual in the reports program, especially project studies:

> He will develop sound technical reporting simply but effectively stated with attention being given to realistic time for preparation of papers and reports. He will maintain a control system for assuring adherence to schedules for completion and transmittal of reports. He has responsibility for the general review of reports originating in the District and project offices, consisting of screening reports from the standpoint of their scientific soundness and appraising of the subject material consistent with the objectives or program prior to the transmittal of the reports to Washington.

Branch personnel involved in special projects or research who reported to their Branch Area Chiefs until the 1964 reorganization were:

In ACA.—The research unit during 1959 to 1962 was under the leadership of Leland L. Thatcher. Others assigned to the unit at times included Joseph Haffty, C. Michael Hoffman, Blair F. Jones, George B. Magin, Jr., and Shirley L. Rettig.

In RMA.—The largest area staff in the Branch was in Denver. The professional members of that staff who served during most of the period 1957 to 1966 include Clifford G. Angelo, Arthur W. Beetem, Marvin J. Fishman, Victor J. Janzer, Jesse O. Johnson, Billy P. Robinson, Samuel J. Rucker IV, and Marvin W. Skougstad. Others who served included Franklin B. Barker, Paul R. Barnett, Kenneth W. Edwards, David B. Grove, Joseph Haffty, John D. Hem, C. Albert Horr, Everett A. Jenne, Vance C. Kennedy, Edward C. Mallory, Eugene T. Oborn, Roger Vernon, James S. Wahlberg, Cooper H. Wayman, and Richard A. Wilson.

A unit at Fort Collins, Colo., conducted laboratory-flume research on sediment-flow mechanics under the leadership of Daryl B. Simons for most of the period. Others who served on the research project include Maurice L. Albertson, Donald L. Bender, A. Ray Chamberlain, Fred F. Chang, Harold P. Guy, William L. Haushild, David W. Hubbell, Carl F. Nordin, and William W. Sayre. (See Part IV, "Geomorphic and Sediment Processes.")

In PCA.—QWB professional staff in PCA during the period included Donald E. Donaldson, Donald F. Goerlitz, John D. Hem, Charles F. Howard, William L. Lamar, Wilfred L. Polzer, Charles E. Roberson, Stanley M. Rogers, Robert Schoen, John P. Schuch, and H. Collins Whitehead.

After the 1964 Division reorganization, the above groups became a part of Division-level area-research staffs. Water-quality research continued to grow through the remainder of the period. Area research staffs (from the January 1, 1966, Organization and Personnel Directory) are listed in table III–3 ("Staff of WRD Headquarters, Area Offices, and Units").

### Program Coordination and Support

The Branch identified the following water problems as identified in QWB memorandum, September 18, 1959:

1. Deterioration of water resources through contamination by inorganic and organic solutes and sediments from the natural and cultural environment.
2. Restrictions in use as imposed by minor elements and wastes (radioactive and nonradioactive).
3. Effects of evaporation and storage on water quality.
4. Reduction in storage capacity in reservoirs from sediment accumulation.
5. Deterioration of water in streams and aquifers from saltwater encroachment.
6. Changes in hydraulic characteristics and capacity of channels resulting from degradation or aggradation.
7. Effects of solutes and sediments on artificial recharge or underground storage.
8. Effects of solutes and sediments on aquatic life.

From 1957 to 1962, Branch funds nearly doubled from about \$2 million to \$3.6 million and increased to about \$5 million in 1965 (table III–10), then decreased to about \$2 million by 1966 as funds for water-quality activities began to be allocated directly to Division-level projects.

From 1957 to 1960, funds for collecting chemical and sediment data decreased from about 68 to 51 percent of the total and remained near that level through 1964. Funds for areal hydrologic studies increased from 18 to 32 percent of the total during the middle of the period, then decreased to just over 20 percent. Research funds remained steady at 14 to 17 percent of the total during the early years of this period, then increased more than 10 percent by 1963 and 1964 (table III–11).

Funds for fluvial-sediment studies increased from $800,000 to $1,700,000 during fiscal years 1957 to 1967 (table III–12) and represented a substantial part of the total Branch program.

Table III–10. Quality of Water Branch funds, fiscal years 1957–65

[In thousands of dollars]

| Fiscal year | Federal program | Federal-State | OFA | Other branches and miscellaneous | Administration | Total |
|---|---|---|---|---|---|---|
| 1957 | 601 | 774 | 524 | 83 | | 1,982 |
| 1958 | 815 | 869 | 668 | | | 2,352 |
| 1959 | 844 | 925 | 656 | | | 2,425 |
| 1960 | 875 | 1,223 | 564 | | | 2,662 |
| 1961 | 994 | 1,157 | 696 | 97 | | 2,944 |
| 1962 | 1,089 | 1,607 | 905 | | | 3,601 |
| 1963 | 1,129 | 1,759 | 1,018 | 116 | 313 | 4,335 |
| 1964 | 936 | 2,319 | 1,163 | 179 | 290 | 4,887 |
| 1965 | 976 | 2,095 | 1,197 | 498 | 227 | 4,993 |

Note: Funding after 1965 not allocated to the Branches for most field programs. Source: From QWB files, tabulation dated September 13, 1967. Amounts differ moderately from Division tabulation of Branch obligations dated April 2, 1964, for fiscal years 1957 to 1963.

Table III–11. Percentage of annual Branch funds expended for principal program activities

| Fiscal year | Program activities | | |
|---|---|---|---|
| | Water records | Areal hydrology | Research |
| 1957 | 68 | 18 | 14 |
| 1958 | 67 | 21 | 12 |
| 1959 | 61 | 24 | 15 |
| 1960 | 51 | 32 | 17 |
| 1961 | -- | -- | -- |
| 1962 | -- | -- | -- |
| 1963 | 49 | 22 | 29 |
| 1964 | 51 | 24 | 25 |

Table III–12. Annual funds available for fluvial-sediment investigations

[In thousands of dollars]

| Fiscal year | Total | Federal | Federal-State | Other |
|---|---|---|---|---|
| 1957 | 800 | 300 | 150 | 350 |
| 1958 | 1,050 | 400 | 200 | 450 |
| 1959 | 1,050 | 450 | 250 | 350 |
| 1960 | 1,100 | 500 | 250 | 350 |
| 1961 | 1,150 | 500 | 300 | 350 |
| 1966 | 1,700 | 500 | 650 | 550 |
| 1967 | 1,700 | 450 | 700 | 550 |

Source: Program-analysis file from Jerry C. Stephens, April 7, 1967. Numbers rounded to nearest $50,000; fund data not available for 1962-65.

The number of water-quality stations operated for collecting basic data on chemical and physical characteristics of streams, lakes, and reservoirs in the United States and its territories during the period 1957 to 1966 are listed in table III–13.

Table III–13. Number of water-quality stations in operation, 1957–66

[X, Figures not available. (See Part X, "District Activities" for State-level station information.]

| Year | Total | Chemical | Sediment | Temperature |
|---|---|---|---|---|
| 1957 | 1,060 | X | 217 | X |
| 1958 | 1,090 | X | 220 | 200 |
| 1959 | 1,100 | X | X | X |
| 1960 | 1,120 | X | X | X |
| 1961 | 1,150 | X | X | X |
| 1962 | 1,236 | X | X | X |
| 1963 | 1,367 | 942 | 307 | 1,133 |
| 1964 | 1,497 | 1,003 | 431 | 1,133 |
| 1965 | 1,674 | 1,116 | 477 | 1,360 |
| 1966 | 1,958 | 1,353 | 502 | 1,623 |

In 1957, the Branch performed about $0.5 million in work for other Federal agencies (table III–10) of which the AEC was the largest OFA source of funds. The OFA funding reached about $1.2 million by 1965.

The Branch was particularly effective in the early work with Federal Water Pollution Control Administration (FWPCA), which joined the DOI in May 1966 and later became the EPA, in implementing the National Water-Quality Surveillance System (NWQSS) by means of a data-collection program financed through transfer funds from FWPCA (and later EPA) of about $0.5 million annually.

The Federal Committee on Pest Control was established in 1964 by an agreement among the Secretaries of Defense, the Interior, Agriculture, and Health, Education, and Welfare to coordinate all Federal efforts in pest control and studies of the effects of pesticides. Subcommittees were established to give special attention to research, pesticide monitoring of the environment, public information, review of Federal pest-control measures, and safety in pesticide marketing and disposal. A representative of the QWB in Washington, D.C., participated in committee work.

### Field Offices—Configuration and Functions

The QWB maintained 16 district offices and 22 associated laboratories during all or part of the period 1957 to 1966. These offices were concerned primarily with investigational programs in cooperation with State and local agencies and conducted or supported QWB activities in 35 States (in 1961). The program included collecting records, preparing interpretive areal reports, and performing limited research. Table III–14 lists the locations and the names of those in charge.

Most of the small laboratories operated on annual budgets of approximately $50,000 to $75,000 during the years 1957 to 1966. Generally the budget increased two- to sixfold during the lifetime of most laboratories as new personnel and sophisticated equipment were added.

Earlier methods of analysis were gradually supplanted by use of more sophisticated equipment through the 1950's and 1960's. In the 1950's a Beckman Model DU or equivalent spectrophotometer for flame measurement of sodium and potassium was common to most laboratories. This was followed by the addition of the Beckman Model B spectrophotometer for measurements such as iron, nitrate, boron, and manganese. By 1964, the atomic absorption spectrophotometer (PE Model 303, or equivalent) for measurement of minor elements was added to the larger laboratories. A second atomic absorption spectrometer with refinements for measurement of calcium and magnesium was purchased by a few laboratories. By 1966, acquisition of more advanced equipment, such as the "Autoanalyzer," infrared spectrophotometer, and carbon analyzer, had begun to enhance productivity, accuracy, and diversity of laboratory analytical services.

As late as the 1950's, a good production rate for a well-trained chemist was about 240 adjusted complete inorganic analyses, annually. Benefiting from advanced analytical and automated equipment, the individual analyst's production rate grew severalfold in the next few years. Fortunately, production efficiency of analytical procedures improved dramatically as the demand for water-quality increased similarly. The number of chemical quality-of-water analyses performed in 1946, in six laboratory facilities, was about 7,000 adjusted complete analyses. By 1960, total output had increased fourfold to more than 30,000 and continued to increase.

The Division participated directly in the technical phases of the Federal Interagency Sedimentation Project at the St. Anthony Falls Hydraulic Laboratory, University of Minnesota, Minneapolis, Minn. Under the auspices of the Interagency Committee and the supervision of Byrnon C. Colby, 14 numbered reports and "Lettered Reports," A through T were completed and published by the early 1960's on the design and development of field equipment for sampling

Table III–14. Quality of Water Branch laboratories and leadership, 1957–66

| Location | Supervisor | Position | Period |
|---|---|---|---|
| Albany, N.Y. | F.H. Pauszek | District Chemist* | All |
| Albuquerque, N. Mex. | J.M. Stow | District Chemist | to 1964 |
| | J.K. Culbertson | Acting Dist. Chem. | 1964 |
| | R.G. Schupp | District Chemist* | 1964–66 |
| Anchorage, Alaska | F.B. Walling | District Chemist | to 1961 |
| | R.G. Shupp | District Chemist* | 1962–64 |
| | C. G. Angelo | Chemist | 1966 |
| Austin, Texas | B. Irelan | District Chemist | to 1961 |
| | C.H. Hembree | District Geol. | 1961–65 |
| | L.S. Hughes | Chemist | 1965– |
| Baton Rouge, La. | S.F. Kapustka | Chemist-in-Charge | 1957–61 |
| | do. | District Chemist | 1961–64 |
| | R.L. McAvoy | District Chemist* | 1964– |
| Columbus, Ohio | G.W. Whetstone | District Chemist | to 1964 |
| | C.R. Collier | District Chemist | 1964–65 |
| | R.J. Pickering | Hydrologist* | 1965– |
| Harrisburg, Pa. | J.K. Culbertson | Engr.-in-Charge | to 1957 |
| (Sediment lab) | J.W. Wark | Engr.-in-Charge | 1957–60 |
| | J.R. George | Geologist-in-Charge | 1960– |
| Philadelphia, Pa. | N.H. Beamer | District Chemist | All |
| | D. McCartney | Chemist | 1960– |
| Lincoln, Nebr. | D.M. Culbertson | District Engr* | 1957–65 |
| Chemical lab | L.R. Petri | Chemist | to 1959 |
| | S.C. Downs | Chemist | 1960– |
| Sediment lab | J.C. Mundorff | Soil Scientist* | to 1964 |
| Little Rock, Ark. | M.E. Schroeder | District Chemist | to 1961 |
| | J.H. Hubble | District Chemist* | 1961– |
| Ocala, Fla. | J.W. Geurin | District Chemist | to 1961 |
| | K.A. MacKichan | District Engineer | 1962–65 |
| | B.F. Joyner | Chemist-in-Charge* | 1965– |
| Oklahoma City, Okla. | T.B. Dover | District Chemist | to 1958 |
| | R.P. Orth | District Chemist | 1959– |
| Portland, Oreg. | H.A. Swenson | District Chemist | to 1958 |
| | L.B. Laird | District Chemist | 1958–64 |
| | G.L. Bodhaine | District Engineer | 1964– |
| Raleigh, N.C. | G.A. Billingsley | District Chemist | to 1964 |
| | H.B. Wilder | Chemist | 1964– |
| Sacramento, Calif. | E. Brown | District Chemist | to 1964 |
| | S.F. Kapustka | District Chemist | 1964–65 |
| | G. Porterfield | Engineer* | 1965– |
| Salt Lake City, Utah | J.G. Connor | District Chemist | to 1961 |
| | R.H. Langford | District Chemist* | 1961– |
| San Juan, P.R. | J.R. Crooks | Chemist-in-Charge | to 1962 |
| | J.J. Murphy | Chemist* | 1962– |
| Tacoma, Wash. | E.B. Welch | Biologist | 1964–65 |
| | N. Leibbrand | Chemist | 1965– |
| Tuscaloosa, Ala. | J.R. Averett | Chemist-in-Charge* | 1964– |
| Washington, D.C. | D.E. Weaver | Chemist-in-Charge | to 1960 |
| | H.R. Feltz | Chemist-in-Charge | 1960– |
| Worland, Wyo. | T.F. Hanly | Engr.-in-Charge | to 1958 |
| | do. | District Engineer | 1958– |
| Yuma, Ariz. | B.Irelan | Chemist | 1961– |

* Title terminated with activation of Division-level District.

suspended sediment and bed material, methods for making particle-size analysis, and field procedures for determining fluvial sediment discharge (Report 14, 1963, Determination of fluvial sediment discharge). (See also Part VIII, "Subcommittee on Sedimentation.")

In addition to a principal laboratory, some operations like the Missouri River Basin program at Lincoln, Nebr., required separate field units (Norton, Kans.; Dickinson, N. Dak.; and Worland, Wyo.) for handling a large volume of sediment analysis during the peak years of the program.

Highly specialized analytical equipment for pesticide and other organic analyses by gas chromatograph were centered in the Washington, D.C., and Austin, Tex., laboratories, and the Menlo Park, Calif., and Denver, Colo., research centers during 1964 to 1967.

Aquatic biological and microbiological studies, historically a small but significant part of some District laboratories, began to tool up late in the period as the broad scope of environmental concerns about natural resources unfolded and the impact was felt in the Division programs. Laboratories at Albany, N.Y., Harrisburg, Pa., Washington, D.C., and Ocala, Fla., began small-volume biochemical and biological analysis principally through the Albany laboratory leadership and facilities.

The first field-station recording of multiparameter water-quality characteristics began when a water-quality monitor was installed in the Delaware River estuary at Philadelphia in 1959 and 1960. The Philadelphia QWB District tested and made innovative improvements to monitoring equipment for the next several years in cooperation with the City of Philadelphia and equipment manufacturers. In November 1962, a water-quality monitor was installed on the Cuyahoga River at Center Street in Cleveland in cooperation with the Ohio Department of Health. By 1966, the Division reported that the digital recording of water-quality parameters was a link in the automated data-collecting and processing system of the Survey.

In summary, the significant increases in analytical productivity during the period clearly reflect the rapid advancement instrumentation technology and the dramatic increase in demand for water-quality information. These factors, coupled with the increasing sophistication and cost of instrumentation, would later lead to consolidation of field laboratories into a central laboratory system.

## Quality Control

As advances in instrumentation accrued in the 1950's, procedures were standardized in the District laboratories through updated manuals and specifically, WSP 1454 (Rainwater and Thatcher, 1960), "Methods for the collection and analysis of water samples."

Beginning in 1962, the Methods Development Unit at Denver, directed by Marvin Skougstad, undertook a Standard Reference Program in which prepared samples of a single element were analyzed by participating laboratories. The results and performance of each laboratory in comparison with the mean values obtained by all laboratories were reported. A competitive edge developed from the comparative report as District supervisors could expect a congratulatory letter from Branch headquarters for excellent results or something less complimentary when results were unsatisfactory.

## Conferences and Training

New program thrusts in the late 1950's conveyed the need for broad technical training in hydrology to supplement that given new employees in the District offices. Love, Hastings, and other members of the staff gave much effort to this task. The first QWB Technical Training School convened at Charlottesville, Va., May 21–26, 1956, with 29 students and faculty in attendance. Participants enthusiastically endorsed the value of the training which was repeated at Raleigh, N.C., June 1958 and Austin, Texas, January 1960. (See Part VI, "Training.")

A symposium on water-analysis methods in Philadelphia, Pa., October 11–13, 1966, included papers and discussion on operation and management of the laboratories. Discussions on new advances in technology included the use of the atomic absorption spectrophotometer with digital readout attachment for many major and minor elements and by extraction concentration techniques, for the detection of as little as 1 microgram per liter (μg/L) of certain elements. This was at least one order of magnitude lower than wet chemical procedures. Attention was directed, as it had been at a Division Conference on Nitrogen Chemistry held a year earlier in Menlo Park, to research on the effects of land use on nutrients in streams and lakes. The need for more extensive use of mobile laboratories and on-the-spot analysis for accurate nutrient determinations was affirmed.

## Records Processing and Storage

Four records-processing centers were established in 1962 to prepare quality of surface-water basic records for publication. These centers at Columbus, Ohio, Lincoln, Nebr., Raleigh, N.C., and Sacramento, Calif., were assigned organizationally to the local

QWB District supervisor. Each District reimbursed the appropriate center for data processed. Effective August 3, 1965, the four centers became organizational units under the local WRD District supervisors.

By the close of the period, all chemical-quality data were stored in the Division's Water Data Storage and Retrieval System (WATSTORE). All data for the Leopold years were published annually in Water-Supply Papers.

### Major Studies and Investigations

Extensive quality-of-water studies were conducted during 1957 to 1966, involving specific-purpose data networks for chemical quality and sediment, basin studies where water-quality problems were predominant, and research and areal studies in sedimentation and radiohydrology. The major field and research projects are described in Part IV and other field studies, in Part X.

Intensive studies of the sediment transported by the Rio Grande and its major tributaries provided information for planning of Federal projects in that basin. Sediment transport and chemical-quality studies continued in the Pecos River Basin to meet the requirements of the Pecos River Compact. A sediment-index station program was developed through the Federal Interagency River Basin Committee involving the collection of sediment-discharge records over long periods at sites throughout the United States. An observation network on western streams was operated to determine changes in chemical quality over long periods as a result of return flows from irrigation projects.

Notable District-level activities during the period were investigations of oil-field brine pollution in the Ouachita River Basin, Ark.; inorganic pollutants in streams in the Central Valley of California, and along the Suwanee and Withlacoochee Rivers in Florida; sediment-load data on major streams of Kentucky; evaluation of the ground- and surface-water quality of northwest Minnesota; chemical characteristics of ground and surface waters of New York as part of a program to evaluate the industrial utility of the State's water resources; special studies in the Little Miami River Basin and the Ohio River, Ohio, along the North Canadian River and Salt Fork of the Arkansas River in Oklahoma, and the lower Delaware River in Pennsylvania and sedimentation studies in Black Earth Creek and elsewhere in Wisconsin as part of hydrologic studies of a watershed-improvement area.

The Florida District, active in the Survey's nationwide program to evaluate the effects of underground waste disposal on the Nation's subsurface environment, investigated the hydrochemical effects of injecting wastes into a limestone aquifer near Pensacola, Fla.

Foreseeing the time when the increasing demands for Colorado River water might cause the total demand to exceed the available supply, the Division, in 1960, undertook a regional approach to a comprehensive study of the water resources of the Lower Colorado River-Salton Sea areas. (See Part IV, "Lower Colorado River Project.") The project, started July 1, 1960, followed the earlier investigation of the Upper Colorado River, also described in Part IV.

By 1959, sedimentation research had broadened to include the relationship of sediment transport to roughness and shape of stream channels, bedload discharge of sediment, development of automatic equipment for measuring sediment discharge of streams, and improved techniques and standards for analyzing and interpreting sediment data and records. Fluvial sediment experimental studies were done collaboratively with Colorado State University, Fort Collins, Colo. Equipment development, sampling methods, and other studies were centered at the St. Anthony Falls Hydraulic Laboratory, University of Minnesota, Minn., jointly with the Federal Inter-Agency Committee on Sedimentation. (See Part IV, "Geomorphic and Sediment Processes" and Part VIII, "Subcommittee on Sedimentation.")

Through arrangements made by Leopold, Dr. R.H. Bagnold, Civil Engineer, England, and other scientists offered constructive suggestions for improving the scope of the Division's sediment-research program. Dr. Bagnold met with Division participants February 5–11, 1958. Discussions ranged widely from the relation between transport rate and streambed stress to grain velocity, fall velocity, drag coefficient, and size-analysis plots.

By early 1958, Leland L. Thatcher was operating the tritium laboratory at the Old Post Office Building in Washington, D.C., and plans for future work were reviewed with other representatives of WRD, the Geologic Division, and the Weather Bureau regarding field projects, research at Socorro, N. Mex., and deuterium studies on Lake Hefner in Oklahoma. The program in 1959 included the analysis of the tritium content of water and the study of deuterium in water to determine the extent to which it may be helpful in hydrologic investigations. The work on deuterium was in close cooperation with the Geologic Division.

By October 1958, comprehensive investigation of the natural occurrence of radioactivity and radioelements in United States waters had been in progress for about 6 years. Franklin B. Barker (QWB) and Robert C. Scott (GWB) had coordinated their planning and operations closely. The trend of the program was toward increased attention to the geochemical interrelationships of radioelements and hydrologic environments.

### Other Program Highlights

Atlantic Coast Area.—Research and project activities in the ACA were carried out by a sizable staff during the period 1957 to 1966. The main thrusts in research activities were chemical reactions and exchange phenomena and solute-mineral relations. In the early and middle parts of the period, projects included methods for determining the extent of calcium carbonate saturation in ground water, described by Back (WSP 1535–D, 1961) and Hem (WSP 1459–B, 1960); field measurement of alkalinity and pH, Barnes (WSP 1535–H, 1964); and significant new developments in techniques for study of solution equilibrium, including equipment for field measurement of redox potential in ground water, utilized by Back and Barnes (PP 498–C, 1962).

"Quantitative determination of tritium in natural waters," C.M. Hoffman and G.L. Stewart (WSP 1696–D, 1966) was one of several chapters published under the general title "Radiochemical analysis of waters." Thatcher (Bulletin of the International Association of Scientific Hydrology, June 1962, p. 48–58) concluded from studies of continental United States begun in 1958 that tritium in rainfall was maximum in the north-central part of the Nation and minimum in coastal areas.

Other key papers of national interest published during the period included "Stream composition of conterminous United States," F.H. Rainwater (Hydrologic Atlas 61, 1962), "Public water supplies of the 100 largest cities in the United States," C.N. Durfer and Edith Becker (WSP 1812, 1964), and "Chemical composition of rainfall, eastern North Carolina and southeastern Virginia," A.W. Gambell and D.W. Fisher (WSP 1535–K, 1966).

The 1960's saw the emergence of hydrologic effects of urban growth and a response by staff in ACA under topic: "Sediment movement in an area of suburban highway construction, Scott Run Basin, Fairfax County, Va., 1961–64"; by R.B. Vice, H.P. Guy, and G.E. Ferguson (WSP 1591–E, 1969).

Mid-Continent Area.—Coordination of District program activities was the main effort of the small QWB Area Chief's staff during the period. Staff of QWB studied the effects of strip mining in the Beaver Creek watershed in McCreary County, Ky. Results of their studies were published in 1970 as Professional Paper 427–C, "Influences of strip mining in parts of Beaver Creek basin, Kentucky, 1955–1966," edited by C.R. Collier, R.J. Pickering, and J.J. Musser.

Skougstad and Horr investigated the occurrence of strontium in natural water and reported the results in Circular 420 (1960). Relatively large amounts of strontium were found in natural water in Champaign County, Ohio, by Feulner and Hubble (Economic Geology, v. 55, Jan.-Feb., 1960, p. 176-186).

Rocky Mountain Area.—In 1957, research relevant to the area and in the development of laboratory and field procedures for Division-wide use were underway at Denver headquarters. A state-of-the-art research facility, including a "TRIGA" reactor for experimental studies in radiochemistry, was built during the mid-1960's to house the shared activities of the Water Resources and Geologic Divisions.

Publications of Denver-based research studies included "Chemical degradation on opposite flanks of the Wind River Range, Wyo.," by C.H. Hembree and F.H. Rainwater (WSP 1535–E, 1961) and "Solutes in small streams draining single-rock types, Sangre de Cristo Range, N. Mex.," by J.P. Miller, WSP 1535-F, 1966.

John D. Hem's report, "Study and interpretation of the chemical characteristics of natural water" (WSP 1473, 1959), has been widely used as a technical and classroom reference.

Other noteworthy reports included: "Chemical equilibria and rates of manganese oxidation," J.D. Hem (WSP 1667–A, 1963); "Some effects of the larger types of aquatic vegetation on iron content of water," E.T. Oborn and J.D. Hem, WSP 1459–I, 1962; "Determination of beta activity in water," F.B. Barker and B.R. Robinson, WSP 1696-A, 1963; and "Determination of radium in water," F.B. Barker and J.O. Johnson, WSP 1696–B, 1964.

Pacific Coast Area.—Research activities were relatively few in the years 1957 to 1960, then expanded in 1961 to 1963 with the growth of western problems of organic compounds and pesticides in water. Reports on research activities in the PCA included "Organic acids in naturally colored surface waters," W.L. Lamar and D.F. Goerlitz WSP 1817–A, 1966, and "Identification and measurement of chlorinated organic pesticides in water by electron-capture gas chromatography," W.L. Lamar, D.F. Goerlitz, and L.M. Law (WSP 1817–B, 1965).

Activities further broadened beginning in 1964 when Hem's studies of hydrosolic metals moved from Denver to Menlo Park and solute-solid and soil-relations studies were expanded with the transfer of Barnes and others to Menlo Park.

Slack and others began an orderly identification of biological substances in water and developed field and laboratory techniques for use in District programs.

## General Hydrology Branch

*By* Arvi O. Waananen *and* reviewed *by* Wilbur Simons, Garald G. Parker, Sr., *and* Richard F. Hadley

The General Hydrology Branch (GHB) was established in May 1956 as a part of the 1956 Division reorganization and included transfer of most of the functions, activities, and personnel from the former Technical Coordination Branch (TCB).

The GHB continued significant activities in a variety of research and exploratory studies, hydrologic and geomorphic, initiated during or before the preceding decade. Though the staff was small, it carried forward the former TCB responsibility to "...explore and develop ways by which the Division policy could better adapt to new demands that went beyond the traditional roles of the three operating branches, and to represent the Division in interagency relations on technical matters considering the Division as a whole" (Ferguson's Volume V, p. 16). The staff was composed of scientists from several disciplines, selected for their interest, creative abilities, and qualifications for research and studies related to water use, water loss, industrial water requirements, and land-use and land-water problems, particularly as many involved interdisciplinary investigations.

In the development of the GHB program, several individuals made very substantial contributions relating to the scope, objectives, and needs for investigations. Two had been members of the predecessor TCB. Walter B. Langbein, who was reassigned in 1956 to the Office of the Division Chief, had been instrumental, for example, in the initiation of the Water Resources Review and the "Handbook for Hydrologists" series, development of the programs for water-loss investigations, inter-Branch and Division research aspects of the Soil and Moisture Conservation (S&MC) program, and other nonroutine studies. Langbein's extensive activities and contributions had a tremendous impact on the nature and extent of the GHB programs after 1956. His helpful counsel and guidance continued throughout this period of history.

Luna B. Leopold, similarly, had pressed for greater emphasis on research and interpretive hydrologic studies, as well as the career development and training of young professionals. The TCB/GHB structure afforded flexibility in development of special project studies and research. Thus the emphasis on basic research was incorporated in the GHB "charter." Leopold's interests were reflected also in his promotion and support of graduate-student research in topics beneficial to the work of the Division. His ideas and objectives contributed markedly to the broadening of research on subjects such as the morphology of streams, land-water relations, and vegetative influences throughout this period.

The mission and organizational structure of the GHB, and the roles and duties of the Office of the Branch Chief and the four Branch-level staff sections, are defined in figure III-8.

The GHB functions and inter-Branch relationships were further defined in Leopold's January 16, 1958, memorandum "Functions of the General Hydrology Branch and their relation to the work of other Branches" in which he stated:

> The General Hydrology Branch was created specifically to make special types of studies which otherwise would receive inadequate attention, and to take the lead in certain types of work in which all the Branches have essential equality of interest but for which no single Branch is exclusively or preponderantly responsible....

### Headquarters Organization

Charles C. McDonald was appointed Chief, GHB, with the creation of the Branch in May 1956. His principal assistant was Arvi O. Waananen. Lorena H. Blankemeyer, as secretary, was succeeded in 1958 by Helen S. Baxter.

In addition to supervising Branch operations, McDonald also assisted Carl G. Paulsen, Chief Hydraulic Engineer, with international engineering board studies of boundary water problems of the United States and Canada for the International Joint Commission (IJC). After Paulsen retired in April 1957, these responsibilities were transferred to the Office of the Assistant Secretary, Water and Power, DOI. McDonald continued to represent the Division and the Survey in liaison with Departmental representatives on the IJC studies and other interagency activities.

In July 1960, McDonald was transferred to the GWB, and moved to Yuma, Ariz., as project chief for the Lower Colorado River project (see Part IV, "Lower Colorado River Project").

Waananen carried out numerous technical and administrative functions including work in connection with the IJC and stream-gaging requirements for FPC permits and licenses. In August 1958, he was transferred to project studies in Menlo Park, Calif.

WATER RESOURCES DIVISION

OFFICE OF THE CHIEF

BRANCH OF GENERAL HYDROLOGY

The Branch of General Hydrology does basic hydrologic research, especially in the interrelation between climate, topography, vegetation, and soils, on the water supply. It studies applications of data and of results of research to specific water problems, and investigates broad and fundamental problems of hydrology. Studies include water use and water requirements, evapotranspiration, infiltration, erosion, basic mechanisms of sediment transport, and the effects of human activities on the water balance. Maintains an equipment-development laboratory for the design and testing of specialized scientific instruments and equipment required for the Division.

RESEARCH SECTION

Guides and assists the planning and execution of research activities of the Branch, inspects and promotes progress on research projects, and maintains liaison with and between other research sections in the Division.

Maintains liaison with the National Hydraulic Laboratory and hydrologic research organizations for the purposes of coordinating or negotiating hydraulic or hydrologic research. Investigates and appraises the applicability of new hydrologic techniques and methods to Branch operations.

PLANS AND TRAINING SECTION

Establishes and evaluates criteria for determining the type and scope of investigations that will be undertaken, and for determining the program under which such investigations will be made. Develops and maintains short- and long-range plans and programs, and coordinates these with the plans and programs of other branches. Prepares budgets and justifications for projects and programs.

Establishes qualifications criteria for employment and promotion of personnel. Develops and directs Branch training courses.

REPORTS SECTION

Coordinates, assists in the preparation of, and provides technical review of scientific reports prepared by the Branch; edits reports prepared for outside publication.

Coordinates, compiles, edits, and releases through the Division Publications Officer reports of a Divisional nature, such as the Water Resources Review and Water Resources Bulletin.

Prepares catalogs and abstracts of reports, papers, articles, and news items about general hydrology; prepares reference lists and bibliographies.

HYDROLOGIC STUDIES SECTION

Guides and assists the Branch Chief and the operating offices in the planning and execution of the Branch program. Advises on operational, analytical, and interpretive functions such as the soil-moisture conservation investigations, appraisals of basin water resources, studies of the effects of climate, vegetation, and other factors of water supply, studies of the sediment budgets of basins, and other hydrologic analyses performed by Branch personnel.

Coordinates and assists in the collection, compilation, and analysis of data on water use and water resources of industrial areas, and in the preparation of reports thereon.

Figure III-8. Organizational units and functions of General Hydrology Branch at Headquarters, July 1, 1957.

Subsequently the GHB activities relating to IJC gaging stations and FPC stream-gaging requirements were assigned to the SWB.

Garald G. Parker, Sr., appointed Assistant Chief, GHB, in December 1958, served as Acting Branch Chief in August and September 1960 after McDonald's transfer to the field. In late September 1960, Parker was transferred to Denver, Colo., as Chief, Soil and Moisture Conservation (S&MC) program.

In 1959, Hallard B. Kinnison was transferred from the Division's Planning Section to the Office of the Branch Chief, GHB. After late 1960, he served as assistant to the Branch Chief until his transfer to the SWB District, Menlo Park, Calif., in 1961.

The work at Headquarters was carried out by three sections—Research, Hydrologic Studies, and Reports. The Plans and Training Section was never activated.

The Research Section was established with Ernest L. Hendricks as Chief, assisted by Ethel W. Coffay, hydraulic engineer, Eva M. Patton, illustrator, and Mary Jane Burks, secretary. The Section represented the GHB in inter-Branch planning of research activities, and provided appropriate program coordination, guidance and counsel to research projects in the field relating to hydrologic techniques and methods, water loss, land-use studies, and others. In early 1960, Hendricks was transferred to the SWB as Chief of the Branch. Concurrently the Research Section, GHB, was dissolved and the personnel reassigned to the Office of the Branch Chief.

The Hydrologic Studies Section was organized with Kenneth A. MacKichan as Chief, assisted by Orville D. Mussey, John C. Kammerer, Charles N. Durfor, Louis E. Otts, George B. Magin, Jr., Lois E. Randall, and Alta B. Lane. Major activities included studies of water resources and water use in key industrial areas and compilation of data on water use in the United States at 5-year intervals (see Part IV, "Water-use Studies"). MacKichan transferred to the QWB in 1961 as District Engineer, QWB, in Ocala, Fla. In 1962, functions of the Hydrologic Studies Section were assigned to the QWB (Nace Memorandum, March 5, 1962), and consolidated with related functions in the QWB. Section personnel remaining after transfer of Kammerer, Durfor, and Magin to other assignments, and Mussey's retirement in 1961, were reassigned to other Division units.

The Technical Reports Section was organized with William S. Eisenlohr, Jr. as Chief, assisted by Lois M. Caston and Lois Fleshmon, editorial clerks, Elsie Phillips, secretary, and several assistants. Primary responsibilities of the Section included reviewing and processing of reports produced at headquarters and in the field, and particularly preparing the monthly Water Resources Review and the WRD Bulletin. Eisenlohr continued as Chief, Reports Section, until he moved to Denver, Colo., in 1961 for studies of the hydrology of prairie potholes (see Part IV, "Prairie Pothole Project"). Later, the Reports Section was dissolved and its functions and personnel were assigned to the Office of the Branch Chief.

In addition to the staff sections, a project office was established at the GHB headquarters. Personnel assigned to this office included Robert S. Sigafoos, M. Gordon Wolman, Lucien M. Brush, Jr., and others, usually graduate students on limited appointments.

From 1960 onward, the GHB headquarters organization and leadership experienced more changes. These were generally related to reorientation of the role of the Branch in accord with the ultimate objective, expressed by Leopold, of establishing the GHB as a research-oriented entity. The changes occurred in several stages or phases. They included transferring several key personnel of the Branch to other assignments in the Division, at Headquarters or in the field, terminating GHB Sections, as noted above, and restructuring of the Branch program.

In October 1960, G. Earl Harbeck, Jr., GHB Area Chief, RMA, Denver, Colo., served as Acting Branch Chief from his Denver headquarters until August 1961 when Thomas Maddock, Jr., was appointed Chief, GHB. He served in that capacity, from headquarters in Washington, D.C., until November 1962. Frank E. Clarke succeeded Maddock in December 1962 and continued as Branch Chief until he was appointed Division Assistant Chief in August 1965. Subsequently Joseph E. Upson, II, Assistant Chief, GHB, served as Acting Branch Chief until the Branch was terminated.

In 1962, personnel of the abolished Branch staff sections who had been reassigned to the Office of the Branch Chief, were transferred to the WRD Special Reports Section, except for Ethel W. Coffay, who was transferred to the Division Staff Scientist group. By late 1962, as a result of these changes, and earlier reassignments of key personnel, the headquarters staff of the Branch was decimated, but only for a short time, leaving Frank E. Clarke, Branch Chief, and Robert L. Corey, a newly assigned oceanographer.

In late 1962, Leopold focused further attention on the organization of research activities. He asked Rolland W. Carter, Chief, SWB Research Section, Frank E. Clarke, Chief, GHB, and Robert Schneider, Acting Chief, GWB Research Section, to consider: "What scope should the Division research activities encompass? What should be the organizational structure of the research group?" Their study led to reorganizing and adjusting the GHB program. Organizational changes described under "Offices of the Division" and announced in WRD memorandums 64.9 dated July 24, 1963, and 64.14 dated August 7, 1963, resulted in: (1) Transfer of the operational Soil and Moisture Conservation program from the GHB to the Office of the Division Hydrologist, RMA; (2) transfer of the research activities of the Division's Radiohydrology Section to the GHB; and (3) reassignment of a number of research projects of an interdisciplinary character and most ground-water research from the Branch Research Sections to the GHB.

These actions resulted in a large number of personnel transfers in 1963 and 1964 from the other Branches, at Headquarters, and in the field to the GHB headquarters office as follows:

From WRD Radiohydrology Section: Alfred Clebsch, Jr., George D. DeBuchananne, and Paul H. Jones.

From the Office of the Assistant Division Chiefs: John H. Adamson.

From the Ground Water Branch: William Back, Robert R. Bennett, Edward Bradley, John D. Bredehoeft, Charles W. Carlston, Hilton H. Cooper, James E. Eddy, Warren D. Haney, Bruce B. Hanshaw, C. Lee McGuinness, Harold W. Olsen, Robert Schneider, William O. Smith, Ren Jen Sun, Frank W. Trainer, Joseph E. Upson, II, and Roger M. Waller.

From the Surface Water Branch: Eric L. Meyer and Charles W. Reck (deceased 1964).

The research projects transferred to the GHB headquarters office included studies such as recognition of late glacial substages (Upson); permeability and sedimentational features (Bennett); petrofabrics—directional permeability of marine sandstone (Bennett); geochemistry of water in carbonate rocks (Back) and in sedimentary basins (Hanshaw); liquid movement in clay (Olsen); unsaturated flow in porous media (Smith); hydrodynamics of a coastal plain (Bredehoeft); permeability of fractured rocks (Trainer); meanders (Carlston); marine hydrology (Bradley); electronic equipment research (Eddy); and water management (Reck).

Other research conducted by GHB Headquarters personnel during this period included studies of the effects of heated water outfalls into brackish water (Corey) and stream-channel erosion and sedimentation (Garnett P. Williams, appointed in 1964).

During 1964, further attention was given to Division reorganization and the development of area operations. The Chief Hydrologist, in WRD memorandum 64.41, December 3, 1964, announced that a proposed overall Division reorganization had been approved, to be effective December 9, 1964. He advised that overall direction of research was to be retained by the Chief Hydrologist, acting through the GHB. Division Hydrologists were directed to designate deputies for research (later to be titled Area Research Hydrologists).

In July 1965, Ernest L. Hendricks, Associate Chief, WRD, and Frank E. Clarke, Chief, GHB, recommended patterns of research supervision and Area staff positions which assigned most research personnel at project and field offices to their Area Hydrologist through their Area Research Hydrologist.

Commencing in 1965, a number of the GHB headquarters personnel were reassigned to the Division, at Headquarters or to offices of Area Hydrologists, as follows:

To Assistant Chief, WRD: Frank E. Clarke.

To Division Staff Scientist: C.L. McGuinness.

To Office of Area Hydrologist, ACA: William Back, Robert R. Bennett, John D. Bredehoeft, Charles W. Carlston, Robert L. Corey, George D. DeBuchananne, James E. Eddy, Bruce B. Hanshaw, Harold W. Olsen, Robert S. Sigafoos, William O. Smith, Frank W. Trainer, and Garnett P. Williams.

To Office of Division Hydrologist, MCA: Paul H. Jones (Baton Rouge, La.)

As of January 1, 1966, a relatively large staff, mostly associated with the radiohydrology program, continued to report directly to the Chief, GHB.

By late 1966, the remaining GHB headquarters personnel were reassigned to units of the Division, thus terminating the GHB as an organizational entity.

### Project and Field Offices

The field program of the GHB encompassed research studies and investigations that included activities such as water use (industries, areas, nationwide); evaporation and evapotranspiration water losses; theory and mechanics of erosion and sedimentation; channel processes and mechanics related to fluvial morphology; land-use effects; glaciers; stock-water supplies in the public domain; international water problems; water-resource appraisals; and the operation of an equipment development laboratory. (From CHE January 16, 1958, memorandum, "Functions of the General Hydrology Branch and their relation to the work of other Branches.")

Research and other investigations were conducted generally from project offices in several States within or near the areas of interest. The GHB did not operate as a tightly organized unit with established and continuing district or field offices such as those of the other Branches. Rather, it functioned as a collection of a diverse group of projects and project chiefs. Many functioned more or less separately from the others, even though two or more activities may have been housed in the same vicinity. Denver was the principal field center. Each project team looked to the Branch office in Washington for guidance, and each was not only given but was expected to exercise freedom in developing its project investigation. Branch headquarters personnel maintained close liaison with the research project teams in the field and through correspondence and progress reports.

Although the 1956 Division reorganization plan provided for four field areas with the Branches represented by Branch Area Chiefs (BAC), the GHB, nevertheless, elected to designate a BAC only for the RMA, naming Harold V. Peterson to that position. He served until his transfer to Menlo Park, Calif., in September 1960 and was succeeded by G. Earl Harbeck, Jr., who served through 1964. The BAC provided general program coordination within the Branch and with the other Branches in RMA.

In other areas GHB representation in State WRD Councils and inter-Branch activities was provided by Branch project personnel within the area. In the PCA, Arvi O. Waananen in Menlo Park served as the GHB representative until his transfer to the Office of the BAC–SWB–PCA in July 1961. Wilbur D. Simons, in Tacoma, Wash., represented the Branch in the Pacific Northwest and assisted the CHE in overseeing international and interagency investigations and activities in the Columbia River Basin.

The Soil and Moisture Conservation program (see Part IV, "Soil and Moisture Conservation Program") combined operational activities and research studies. These were supervised and coordinated by the Project Chief, S&MC, and carried out from project offices in Denver, Colo., Menlo Park, Calif., and Albuquerque, N. Mex. Harold V. Peterson was the project chief in 1957. He was succeeded by Kenneth R. Melin from 1957 to 1961 and 1962 to 1966, and by Garald G. Parker, Sr., in 1961 and 1962.

Some investigations, notably in water-loss studies and in inter-Branch and Division research, were directed or coordinated by G. Earl Harbeck, Jr., heading the Branch Research Section Field Unit in Denver. Others were coordinated directly through the Office of the Branch Chief.

The specialized instrumentation and equipment needs for evaporation and evapotranspiration research in the 1950's, and in other research, led to establishing an instrument-development laboratory in Denver under the direction of Claude R. Daum.

For a short period during 1956 to 1958, the Branch was assigned responsibility for the Equipment Development Laboratory in Columbus, Ohio, under the administrative direction of Arthur H. Frazier and later Keith S. Essex. As the principal function of that laboratory was related largely to supplying major operational equipment needs, the Branch subsequently relinquished this responsibility to the Survey's Administrative Division.

The GHB held its first and only Branch conference in Denver, Colo., February 24–27, 1958, with participation by almost all the professional personnel of the Branch. The program presented a review of the work in progress in the Branch, at the headquarters office, and at the project and field offices, aimed toward fulfilling the Branch's responsibilities. The conference and program provided opportunity for the dispersed staff to become better acquainted and for an improved understanding of the Branch mission. Conference attendees, pictured in Part VII, figure 7, included representatives of WRD offices and of the other Branches.

Listed below are GHB scientific and technical personnel stationed in project and field offices during all or part of the period 1957 to 1966. All WAE employees are not listed. Research personnel transferred from GWB are denoted by (a), from QWB by (b), and from SWB by (c).

Denver, Colo.: R.S. Aro, 1960–63; F.A. Branson, 1957–63; W. Buller, 1962–63; R.C. Culler, 1957–58; C.R. Daum, 1957–61, 1963–65; W.S. Eisenlohr, Jr., 1961–65; G.E. Ghering, Sr., 1963–65; R.E. Glover, 1957–60; M.C. Goldberg, 1963–65; R.F. Hadley, 1957–65; W.E. Hale, 1963–65; G.E. Harbeck, Jr., 1957–65; Lloyd Kahn, 1963–66; J.A. Kast, 1963–65; W.S. Keys, 1963–65; N.J. King, 1957–61, 1963–64; G.E. Koberg, 1957–61, 1963–65; O.E. Leppanen, 1957–60; R.W. Lichty, 1957–65; G.C. Lusby, 1957–63; R.A. McCullough, 1963–65 (a); I.S. McQueen, 1957–63; J.S. Meyers, 1957–61; K.R. Melin, 1957–63; R.F. Miller, 1957–63; W.R. Osterkamp, 1962–63; H.G. Page, 1963–64 (a); G.G. Parker, Sr., 1961–65; H.V. Peterson, 1957–60; K.W. Ratzlaff, 1959–63; J.B. Robertson, 1963–65 (b); S.A. Schumm, 1957–65; C.E. Sloan, 1958–61, 1963; R.W. Stallman, 1963–65 (a); C.T. Sumsion, 1957–59; M.C. Van Lewen, 1957–61; P.T. Voegeli, 1963–65; C.H. Wayman, 1963–65 (b); R.L. Wershaw, 1963–65; and F.F. Zdenek, 1958–60.

Fort Collins, Colo.: R.K. Fahnestock, 1960–65, and G.H. Splittgerber, 1957–66.

Phoenix, Ariz.: T.W. Anderson, 1963–64 (a); R.H. Brown, 1964–65 (a); H.T. Chapman, 1963–65 (a); J. da Costa 1963–65 (a); R. Lafferty, Jr., 1963–65 (a); O.E. Leppanen, 1960–65; M.G. Magness, 1963–65 (a); A.E. Robinson, 1963–65 (a); H.E. Skibitzke, 1963–65 (a); and T.E.A. Van Hylckama, 1958–65.

Tucson, Ariz.: D.E. Burkham, 1962–64; M.R. Collings, 1963–65 (c); R.C. Culler, 1958–65; T. Maddock, Jr., 1961–64; R.M. Myrick, 1963–65 (c); C.T. Sumsion, 1959–60; and A. Wilson, 1963–65 (c).

Albuquerque, N. Mex.: D.E. Burkham, 1957–62, and F.W. Kennon, 1956–58.

Oklahoma City, Okla.: F.W. Kennon, 1958–62.

Salt Lake City, Utah: C.T. Snyder, 1957–59.

Menlo Park, Calif.: I.K. Barnes, 1963–65 (b); H.V. Peterson, 1960–65; T.W. Robinson, 1957–65; J. Rubin, 1963–65; C.T. Snyder, 1959–61, 1963; A.O. Waananen, 1958–61; and F.F. Zdenek, 1960–61, 1963.

Tacoma, Wash.: M.F. Meier, 1957–65; M.I. Rorabaugh, 1963–65; J. Savini, 1957–60; W.D. Simons, 1957–61, 1963–65; and W.V. Tangborn, 1960–66.

Upper Darby, Pa.: A.G. Hely, 1957–60; W.B. Keighton, 1957–59; F.H. Olmsted, 1957–60; and G.G. Parker, Sr., 1957–58.

Boston, Mass.: A.V. Jopling, 1958–60, 1963–65, and J.C. Kammerer, 1957–61.

Fort Wayne, Ind.: J. Ficke, 1963–67 (c).

Baton Rouge, La.: J.N. Payne, 1963–65 (a).

Austin, Tex.: P.R. Stevens, 1963–65 (a).

Among the research projects transferred to GHB project and field offices from the other Branches in 1963 and 1964 were these: analog models—unsaturated flow and unsteady-state flow (Skibitzke, Phoenix); effects of heterogeneity (Skibitzke, Phoenix); seismic-wave propagation in porous media (daCosta, Phoenix); systems analysis (Brown, Phoenix); geohydrologic environments (Payne, Baton Rouge); multiphase flow theory (Stallman, Denver); erosion characteristics of clays (Jopling, Boston); behavior of detergents and other pollutants in soil-water environments (Wayman, Denver); and thermal characteristics of lakes (Koberg, Denver, and Ficke, Fort Wayne).

Many other studies and research investigations of GHB were conducted from the project and field offices. Among these were: hydrologic effects of vegetation modification (Culler, Collings, Myrick—Tucson); hydrologic effects of urbanization (Waananen—Menlo Park); effects of exposure on slope morphology (Hadley—Denver); channel erosion (Fahnestock—Fort Collins); effect of particle size on flow in alluvial channels (Fahnestock—Fort Collins and Maddock - Tucson); erosion in dry-land areas (Parker—Denver); mechanics of evaporation (Meyers—Denver); hydrologic effects of flood-retarding structures (Kennon - Oklahoma City); evaporation measurement (Meyers - Denver); thermal loading (Harbeck and Messinger [QWB], Denver and Washington, D.C.); and channel changes below dams (Wolman—Washington, D.C.). Most of the major field investigations and research of GHB are described in Part IV of this volume.

Several members of the GHB were involved in interagency activities. Harold V. Peterson, in Denver, represented the USGS on the Pacific Southwest Inter-Agency Committee prior to his move to Menlo Park in 1960. Thomas W. Robinson, in Menlo Park, represented the Geological Survey on the Phreatophyte Subcommittee of the Pacific Southwest Inter-Agency Committee (see Part IV, "Phreatophytes"). Wilbur D. Simons was an active participant in interagency technical studies in the Columbia River Basin. Mark F. Meier, in connection with his study of glaciers in Washington and Alaska, maintained contact with others around the world doing research on glaciers.

### Sources of Funding

The GHB program was supported largely by Federal and S&MC program funds, supplemented by funds from other Federal agencies (OFA) as listed in the following table III–15.

## PART IV—THE PROGRAM—POLICY, PLANNING, AND EXECUTION

The Division's program underwent considerable change during the Leopold years. As Division Chief, Leopold pressed diligently and consistently for a redirection of program emphasis from mainly that of data collection and descriptions of the occurrence and availability of water to field investigations and research more attuned to providing information needed to solve current and emerging water problems.

This section summarizes the Division's program for the 1957–66 period for program policy and formulation and for overall program content by: (1) the principal program elements of water records, analytical and interpretive investigations, and research; and (2) the three principal sources of funding support for program—Federal (Fed), Federal-State cooperative (Coop), and other Federal agencies (OFA).

Following these general accounts, an array of the major programs and projects of the period are described in some detail, most of them authored by individuals who led or were personally involved in the particular activity.

Table III–15. Sources and amounts of funding, General Hydrology Branch, fiscal years 1957–66

[OFA, other Federal agencies; Coop, cooperative program; S&MC, Soil and Moisture Conservation]

| Year | Federal | OFA | Coop | S&MC | Total |
|---|---|---|---|---|---|
| 1957 | $428,491 | $66,047 | - | $129,466 | $624,054 |
| 1958 | 477,124 | 44,661 | - | *165,498 | 687,283 |
| 1959 | 596,483 | 51,037 | - | 174,000 | 821,520 |
| 1960 | 577,647 | 14,366 | $18,752 | 174,825 | 785,590 |
| 1961 | 644,804 | 19,023 | 19,480 | 184,312 | 867,619 |
| 1962 | 438,844 | 12,528 | 4,364 | 157,094 | 612,830 |
| 1963 | 632,611 | 32,082 | 6,312 | 189,000 | 860,005 |
| 1964 | NA | NA | NA | 192,954 | NA |
| 1965 | NA | NA | NA | 197,467 | NA |
| 1966 | NA | NA | NA | 201,000 | NA |

Notes: NA—Not available, funds allocated all or in part by WRD directly to projects through Area (Division) Hydrologists. Funds shown based on memorandum of April 2, 1964, from Administrative Officer to Division Hydrologists, subject "Accounting—Analysis of obligations for WRD, period 1953–63, except for (*) below.

*From 1960 Appropriations Hearings showing actual obligations for 1958.

## Program Policy and Formulation

Leopold set the tone of Division policy on program emphasis and project selection early on, when by memorandum of May 21, 1957, he declared to District Chiefs and staff officials:

> We wish to establish the unequivocal and acknowledged leadership of the Water Resources Division in the field of scientific hydrology as well as in water-resources investigations. To do so, we must correctly identify specific present and future problems in water resources, and we must develop a program which will either solve these problems or provide the basis for solutions. Widened interpretation of our data and intensified research are essential. Cooperative programs which include interpretative aspects, in general, are preferred over those which do not.

Though he was speaking about the cooperative program in that memorandum, this policy stance was already well understood for new activities in the Federal program, and would be considered whenever possible in new work for other Federal agencies.

Later, in WRD policy statement no. 3 dated March 7, 1960, he formally confirmed a program-formulation process based on the three program elements of water records, analytical and interpretive studies, and research. He stated further, "The degree of effort directed to the three elements of our work shall be determined by (1) recognition of need, and (2) present state of knowledge."

This three-part program-element structure was used throughout the period in program planning, formulation, and management at all levels of the Division. A standardized nationwide system of program documentation, devised earlier by George Ferguson in the 1950's (see Part VII, "Program Planning and Project Management") was adapted to this three-element structure. At the same time, program funding had to observe the three traditional budget elements of Federal program, Federal-State Cooperative program, and Other Federal Agencies program. So, in summarizing program content and accomplishment for this volume of WRD history the following sections recount the programs by both the activity and budget elements. Table IV–1 (adapted from table V–2 of "Budget and Appropriations") shows the changes in program funding for the period for both the activity and budget elements.

Much attention also was given during this period to long-range planning. Districts were directed to develop their long-range plans, with assistance, review, and approval by their Division Hydrologists and Branch Area Chiefs. The Survey developed a bureau-level nationwide long-range plan, published in 1964 as "Long Range Plan for Resource Surveys, Investigations, and Research...."

In the bureau-level report, WRD outlined 10-year program goals and content that would about double the 1964 budget and increase manpower by 60 percent to greatly expand its program components

Table IV–1. WRD funding distribution among primary program elements and objectives, fiscal years 1958 and 1967

[In millions of dollars]

| Program funding source | Total funds | | Water records | | Studies | | Research | |
|---|---|---|---|---|---|---|---|---|
| | $ | Percent | $ | Percent | $ | Percent | $ | Percent |
| | | | FISCAL YEAR 1958 | | | | | |
| Federal | 4.5 | 22 | 1.9 | 41 | 1.3 | 29 | 1.4 | 30 |
| Federal-State Cooperative | 12.0 | 57 | 8.2 | 68 | 3.5 | 29 | .4- | 3 |
| OFA | 4.5 | 21 | 3.6 | 79 | .8 | 17 | .2- | 4 |
| Total | 21.1 | 100 | 13.7 | 65 | 5.5 | 26 | 1.9 | 9 |
| | | | FISCAL YEAR 1967 | | | | | |
| Federal | 11.9 | 25 | 4.5 | 38 | 3.2 | 27 | 4.2 | 35 |
| Federal-State Cooperative | 26.9 | 56 | 14.5 | 54 | 8.9 | 33 | 3.5 | 13 |
| OFA | 8.9 | 19 | 6.2 | 70 | 2.0 | 23 | .7- | 7 |
| Total | 47.6 | 100 | 24.8 | 52 | 14.3 | 30 | 8.6 | 18 |

Note: Totals may not add exactly due to rounding.

of basic data, areal and interpretative studies, and hydrologic research. (Authors note: These projections turned out to be less unrealistic than might have been judged at that time. At the National District Chiefs Conference in 1975, program growth in constant dollars was reported as about 50 percent for the period 1965–75. Employment had increased about 20 percent by 1970, but with the strict control of personnel ceiling thereafter, it remained static at about 3,000 through 1975.) Greatest emphasis for increased funds and manpower in the WRD plan was placed on research—research needed to deal with water and environmental problems of increasing complexity.

Division policy on and management of program formulation stressed recognition of need for proposed program and present state of knowledge. This basis of philosophical but practical priority setting effected a gradual transition in program content desired by Bureau and Division management. The content of major program components and specific projects as described in the following sections attests to the success of Leopold's objectives.

## Water Records

This program element included systematic, repetitive measurements of the quantity, quality, and use of the water resource and of related geologic and hydrologic parameters needed to describe the temporal and spatial variations of the resource. Included also was the establishing and equipping of observation stations and the organizing and processing of data for storage and dissemination.

In FY 1958, funding for water records totaled about $13.7 million (table IV–1), 65 percent of WRD funds; in FY 1967, about $24.8 million but only 52 percent of Division funds. The activity grew substantially but proportionally less than the other program elements. The status of principal data networks for the two fiscal years are tabulated in table IV–2.

Some observations to be noted about water records from table IV–2 are:

> Numbers of stations in all categories increased materially except snow measurements; greater emphasis on periodic rather than daily observations; Federal program support for network-type operations diminished in contrast to the sizable increases in Coop and OFA; and snow measurements decreased, but rain measurements increased greatly owing to the addition of small streams flood-hydrograph stations in the Coop program.

Major technological advances in data-collecting instrumentation and in computer processing of data were attained and made operational during the period, thus greatly improving the scope and effectiveness of data collection and analysis. These successes are recounted herein in several of the articles under "Research and Development."

Table IV–2. Types and numbers of water records collected by U.S. Geological Survey during fiscal years 1958 and 1967

[From annual program summaries]

| Type of record | Federal program | | Federal-State program | | Other Federal agencies | | Total, 1958 | |
|---|---|---|---|---|---|---|---|---|
| | Daily | Periodic | Daily | Periodic | Daily | Periodic | Daily | Periodic |
| | | | FISCAL YEAR 1958 | | | | | |
| **Stream records** | | | | | | | | |
| Stage | 8 | | 87 | 297 | 97 | 25 | 192 | 322 |
| Water discharge | 566 | 573 | 4,214 | 2,657 | 2,052 | 162 | 6,832 | 3,392 |
| Sediment discharge | 52 | 87 | 71 | 76 | 66 | 53 | 189 | 216 |
| Chemical quality (conductivity) | 68 | 85 | 174 | 1,436 | 41 | 107 | 283 | 1,628 |
| Temperature | 109 | 266 | 317 | 3,872 | 118 | 1,009 | 544 | 5,147 |
| **Reservoirs, lakes, and ponds** | | | | | | | | |
| Water level and tidal bays | 3 | 2 | 338 | 156 | 69 | 25 | 410 | 183 |
| Reservoir content | 1 | 3 | 140 | 141 | 131 | 39 | 272 | 183 |
| Chemical quality | | 5 | 8 | 49 | 3 | 49 | 11 | 103 |
| Temperature and evaporation | 10 | 3 | 21 | 176 | 3 | 57 | 34 | 236 |
| Sediment discharge | | | | | 4 | 2 | 4 | 2 |
| **Springs records** | | | | | | | | |
| Water level—discharge | 5 | 5 | 42 | 491 | 7 | 60 | 54 | 556 |
| Chemical quality | | | | 79 | 1 | 13 | 1 | 92 |
| Temperature | | 10 | 1 | 117 | 1 | 51 | 2 | 178 |
| **Ground-water records** | | | | | | | | |
| Water level | 152 | 1,377 | 1,443 | 18,649 | 195 | 3,827 | 1,790 | 23,853 |
| Well discharge | | 5 | 3 | 2,194 | 14 | 179 | 17 | 2,378 |
| Recharge | 3 | | 6 | 1 | | 1 | 9 | 2 |
| Chemical quality | 3 | 68 | 1 | 4,341 | 12 | 1,356 | 16 | 5,765 |
| Temperature | 1 | 20 | 21 | 2,726 | | 1,108 | 22 | 3,854 |
| **Snow measurement** | | | | | | | | |
| Depth only | | | 6 | 38 | 27 | 1 | 33 | 39 |
| Water content | | 1 | 6 | 186 | | | 6 | 187 |
| **Rain measurement** | 45 | 19 | 209 | 166 | 124 | 25 | 378 | 210 |
| Number of projects | 387 | | 898 | | 421 | | 1,706 | |

Table IV–2. Types and numbers of water records collected by U.S. Geological Survey during fiscal years 1958 and 1967--continued

[From annual program summaries]

| Type of record | Federal program | | Federal-State program | | Other Federal agencies | | Total | |
|---|---|---|---|---|---|---|---|---|
| | Daily | Periodic | Daily | Periodic | Daily | Periodic | Daily | Periodic |
| | | | FISCAL YEAR 1967 | | | | | |
| **Stream records** | | | | | | | | |
| Stage | 8 | | 118 | 362 | 117 | 128 | 243 | 490 |
| Water discharge | 679 | 75 | 5,189 | 9,107 | 2,472 | 489 | 8,340 | 9,671 |
| Sediment discharge | 33 | 79 | 121 | 440 | 75 | 101 | 229 | 620 |
| Chemical quality (conductivity) | 66 | 112 | 340 | 2,644 | 102 | 557 | 508 | 3,313 |
| Temperature | 108 | 183 | 616 | 3,470 | 233 | 651 | 957 | 4,304 |
| **Reservoirs, lakes, and ponds** | | | | | | | | |
| Water level and tidal bays | 4 | | 456 | 186 | 115 | 31 | 575 | 217 |
| Reservoir content | 11 | | 139 | 568 | 156 | 99 | 306 | 667 |
| Chemical quality | | 1 | 56 | 235 | | 13 | 56 | 249 |
| Temperature and evaporation | 1 | | 35 | 125 | 8 | 14 | 44 | 139 |
| **Springs records** | | | | | | | | |
| Water level—discharge | | 18 | 87 | 498 | 1 | 19 | 88 | 535 |
| Chemical quality | | 15 | 6 | 318 | 7 | 22 | 13 | 355 |
| Temperature | | 3 | 8 | 278 | 7 | 15 | 15 | 296 |
| **Ground-water records** | | | | | | | | |
| Water level | 59 | 553 | 1,790 | 20,054 | 215 | 2,782 | 2,064 | 23,389 |
| Well discharge | | 1 | 1 | 3,893 | 1 | 24 | 2 | 3,918 |
| Recharge | | | 1 | 10 | | | 1 | 10 |
| Chemical quality | | 50 | | 4,251 | | 861 | | 5,162 |
| Temperature | | 35 | 3 | 2,283 | 1 | 358 | 24 | 2,676 |
| **Snow measurement** | | | | | | | | |
| Depth only | | | | 27 | | 37 | | 64 |
| Water content | | | | 102 | 13 | 32 | 13 | 134 |
| **Rain measurement** | 31 | 11 | 951 | 896 | 97 | 50 | 1,079 | 957 |
| Number of projects | 250 | | 1,377 | | 553 | | 2,180 | |

An essential component of water-records activity—publication of data—underwent considerable change (see Part IX, "Publication and Information Services"). The traditional WSP series for reporting streamflow data by 14 major drainage basins gave way to State-level data reports, greatly improving timeliness of publication and user convenience. This changeover followed intensive study, analysis, and data-user surveys conducted within the operations-research program of the SWB in 1957–60 by Irving E. Anderson and Charles W. Reck (see "Operations Research") and became effective with publication of the water year 1961 surface-water records. The State-level mode of data publication was later adopted for ground-water and water-quality data.

The nationwide network analysis of surface-water gaging stations, completed in 1957, provided an improved objective-oriented process for network management during the Leopold years. Network strategy provided for primary (long term), secondary (short term), and water-management (specific purpose) station justification. It also gave added impetus for a more diversified network, including low-flow and flood-flow partial-record stations. The latter provided a lower-cost alternative for expanding the data base to small drainage areas where information was sorely needed to improve estimates of drought and flood frequency. Also a new network component—hydrologic bench-marks—was launched in 1963 with the establishment of six stations and expanded in the years following, the objective being to monitor hydrologic conditions over the long term in basins not significantly affected by man (see "Hydrologic Data Networks").

The nationwide compilation of streamflow records from the beginning of systematic stream gaging in 1888 through 1950, which began in 1951, was completed in 1961. This monumental effort is recounted to 1950 herein under "Compilation of Surface-Water Records to 1950."

National compilations of water-use data were prepared for the years 1960 and 1965 to continue the 5-year series of such reports, begun in 1950 (see "Water-Use Studies").

Other water-records activities included intensified measurements of extreme floods and droughts (see Part VIII, "Floods, Droughts, and Other Hydrologic Events"), and time-of-travel measurements in selected stream reaches (see "Tracers in Hydrology"). All types of hydrologic data—precipitation, evaporation, transpiration, sediment and erosion, subsurface geophysical and geochemical measurements, and other types of information—were collected in increasing amounts through the period to support special field investigations and research.

In October 1964, the Division established the Office of Water Data Coordination (OWDC) to implement the provisions of Bureau of the Budget's Circular A–67 (See Part VIII). That office became the focal point in years following of Federal interagency data coordination—the inventorying, cataloging, and standardizing the methods of water-data acquisition activities and the design of national data networks. This added a highly significant national program responsibility to WRD's water-information mission.

More details on water-records activities are covered in other sections of this volume, especially in the articles about special programs and projects in this section and in Part X, "District Activities."

## Analytical and Interpretive Studies

This program element included all activities that involved the use of basic data (from water records) and established hydrologic principles (from research) to describe and assess the temporal and spatial characteristics of the water resource and its interactions with natural and man-affected environments. Included were the traditional descriptive studies of the water resources and hydrology of specific areas; documentation of unusual hydrologic events; specialized statistical studies of resource variability, such as frequency of floods and droughts, water use and losses, and seasonal ground-water levels; special studies to support needs for water planning, project design, and management; and, late in the period, hydrologic studies in support of new, major Federal initiatives such as comprehensive river-basin planning (Water-Resources Planning Act of 1965) and water-quality management (Water Quality Act of 1965).

Funding for this component of WRD program increased from about $5.5 million to $14.3 million between fiscal years 1958 and 1967 and received a larger proportional share of total funding (from 26 percent to 30 percent) during that period (table IV–1).

The vast bulk of these studies, measured either by funding and manpower or by numbers of projects, were planned, executed, and reported on by the Districts. They were funded primarily in the cooperative program or by other Federal agencies. Federal program funding for these intra-State projects was limited. This program activity represented a great diversity in purpose and scope ranging from reconnaissance-level studies of the occurrence and availability of water to highly sophisticated assessments of water-environmental interrelationships. The period experienced rapid expansion of the latter, both in response to WRD leadership urgings as a matter of policy direction and to mounting needs for such assessments by State and Federal developmental and environmental agencies.

The number of active District-conducted projects increased from about 1,700 in fiscal year 1957 to about 2,200 in fiscal year 1967, as aggregated from District work plans for those years. The reader is referred to the individual District histories for detailed information on these studies.

Federal funding for analytical and interpretive studies was directed to current issues of national or regional (multi-State) significance. Major areal investigations, such as those in the Upper and Lower Colorado Basins, the Delaware River Basin, and the Mississippi Embayment were initiated and designed to respond to water-management problems of that time. Other major Federal program investigations responded to topical issues of the period, such as industrial water requirements, water-conservation demonstrations, water quality of public supplies, saline ground-water resources, and the like.

The Soil and Moisture Conservation program, a line-item budget activity throughout the period, was designed and conducted to meet the hydrologic information needs for management of the arid western lands, largely the Federal lands managed by Interior's Bureau of Land Management.

These and other Federal program studies are recounted in detail in the following section on "Special programs and projects."

The Federal program projects were largely planned by the Division and managed by the Branches until the 1964 reorganization, after which they came under the direction of the Area (Regional) Hydrologists or one of the Division sections. Before 1964, studies largely of one discipline (surface water, ground water, or quality of water) were directed by the appropriate Branch; those involving multiple disciplines and the Soil and Moisture Conservation program were directed by the General Hydrology Branch, or in some cases by a designated lead Branch. The historical accounts of Branch organizations in the preceding section of this volume highlight many of the Branch-managed projects.

Two major programs—involving mostly problem-oriented investigations but also including some water records and research activity planned and overseen by special offices of the Division during the period—were funded by other Federal agencies. These were the International program, funded by the International Cooperation Administration (ICA) until 1962 and by the Agency for International Development (AID) afterwards, and the "Radiohydrology program" funded by the Atomic Energy Commission (AEC). Both are recounted herein under "Special programs and projects." These two activities alone obligated more than $13 million during the 9 fiscal years, 1958–66, and required extensive use of specialized and experienced professionals, drawing largely upon the field corps of the Districts for that expertise.

## Research

Classifying certain WRD activities as research has never been precise because research projects frequently require water records and hydrologic analysis and interpretation, or vice versa. Nevertheless, research within WRD was considered to be those activities seeking to better understand the fundamental hydrologic and hydraulic principles and systems, including development of improved equipment, instrumentation, methods of measurement, and techniques of analysis and data processing.

In terms of budget (table IV–1), the research program increased from about 9 percent of total funding ($1.9 million) to about 18 percent ($8.6 million) between fiscal years 1958 and 1967, with commensurate increases in personnel assigned to research projects.

Ferguson (Volume V) described the research program with the Division as having its beginnings in 1947 with a $37,000 appropriation in the Federal program; but in spite of recognized need for a continuing budget base for this purpose, little success was achieved except for what could be done in the cooperative program until the budget cycle for 1957. The proposals for that year included a new item in water-resources investigations labeled "New responsibilities in hydrology" for $607,000, which Congress appropriated. This item, in effect, can be said to be the beginning of the Division's core research program. An additional increase in fiscal year 1958 provided this Federal program item, by then retitled "Water-resources policy (WRP) funds," to $1.2 million, which further strengthened WRD's foothold in research, reaching a total funding base of $1.4 million. Additional funds for research were obtained during the remaining years through Leopold's priority and persistence for Federal program increases to reach about $4.2 million by fiscal year 1967. At the same time, cooperative and OFA funds for research increased during the period to about $3.5 million and $0.7 million, respectively, adding up to the $8.6 million total shown in table IV–1.

The Division's success in enlarging its research program was undoubtedly aided by three external Federal actions of the period, which influenced the Bureau of the Budget and the Congress in responding favorably to Survey budget proposals. The first of these, the President's Advisory Committee on Water Resources, recognized in its 1956 report a greater need for improved water-resources information. The second, the Senate Select Committee on National Water Resources, strongly urged in its 1961 report a much increased Federal effort on comprehensive river-basin planning and on water research. Third, coming out of the Senate Select Committee report, was the passage of the Water-Resources Research Act of 1964 and Water-Resources Planning Act of 1965. All these actions stimulated recognition of the need for more and better hydrologic information, and the Division's research program benefited therefrom.

### Program Structure and Content

Throughout most of the period, the Division generally classified its research program into two major categories representing its primary objections: (1) hydrologic principles and (2) techniques. The first included all research related to the hydrologic cycle, primarily the land phases and the land-atmosphere interface. The second included instrumentation and equipment development, methods of hydrologic analysis, and computer applications in data processing and hydrologic analysis. Research categories and individual projects varied throughout the period. The following summaries for fiscal years 1958, 1962, and 1966 that highlight emphasis, diversity, and growth of the Federal research program but represent only, for the most part, the so-called "core" research activities.

The more elaborate classification structure used for the 1966 research summary was devised by the Interagency Committee on Water Resources Research (COWRR), a Federal research-coordination entity established by the Federal Council for Science and Technology in 1963. It was to classify, coordinate, and

Fiscal Year 1958.—Summary of Federal "Core" Research Program

| Research category | Number of projects | $1,000 | Number of principal investigators |
|---|---|---|---|
| **Hydrologic Principles** | | | |
| Hydrologic mechanics/processes | 2 | 43 | 4 |
| Porous media | 5 | 141 | 5 |
| Chemical physical processes | 3 | 42 | 4 |
| Radiohydrology | 2 | 138 | 4 |
| Geomorphic/fluvial processes | 2 | 53 | 5 |
| Evaporation/transpiration | 3 | 51 | * |
| Areal extension, floodflows | 2 | 55 | 2 |
| Hydrologic interrelations | 5 | 53 | *1 |
| Glacier studies | 1 | 15 | 1 |
| Graduate students' research | - | 20 | - |
| **Techniques** | | | |
| Equipment development | 1 | 48 | 1 |
| Surface-water data analysis | 1 | 27 | 1 |
| Operations research | 1 | 25 | 1 |
| Aquifer analytical methods | 1 | 16 | * |
| Analog methods | 1 | 16 | * |
| Ultrasonic velocity meter | 1 | 20 | * |
| Bedload sampler | 1 | 15 | 1 |
| Totals | 35 | 778 | 30+ |

Source: WRD memorandum dated April 27, 1957.
* One or more project investigators not yet designated.

Fiscal Year 1962.—Summary of Federal "Core" Research Program

| Research category | Number of projects | $1,000 | Number of principal investigators |
|---|---|---|---|
| **Hydrologic Principles** | | | |
| Flow and diffusion | 15 | 289 | 14 |
| Chemistry | 11 | 287 | * 8 |
| Geology | 6 | 128 | 6 |
| Morphology | 7 | 133 | 7 |
| Evaporation/transpiration | 6 | 113 | 5 |
| Hydrochronology | 2 | 50 | 2 |
| Graduate students' research | - | 22 | - |
| **Techniques** | | | |
| Data measurement, instrumentation | 7 | 196 | * 6 |
| Data processing and analysis | 5 | 82 | 5 |
| General operations | 2 | 29 | 2 |
| Totals | 61 | 1,329 | 55+ |

Source: WRD memorandum dated March 7, 1961. *One or more project investigators not yet designated.

to report annually on Federal-agency water research. The COWRR developed and first applied this classification structure in reviewing agency research programs proposed for fiscal year 1966, and it was to be continued in use for a number of years thereafter.

Almost no information on the content of research in the Federal-State cooperative program was available in any summarized fashion from WRD files until 1966, but would most likely have been a part of hydrologic investigations within the District programs (see Part X, "District Activities"). From the Division's report of Water Resources Research for fiscal year 1966, part 2, research activities from the cooperative program are summarized in the following table:

## Program Funding and Sources

For many years prior to this period and continuing up to the present, the WRD program had been justified in the annual Federal budget and appropriation process in terms of three funding sources: (1) the Federal program (Fed), funded by direct Federal appropriation for water-resources investigations; (2) the Federal-State cooperative program (Coop), funded by a specified part of the Federal appropriation which requires at least 50 percent cost sharing by State and local agencies; and (3) the other Federal agency program (OFA), funded by other agencies requesting special services from the Survey. This section highlights WRD's program activity for the period as aligned with this budget and appropriation structure.

### The Federal Program

Policy on work funded under the Federal program was set forth in Part 900.1.3 of the January 30, 1959, provisional draft of the Survey Manual which read:

> A. Federal Program. The work under the Federal Program is aimed directly at serving national interests and general welfare. Although this work includes some collection and interpretation of data, special emphasis is placed on basic studies of hydrologic principles and processes and on other research necessary for continued growth in hydrologic knowledge. To qualify for inclusion in the Federal Program, projects must have national or broad regional scope. A project is of national significance if (a) the work is done simultaneously or successively in several parts of the country for nationwide purposes, (b) the results of the work add to knowledge of general hydrologic situations, (c) the results are widely applicable geographically and technically in relation to other programs, and (d) the work is required to serve specific Federal interests.

Fiscal Year 1966.—Summary of Federal "Core" Research Program

| | Research category (Committee on Water Resources Research) | Number of projects | $1,000 | Number of principal investigators |
|---|---|---|---|---|
| I. | Nature of water | | | |
| | Aqueous solutions and suspensions | 2 | 72 | 2 |
| II. | Water cycle | | | |
| | General | 11 | 430 | 10 |
| | Snow, ice, and frost | 2 | 90 | 2 |
| | Evaporation and transpiration | 3 | 69 | 3 |
| | Streamflow | 6 | 132 | 7 |
| | Ground water | 21 | (a)518 | 21 |
| | Water in soils | 6 | 152 | 3 |
| | Lakes | 4 | 69 | 4 |
| | Water and plants | 6 | (b)75 | 6 |
| | Erosion and sedimentation | 19 | 273 | 17 |
| | Chemical processes | 11 | 270 | 13 |
| | Estuarine problems | 4 | 60 | 4 |
| III. | Water-supply augmentation conservation | | | |
| | Water-yield improvement | 4 | 270 | 4 |
| IV. | Water quantity management and control | | | |
| | Effects of man's activities | 2 | 22 | 2 |
| V. | Water-quality management and protection | | | |
| | Identification of pollutants | 6 | 144 | 6 |
| | Sources and fate of pollution | 7 | (b)643 | 7 |
| | Effects of pollution | 1 | (a) | 1 |
| | Ultimate disposal of wastes | 1 | (b)20 | 1 |
| VI. | Water resources planning | | | |
| | Techniques of planning | 1 | 43 | 1 |
| VII. | Resources data | | | |
| | Data acquisition | 11 | 602 | 8 |
| | Evaluation, processing, publication | 5 | 287 | 5 |
| VIII. | Engineering works | | | |
| | Design | 1 | (b)14 | 1 |
| IX. | Manpower, grants, facilities | | | |
| | Education-extramural | 4 | (a) | 4 |
| | Totals | 138 | 4,255 | 132 |

Source: Report of Water Resources Research, July 1, 1965–June 30, 1966, Part 1. Federal Program Research, Geological Survey-WRD.

Notes: (a) Funding not shown for one or more projects. (b) Includes funding from Atomic Energy Commission.

Fiscal Year 1966.—Summary of research funded in Cooperative program

| | Research category (Committee on Water Resources Research) | Number of projects | $1,000 | Number of principal investigators | States involved |
|---|---|---|---|---|---|
| II. | Water cycle | | | | |
| | General | 4 | 110 | 4 | Fla., Tenn., N.J. |
| | Evaporation/transpiration | 1 | 10 | 1 | Ind. |
| | Streamflow | 2 | 10+ | 3 | Calif.[1] |
| | Ground water | 5 | 85+ | 5 | N.J., Calif., Utah, Kans., S.C. |
| | Lakes | 2 | 18 | 2 | Mo., Calif. |
| | Erosion/sedimentation | 3 | 36 | 3 | Ind., Ark., Pa. |
| | Chemical processes | 2 | 14 | 2 | Utah, Ala. |
| | Estuarine problems | 2 | 10+ | 2 | Pa., Wash. |
| III. | Water supply augmentation/conservation | | | | |
| | Water-yield improvement | 11 | 2 | 1 | N. Mex. |
| IV. | Water quantity management/control | | | | |
| | Control of water on the land | 2 | 28 | 1 | Pa. |
| | Ground-water management | 3 | 337 | 3 | N.Y., La. |
| | Effects of man's activities on water | 3 | 163 | 3 | N.C., Colo., Oreg. |
| V. | Water quality management/protection | | | | |
| | Effects of pollution | 1 | + | 1 | Calif. |
| VI. | Water resources planning | | | | |
| | Techniques of planning | 2 | 30 | 2 | Mich., Minn. |
| VII. | Resources data | | | | |
| | Network design | 1 | 68 | 1 | Nev. |
| | Data acquisition | 4 | 30 | 4 | Calif., N.J, Pa. |
| VIII. | Engineering works | | | | |
| | Design | 1 | 3 | 1 | Ala. |
| | Totals | 39 | 954+ | 39 | 23 |

[1]Work performed by research unit, WRD Headquarters.

Table IV–1 shows how Federal program funds were allocated among the program elements of water records, studies, and research at the beginning and the end of the period, fiscal years 1958 and 1967. Although research was given top priority for new funding during the period, there was little change in the overall balance among the three program elements.

## The Federal-State Cooperative Program

Part 900.3.B of the previously referenced Survey Manual stated:

B. Federal-State Program. Work under the Federal-State Program is aimed at serving both national and local needs. The Federal government and particular State and municipal agencies have a mutual interest in these water resources investigations. Most of this work has related to systematic collection and analysis of basic data and investigative surveys of the occurrence quantity and quality of surface and underground water supplies in specific areas. However, research and general interpretive studies are desirable in the Federal-State Program and should be expanded as more State agencies fully realize the need for this kind of work.

The mutual interest of the Federal government and State and municipal agencies has resulted in joint financial support of cooperative investigations since 1895. Beginning in 1929, the Survey's appropriation language required that the

Survey's share must not exceed one-half of the cost of the investigations.

Examination of table IV–1 clearly demonstrates how important the Coop program was in the conduct and execution of Survey mission and achievement of its goals in water resources. This program supported more than one-half of the Division's total program activity throughout the period. Moreover, and due in no small part to the diligence of Division Area staffs and District leaders, the Coop program made significant gains in those priority areas of interpretation and research, so forcefully sought by Leopold. At the end of the period the field program in studies and research, as well as in water records, involved virtually every aspect of water and environmental problems then extant or perceived.

State and local water-management agencies, more than ever before, were recognizing the need for and offering to cost-share in better hydrologic information for problem solving. Only the limitations of Federal appropriations for matching and personnel controls constrained the rate of growth. Especially evident in the later years of the period were increasing needs for water facts and investigations in those areas of surface- and ground-water pollution, river-basin water-resources planning and assessments, and environmental impact assessments.

The Coop program was strongly supported by Federal leadership throughout the period. The President's Advisory Committee on Water Resources Policy (an Executive Branch, Cabinet-level Committee) stated in its 1956 report:

> Continued cooperation with States and municipalities should be encouraged. Such cooperation serves to supplement the basic-data programs of the Federal Government in fields in which there is substantial joint interest.... Federal matching of State financial support for data programs on a 50-50 basis has been mutually satisfactory and should continue to be a sound basis for such cooperation.

Similarly, the Congress, through its Senate Select Committee on National Water Resources Report of 1961, called for increasing attention to water problems. The Congressional Appropriation Subcommittees consistently provided funding to match estimated cooperative offerings, even to the extent of add-ons above the President's budget proposals in several years of the period (see Part V, "Budget and Appropriations").

All States participated in the Coop program throughout the period. Alaska and Hawaii, both achieving statehood in 1959, rounded the total of States participating as of fiscal year 1958 to 50, plus the territories of Guam, American Samoa, Puerto Rico, and the U.S. Virgin Islands. Cooperation with the Virgin Islands stopped after 1 year but was resumed on a continuing basis beginning in fiscal year 1962. A program with the District of Columbia began in fiscal year 1961 and continued thereafter. By the end of the period, the Division was cooperating with more than 300 State and local agencies and with the four territorial governments. Based on table IV–2, the Coop program supported throughout the period a major portion of the water-records activity and well over one-half of total project activity with virtually all this work executed by the Districts. State-by-State content and accomplishments of the Coop program are summarized in Part X, "District Activities."

### The Other Federal Agencies Program

Part 900.3.C and D of the Survey Manual (Provisional draft 1/30/59) cited authorities for and policy and procedures on work for other Federal agencies and for the permittees and licensees of the Federal Power Commission, quoted as follows:

> C. Work for Other Federal Agencies. The Division assists other Federal agencies, at their request, by making appropriate investigations with funds made available by the agency. The basic authority for one agency to do work for another is Section 601 Economy Act, 1932 (U.S. Code, Title 31, Section 686). This Act states that if funds are available and if it is in the interest of the government, any Federal agency may place orders with any other agency for materials, supplies, equipment, work, or services of any kind that such requisitioned Federal Agency may be in a position to supply or equipped to render..... If such work or services can be as conveniently or more cheaply performed by private agencies, such work shall be let by competitive bids to such private agencies.....
>
> D. Work for Permittees and Licensees of Federal Power Commission. Soon after the establishment of the Federal Power Commission by Congress in 1920, district chiefs of the Geological Survey were given certain responsibility for the supervision of 'the installation of gages, the ratings of said stream or streams, and the determination of the flow thereof' by specific language

written into each license or permit issued by the Federal Power Commission to a utility company for a specific site of a proposed hydroelectric development project. This language in turn was based on provisions in the Rules and Regulations of that agency. Through the years this language has taken various forms giving varying degrees of responsibility to the district engineers. The cost of this work is to be advanced by the licensee or permittee to the Geological Survey for such periods as may be mutually agreed upon.

(For more details, see statement on Responsibility for Streamflow Information for FPC Projects, prepared by the Surface Water Branch, December 1958.)

Table IV–1 shows that this funding component supported about 20 percent of the Division's total activity during the period and increased about twofold during that time. Although most of the funding was for water records, special studies and research formed a significant part of the activity, reaching about 30 percent of the OFA total by FY 1967.

Table IV–3 lists the principal agencies assisted by the Division and related funds obligated in FY 1958 and FY 1967. More details on work for other Federal agencies are contained in the following, "Special programs and projects" and in Part X, "District activities."

## Special Programs and Projects

The major part of program activity during the period was at District level and is recounted in Part X, "District Activities." However, an increasing proportion of program resources was allocated to regional, national, and international activities. These broader scoped programs and projects responded to:

- Needs of other Federal agencies for specialized and continuing hydrologic services
- Executive and legislative requirements for information needed to resolve water problems of national and regional concern
- Division-initiated field investigations of multidistrict scale and involving multidiscipline expertise; and
- Development, demonstration, and coordination of techniques and analyses supportive of new and more diversified district-level programs

The accounts of the special programs and projects summarized in the following sections were authored and reviewed by the individuals who led or served as key team members.

Table IV–3.—Funding from other Federal agencies

[In thousands of dollars]

| Federal agency | FY 1958 | FY 1967 |
|---|---|---|
| Federal Power Commission permittees and licensees | 224 | 415 |
| Bureau of Reclamation | 1,105 | 1,379 |
| Federal Water Pollution Control Administration | - | 313 |
| National Park Service | - | 300 |
| Department of Agriculture | 362 | 273 |
| Department of Defense | 1,528 | 3,469 |
| Department of State | 142 | 166 |
| Atomic Energy Commission | 340 | 953 |
| International Cooperation Administrative* | 377 | 809 |
| National Aeronautics and Space Administrative | - | 170 |
| Tennessee Valley Authority | 97 | 172 |
| All others (see Note) | 339 | 381 |

Note—As of FY 1967: Bonneville Power Administration; Bureau of Land Management; Bureau of Mines; Fish and Wildlife Service; Department of Commerce; Department of Health, Education, and Welfare; and Department of Justice.

*Later, Agency for International Development.

## Evaporation Studies

*By* Alex M. Sturrock, Jr., reviewed *by* Thomas C. Winter

Evaporation studies by WRD during this period of history were conducted by a team of specialists headquartered in Denver, Colo., and assigned to the General Hydrology Branch. The specialists included G. Earl Harbeck, Jr., J. Stuart Meyers, Alex M. Sturrock, Jr., Claude R. Daum, and Gordon E. Koberg.

To mention Earl Harbeck as an evaporation specialist does not properly credit his accomplishments in evaporation research and his international recognition as an expert in the mechanics of evaporation, evapotranspiration, and thermal pollution. Harbeck began his Survey career as a stream gager in Montana, then was placed in charge of a Subdistrict office in Murphy, N.C. Thus, as did many of his contemporaries who became leaders in hydrologic research, Harbeck not only learned the fundamentals of hydrology from field experiences but also quickly became cognizant of deficiencies in knowledge, experience, and techniques in the budding science of hydrology. He became a pioneer in developing high-speed computers for processing streamflow data, in applying rigorous thermal-loading principles to the measurement of lake evaporation, in using the Cummings radiation integrator in evaporation studies, and in evaluating the effectiveness of monomolecular chemicals in evaporation suppression.

Chief Hydrologist Hendricks sent a memorandum to Director Pecora on May 1, 1968, recommending that Harbeck be promoted to Research Hydrologist, GS–16. Hendricks' memorandum crossed Assistant Director Clarke's desk where it picked up this endorsement: "I consider Earl Harbeck to be one of the best scientists in the Survey."

The Denver-based evaporation team investigated evaporation in several lakes and reservoirs largely in but not limited to the Western United States. Other studies were topical and dealt with techniques and instrumentation required for evaporation measurement, and others were in support of water-resources investigations where knowledge of evaporation losses was needed to complete the hydrologic description of an area. A summary of these studies follows.

Effect on evaporation of release from reservoirs on the Salt River, Arizona, 1958–59.—The purpose of the study was to determine the relation between depths of releases from upstream reservoirs and evaporation losses from downstream reservoirs in a system of run-of-the-river impoundments. The system chosen for the study was the Salt River reservoir system consisting of four irrigation and power-generation reservoirs. The largest and uppermost is Roosevelt Lake followed by Apache Lake, the deepest, Canyon Lake, with the smallest storage capacity, and then Saguaro Lake, at the end of the system. Water is withdrawn from Roosevelt Lake at considerable depth and released to the three downstream reservoirs.

The investigations were made and funding was provided in cooperation with the Salt River Valley Water Users Association. Gordon E. Koberg was responsible for field operations. Alex Sturrock and Claude R. Daum installed the radiation station at Roosevelt Dam and the four raft stations on each of the reservoirs. Thermal surveys were performed at biweekly intervals by Sturrock. Salt River Valley employees were responsible for weekly maintenance checks at the radiation and raft stations.

Results of the study showed a considerable difference in evaporation losses from the four reservoirs and wide range in the ratio of reservoir- to pan-evaporation rates. It was shown that evaporation losses from the downstream reservoirs were much less than from the uppermost reservoir. The reason for the difference in evaporation losses was attributed to the release of cold water at depth from Roosevelt Reservoir, leaving the warm surface undisturbed and subject to higher evaporation losses. The cold water then reduced water temperatures in the receiving reservoirs, thus lowering their evaporation losses.

The results of the study were published in 1960 by the International Association of Scientific Hydrology in its Bulletin 19. Gordon Koberg, the principal author, pointed out in the report:

> Engineers and hydrologists who estimate evaporation from pan records should be aware that large amounts of heat usually available for evaporation are sometimes used for water heating [and] a reservoir regularly releasing cold water will have a higher evaporation rate than would be expected.

Evaporation control research, Laredo, Texas, 1959–60.—This project investigated a method of treating the surface of a water reservoir with a monomolecular chemical film to reduce evaporation.

Laboratory investigations had been made to formulate and test various dispersions of alkanol for their spreading ability and ease of dispersing. This field investigation was made to evaluate the effectiveness of the various formulations dispersed from several types of dispersers in reducing evaporation. The investigations were made in cooperation with the Southwest Research Institute and Southwest Agricultural

Institute, both of San Antonio, Tex., who, with the USGS, provided funds for the study.

Field studies were conducted on four 1-acre stock tanks near Laredo, Tex. Two of the tanks were 15 miles southeast of and two were 12 miles northwest of Laredo. The two tanks southeast of Laredo were identified as Briones and Zimmerman and the two northwest were the Carlos and Pinto Valle tanks. In addition to the tank tests, Essar Ranch Lake, a 10-acre lake 10 miles west of San Antonio, was used in the studies. Nine field tests were made beginning in the spring of 1959 at Briones and ending at Essar Ranch Lake in early fall of 1960.

Gordon E. Koberg was responsible for field operations. He was assisted by Alex M. Sturrock, Jr. Claude R. Daum assisted in disperser development and in the installation of equipment. R.R. Cruse, of the Southwest Research Institute, was responsible for providing the different alkanols that were used in the studies. The weekly observations and other details of the study were coordinated by C.L. Shrewsbury of the Southwest Agricultural Institute.

Results reported by Koberg and others in 1963 (WSP 1692) indicated that more studies were needed to define or improve certain aspects in the use of monomolecular films in suppressing evaporation.

Analysis of Techniques Used to Measure Evaporation From Salton Sea, 1961–62.—The purpose of this study was to provide a more accurate measure of annual evaporation losses from the Salton Sea in support of WRD's comprehensive investigation of the water resources of the Lower Colorado River. (See "Lower Colorado River project.") Previous studies were handicapped by the inadequate methods then available for determining evaporation.

From early January 1961 to early January 1963, evaporation from the Salton Sea was determined by three methods. Independent determinations by the water budget and energy-budget methods differed by 5 percent for 1- and 2-year periods. The average evaporation determined by these two methods established a coefficient for the simplified mass-transfer equation, which was the basis for a third independent determination of the yearly evaporation from the Salton Sea. Water-budget studies were made concurrently with the energy-budget and mass-transfer studies of evaporation as a part of determining the hydrologic regimen of the sea.

The investigations covered by this study were under the general supervision of C.C. McDonald, Project Hydrologist. The water-budget study was conducted by Allen G. Hely. Basic data required for the water-budget study were provided by the California SWB District. The Imperial Irrigation District, the Coachella Valley County Water District, the Sandia Corporation of Albuquerque, N. Mex., and the U.S. Navy assisted in the study. Funds for the study were from Federal appropriations to the USGS.

The study disclosed seasonal bias of the energy-budget evaporation attributed chiefly to the flat-plate radiometer. It was recommended that the accuracy for measuring this parameter be improved. G.H. Hughes reported the results of the study in PP 272–H (1967).

Evaporation Study in a Humid Region, 1961–64.—Prior to the 1960's, the techniques of measuring lake evaporation had been developed and applied, generally, to lakes in the Central and Western United States. In order to broaden the scientific basis for use of the mass-transfer and energy-budget methods of measuring evaporation to a more humid region, an evaporation study was begun in 1961 at Lake Michie, near Durham, N.C.

The mass-transfer technique, which is simple to apply, requires inexpensive instrumentation, and allows seepage estimates to be made, was used along with the water budget to determine evaporation losses at Lake Michie.

Data collection began in September 1961 and continued through July 1964. From recorded changes in lake-surface elevation and meteorological observations, a calibration for Lake Michie was developed. Analyses of the 25 months of available data indicated a pronounced seasonal variation in evaporation and in seepage.

James F. Turner, Jr., of the North Carolina SWB District office was responsible for field operations. Claude R. Daum provided instrumentation advice and instrument calibrations for the study. The evaporation study was part of a larger project in cooperation with the city of Durham for an evaluation of the water resources of the upper Neuse River Basin. Turner reported the results of the study in PP 272–G (1966).

A Study of the Effects of the Elimination of Thermal Stratification on Water Quality in and Evaporation From Reservoirs, 1962.—This study was made to evaluate possible changes in the quality of water in a reservoir by using an air-bubbling system to remove undesirable taste and odors from the water used for domestic purposes and to increase the dissolved-oxygen concentration in the hypolimnion of deeper parts of the lake. The study also addressed the effects on evaporation of eliminating thermal stratification in a lake.

The study was conducted at Lake Wohlford on Escondido Creek, 7 miles northeast of Escondido, Calif. During 1962, when the study was made, the contents of the reservoir averaged approximately 2,500 acre-feet with a surface area of 130 acres. Air bubbling was started on April 17 and continued until September

5, 1962, except July 15–24 when the thermocline was allowed to reform.

The seasonal variations in the concentration of dissolved oxygen near the surface and bottom of Lake Wohlford indicated that air bubbling maintained the dissolved-oxygen concentration in the hypolimnion above 5 ppm from April 18 to September 5, except for one period in August. During the rest of the year the natural mixing motion of the wind maintained the concentration above 5 ppm.

Air bubbling reduced the surface temperature in May, June, and July during which period the air-bubbling system was mixing the cold water of the hypolimnion with the warm water of the epilimnion. The mixing action decreased the water-surface temperature with an accompanying decrease in the evaporation rate.

Gordon E. Koberg was responsible for the field operation and liaison with the Escondido Mutual Water Company. M.E. Ford, Jr., of that company, monitored the collection of weekly water samples and was responsible for the air-bubbler operation. Funding for the study was provided through a cooperative agreement between the Survey and the Escondido Mutual Water Company. Koberg and Ford reported the results of the study in WSP 1809–M (1965).

Evaporation from Reservoirs on the Missouri River, 1962–67.—During the early to mid-1960's the Survey cooperated with the U.S. Army Corps of Engineers in reservoir-evaporation studies in the Missouri River Basin. The initial energy-budget studies were started in August 1962 at Kanopolis Reservoir near Salina, Kans., and at Garrison Reservoir at Riverside, N. Dak. Data collecting ended at Kanopolis Reservoir in November 1963 but continued through November 1964 at Garrison Reservoir.

The energy-budget instrumentation from Kanopolis Reservoir was installed at Pomme de Terre Reservoir near Hermitage, Mo., in April 1964, to determine evaporation in a more humid environment, and data collection ended in November 1965. The last of the evaporation studies for the Corps during this period was at Hungry Horse Reservoir near Kalispell, Mont., where data collection started in the spring of 1965 and continued through 1967. J. Stuart Meyers, assisted by Alex Sturrock, was responsible for instrument installation, maintenance, and data analysis at the Corps study sites. Funding by the Corps for the purchase and repair of instruments and for travel expenses was $1,000 to $2,000 per year. Administrative reports were written to the appropriate regional Corps offices, and no formal publications were produced.

Comparing Methods of Computing Lake Evaporation from Pretty Lake, Indiana, 1963–65.—The objective of this investigation was to compare the results obtained from three methods of determining evaporation in a non-Western environment—energy-budget, mass transfer, and water budget.

The hydrology and morphometry of Pretty Lake in northeastern Indiana made it possible to determine evaporation more precisely than would be possible in other settings. Small quantities of surface inflow and outflow, which could be measured accurately, permitted the computation of the water budget. The nearly circular shape of Pretty Lake provided the best conditions for measuring the temperature and wind parameters that are part of the mass-transfer and energy-budget computations for evaporation.

Evaporation from Pretty Lake was calculated during ice-free periods from April 1963 through November 1965 by using the three methods of evaporation determination. The results showed that the water-budget and energy-budget methods were more reliable over longer periods and at higher evaporation rates, but the mass-transfer method was more reliable for low-evaporation rates and provided adequate short-term estimates. The energy-budget method was also shown to be the most costly. The mass-transfer and water-budget methods required minimal equipment and computational costs, but use of incorrect constants and inaccurate estimates of seepage were shown to introduce errors of considerable magnitude during periods of high evaporation.

John F. Ficke of the SWB Research Section, stationed at the Indiana SWB District headquarters in Indianapolis, was responsible for field operations. Claude R. Daum provided instrumentation advice and radiometer calibration. Robert G. Lipscomb and Phillip Reed provided additional field assistance. G. Earl Harbeck, Gordon E. Koberg, and Malcolm D. Hale, District Engineer, SWB, Indianapolis, provided technical advice. The Indiana Department of Natural Resources and the Indiana Institute of Technology, Fort Wayne, assisted in the study. Ficke reported the results of the study in PP 686–A (1972).

Other evaporation studies.—A study of evaporation losses was conducted at San Carlos Reservoir in Arizona during 1964 to 1970 in support of the Gila River Phreatophyte Project that was under the leadership of Richard C. Culler (see "Phreatophytes").

In February 1965, an evaporation study at Falcon Reservoir on the Rio Grande downstream from Laredo, Tex., was started at the request of and funded by the International Boundary and Water Commission (IBWC). The project ended in 1968 and the results were reported to IBWC.

During the early to mid-1960's, evaporation studies were conducted at Morse Reservoir near Nobelsville, Ind., as a part of a water-resources investigation under the leadership of James E. Hiesel of the Indiana WRD District.

Evaporation studies were also made in North Dakota in support of the Prairie Pothole project (see "Prairie Pothole Project") under William S. Eisenlohr's supervision.

## Ground-Water Contamination

*By* George H. Davis

In his monumental treatise "The role of ground water in the national water situation" (WSP 1800, 1963), C. Lee McGuinness identified the following as major sources of ground-water contamination:

* Septic system effluents including nitrate, household detergents, and pathogenic organisms.
* Industrial wastes including chlorinated solvents, petroleum products, toxic metals, and, potentially, radioactive wastes.
* Agricultural chemicals—fertilizers, pesticides, herbicides, and defoliants.
* Migration of saline waters through improperly constructed or abandoned oil and gas wells and deep test holes for mineral exploration.
* Landfill leachates.
* Infiltration of sewage and chemicals from polluted streams.
* Saltwater intrusion from the sea or inland sources of saline waters.
* Acid coal-mine drainage.
* Pollution of cavernous aquifers through direct discharge of sewage.
* Concentration of salts through irrigation returns.

Nearly all these factors were addressed by the Division in specific investigations under the research program or as parts of areal ground-water investigations during the 1957–66 period. Judging by the number of people working on a topic, saltwater intrusion would have to be rated as the most widespread concern at that time. WRD personnel in most of the coastal States were involved in seawater intrusion problems, and workers in several inland States were focusing on other sources of salinity.

Water-Supply Paper (WSP) 1613, with Chapters A through F (1963–66), was devoted entirely to seawater intrusion on the Atlantic Coastal Plain. This included a general wrap-up by Hilton H. Cooper, Francis A. Kohout, Harold R. Henry, and Robert E. Glover. Specific areas were addressed as follows: eastern Long Island, New York, by Nathaniel M. Perlmutter and James J. Geraghty; western Long Island by Perlmutter and Frank A. DeLuca; Savannah area, Georgia, and South Carolina by Morris J. McCullom and Harlan B. Counts; Brunswick area, Georgia, by Robert L. Wait; and Nassau and Queens Counties, New York, by Norbert J. Lusczynski and Wolfgang V. Swarzenski. Others working on seawater intrusion along the East Coast included Harold E. Gill at Cape May, New Jersey; William C. Rasmussen and colleagues at the Chesapeake and Delaware Canal; and a host of people in Florida. The Florida studies included work in the northeastern part of the State by Boris J. Bermes, Gilbert W. Leve, and George R. Tarver; by Clarence B. Sherwood and Howard Klein in south Florida, and Jack T. Barraclough and Owen T. Marsh along the Gulf Coast. Elsewhere on the Gulf Coast, studies were carried out by Robert B. Anders and Wellborn L. Naftel in the Galveston area, and by John B. Wesselman in Orange County, Tex.

Not to be outdone, the Pacific area was represented by Willis L. Burnham and colleagues on the California Channel Islands (WSP 1539–O, 1963); by Robert E. Evenson, Harry D. Wilson, and Kenneth S. Muir in the Santa Barbara, Calif., area; Stuart G. Brown and Reuben C. Newcomb at Coos Bay, Oreg. (WSP 1619–O, 1963); Eugene R. Hampton in the Florence area of Oregon (WSP 1539–K, 1963); Grant E. Kimmel at Tacoma, Wash. (PP 475–B, 1963); and Frank N. Visher and John N. Mink in Hawaii (WSP 1778, 1964).

Among investigators of inland sources of salinity, James W. Hood and George E. Maddox worked in the Roswell Basin, N. Mex. (WSP 1539–M, 1963); Reed W. Mower and others on the problem of groundwater salvage along the Pecos River, Tex. (WSP 1659, 1964). Lester R. Kister and William F. Hardt studied salinity of ground water in Pinal County, Ariz. (WSP 1819–E, 1966); Roger C. Baker, Leon S. Hughes, and I. Dale Yost investigated sources of salinity in the Brazos River Basin, Tex. (WSP 1669–CC, 1964); and Allen G. Winslow, William W. Doyel, and Leonard A. Wood studied saltwater freshwater relations in the Houston area, Texas.

The next most studied topic was septic system effluents and agricultural and industrial pollution. Cooper H. Wayman, John B. Robertson and Harry T. Page carried out extensive research on alkylbenzenesulfonate (ABS) and other detergents and contaminants in soil-water environments (PP 450, 1962, and PP 475, 1963). Nathaniel M. Perlmutter and Irwin H. Kantrowitz studied ABS transport on Long Island, New York (PP 501–B, 1964); John Isbister investigated nitrate from fertilizers and septic systems (WSP 1825, 1966); Perlmutter, M. Lieber, and H.L. Frauenthal studied the movement of cadmium and hexavalent chromium in Nassau County (PP 475–C, 1963); and Donald G.

Jordan studied a wide range of ground-water contaminants in Indiana. Morris Deutsch considered ground-water contamination and legal controls in Michigan (WSP 1691, 1963); and Harry E. LeGrande developed a classification of hydrogeologic factors as related to liquid waste-site investigations. WRD advised and consulted with the Army in connection with problems related to deep-well injection of toxic wastes at the Rocky Mountain Arsenal, Denver, Colo., including the allegation that the injection was triggering earthquakes. Personnel involved included G. Earl Harbeck, Jr., Leonard Wood, Robert Brennan, Robert W. Stallman, Robert R. Bennett, John D. Bredehoeft, and Hilton H. Cooper. (See Part VIII, "Water Issues and Events.")

Another area receiving considerable attention involved problems related to oil-field brines, either through improper disposal of brines or their escape to ground water through improperly constructed or abandoned oil and gas wells or deep mineral test holes. Robert B. Leonard studied oil-field pollution of the Walnut River and shallow ground waters in Kansas (PP 501–B, 1964); and Alvin R. Leonard and Porter E. Ward investigated oil-field and salt-spring brines of western Oklahoma (PP 450–B, 1962); Herbert T. Hopkins investigated oil-field pollution in the Pittman Creek Basin, Kentucky; Charles H. Hembree and James F. Blakey examined brine pollution of the Hubbard Creek Basin, Texas; Robert A. Krieger and Gerth E. Hendrickson investigated oil-field brine contamination in the upper Green River Basin, Kentucky; and Charles W. Poth studied brines in aquifers in western Pennsylvania.

Acid coal-mine drainage was studied by John R. George at Beech Creek and by George W. Whetstone and John J. Musser in the Beaver Creek strip-mining area, Kentucky (PP 450–B, 1962). Ivan Barnes, Wilbur T. Stuart, and Donald W. Fisher investigated the mine waters of the Appalachian anthracite mining district (PP 473–B, 1964), and Barnes and Frank E. Clarke summarized the geochemistry of ground water as related to mine-drainage problems.

Contamination of ground waters by irrigation returns was investigated by Albert S. Van Denbergh in the Columbia Basin Project, Washington; in the Snake River Plain, Idaho, by Eugene H. Walker; and on Oahu, Hawaii, by Kiyoshi J. Takasaki. A multiyear Lower Colorado River Basin study conducted by Charles C. McDonald and others, and concerned in a major way with irrigation return flows, is summarized later herein. (See "Lower Colorado River Project.")

David W. Greenman, Donald R. Rima, William N. Lockwood, and Harold Meisler carried out investigations in the Coastal Plain of southeastern Pennsylvania with special reference to the impact of human activities on the quality of ground water.

Numerous other projects conducted during this period of history in the cooperative program involved ground-water contamination problems as part of broader investigations. These studies are referenced in Part X, "District Activities."

## International Programs

Condensed from material provided *by* Robert M. Beall.

Writing "International Programs" would not have been possible without reference to and liberal use of the "Historical Review of the International Water-Resources Program of the U.S. Geological Survey 1940–70" prepared by George C. Taylor, Jr., and published in 1976 as PP 911. Taylor's review suggestions are gratefully acknowledged. The careful review by George W. Edelen, Jr., is much appreciated as are the several comments by James R. Jones and George F. Worts, Jr.

### *Introduction*

An interim policy statement covering some aspects of international activities of USGS was approved by the Director in April 1963:

> In accepting proposals for activities in foreign areas,... the Survey feels that among the advantages to the agency requesting the work is the ability of the Survey to apply worldwide professional perspective, to select appropriate personnel from its large reservoir of trained specialists, to make available appropriate equipment from its rather complete stock, and to be able to support its work with such specialized professional and technical services as may be required.

Coordinating and directing the international activities of WRD was a Headquarters function, with minor exceptions, largely because the majority of assignments were initiated by State Department agencies and usually required negotiating and much paperwork. Those collaborative arrangements, which were subject to prevailing legislation and Executive Branch administrative policies, were effected through the office of an Assistant Secretary of the Interior and the Survey's Office of International Geology (OIG), which provided legal and administrative support. The Survey's interests were coordinated through its Foreign Activities Committee, for which the Foreign

Hydrology Section Chief (WRD) was the representative of the Division Chief.

### *Personnel*

During the Paulsen years, 1946 to 1957, the international program of WRD grew from a relatively minor effort involving fewer than five people in 1951 to a program involving more than 25 individuals in 1957 (T.E. Eakin, 1960, Foreign Hydrology Program, Water Resources Division 1950–1959, Administrative Report, 26 p., cited in G.E. Ferguson, Volume V, p. 64). Program growth led to establishing at Division level the Foreign Hydrology Section on April 7, 1957. Thomas E. Eakin, who had been Chief, Foreign Activities in the Office of the GWB Chief, was named Chief of the new section. Although Dagfin J. Cederstrom was frequently Acting Chief of the Section, Eakin continued as Chief until 1960 when he was succeeded by George C. Taylor, Jr., who served in that capacity through 1966.

Personnel directories show the following numbers of individuals:

| | Assigned to the Foreign Hydrology Section | On foreign assignments |
|---|---|---|
| July 1, 1957 | 7 | 17 |
| January 1, 1959 | 9 | 16 |
| January 1, 1960 | 9 | 15 |
| January 1, 1961 | 10 | 18 |
| January 1, 1962 | 9 | 19 |
| January 1, 1963 | 9 | 21 |
| January 1, 1964 | 9 | 21 |
| January 1, 1966 | 12 | 20 |
| July 1, 1967 | 10 | 21 |

The numbers do not include those, usually on detail from District offices, who were on short-term assignments of a few days or months in foreign areas. Frequently, individuals between foreign assignments or completing reports were assigned to the Office of the Section Chief. An "Overseas Projects Summary, 1957–1966 Fiscal Years," prepared in November 1965, showed 144 personnel assignments in 39 countries, involving 196 man-years of effort.

The Section Chief and his principal assistants, until 1961, were from the GWB because most of the assignments were to ground-water projects or to organizational development activities in that discipline. Prior to 1961, the staffing and technical support for surface-water projects was by the SWB Chief's Office. From 1961 to 1965, Luther C. Davis, Jr., an engineer, was assigned to assist the Section Chief. He was succeeded by George W. Edelen, Jr., also an engineer, for the remainder of this period of WRD history.

### *Publications*

Each of the projects involved progress reports to the sponsoring agency, to the host country, and to the Section Chief, in addition to a final summary report. Most of these were not published and have vanished from the scene. Many projects additionally reported the results of investigations, prepared regional hydrologic summaries, documented program recommendations, or made data compilations. Depending on the nature of the assignment, reports may have been in the form of memorandums, administrative reports, or open-file reports. Many of the latter were published later as WSP's. In addition, many reports were published by host-government organizations, or by international organizations, or in professional-society journals. Three WSP's document the results of foreign investigations: WSP 1608, "Contributions to the hydrology of Asia and Oceania," 13 chapters, 1961 to 1970; WSP 1663, "Contributions to the hydrology of Latin America and the Antilles," 6 chapters, 1963 to 1969; and WSP 1757, "Contributions to the hydrology of Africa and the Mediterranean region," 10 chapters, 1963 to 1970.

### *Training Foreign Participants*

In addition to providing administrative and technical support of Survey hydrologists overseas, the newly established Foreign Hydrology Section was responsible for planning and supervising training of foreign participants brought to the United States, principally under US AID programs. Requests for training also originated in the United Nations or its agencies, and in direct government-to-government arrangements through the U.S. Department of State (DOS). Training in the United States spanned the full range of WRD activities. Technicians to agency directors with advanced degrees were given training. The number of trainees increased to 57 in 1962 and thereafter declined somewhat. During 1957 to 1966, 244 counterpart scientists, engineers, and other technical personnel from 46 countries were given training (G.W. Brown and H.L. Fleming, 1969, OIG Project Report [IR] DC–15).

Ground-water training was initially the principal participant interest and was programmed by Garald G. Parker, Sr., Chief of the GWB Manpower and Training Section, and Victor T. Stringfield or Dagfin J. Cederstrom, both of whom frequently "sat in" for Eakin early in this period of history. Caroline Bush-Watkins, assigned to the OIG, carried much of the administrative load of the training activities. She transferred to the Foreign Hydrology Section in 1959 and in 1962 was succeeded by Rebecca A. Williams in the position titled "Foreign Training Assistant." Williams remained in that position through 1966. The OIG and particularly Gertrude W. Brown were supportive throughout.

Many of WRD's field offices and laboratories provided training to individual participants. However, the Denver Hydrologic Laboratory, A. Ivan Johnson, Chief, became an essential element in training most of the participants. The increasing numbers of participants led to the scheduling of group sessions at the laboratory preceding field-office assignments, beginning in 1963. (See Part VI, "Training Foreign Participants.")

#### *Bilateral Activities*

In terms of manpower and funding, the projects and assignments sponsored by the State Department's International Cooperation Administration (ICA)—succeeded by the Agency for International Development (US AID) in 1961—were the dominant components of the international program during the years 1957 through 1966. Bilateral activities also included direct arrangements through the U.S. Department of State with foreign governments for similar types of projects and assignments. The latter arrangements had the advantage of removing one layer of bureaucracy but also diminished a level of field support.

In terms of longevity, the program of data collecting performed by WRD for the International Joint Commission—United States and Canada (IJC) under provisions of the Boundary Waters Treaty of 1909—was the grandfather of bilateral foreign activities. This was not generally thought of as a "Foreign program" but rather a special OFA program. (See Part VIII, "International Treaties.")

Summary accounts of the country missions are followed by a section on the several assignments of a bilateral nature undertaken in furtherance of scientific and technical exchange and of domestic research projects.

##### Afghanistan

The basic mission, under ICA/US AID sponsorship, was to provide long-term support to the Afghan Helmand Valley Authority (HVA) in data collecting and in training an Afghan hydrologic staff to carry on those activities in furtherance of a variety of water-resource programs previously performed by Morrison-Knudsen-Afghanistan Company (MKA) employees. Ignatius A. Heckmiller, who had reported to Lashkar Gah in June 1954, was project leader until September 1959 when Robert H. Brigham arrived to replace him. Brigham remained until June 1964 when essentially all of the project objectives had been achieved. Over the course of its 12-year life, the project grew to operating 16 gaging stations, compiling and publishing streamflow, reservoir storage, and climatological records for the Darya-ye Helmand system through 1960, preparing and releasing hydrologic summaries during 1952 to 1964, establishing a Hydrology Section in the HVA, and training 15 Afghani technicians.

Based on recommendations by Taylor in a November 1961 visit, and implemented by Brigham, the Afghan government created an independent Water and Soil Survey Authority (WSSA) to continue the Helmand Basin work and to extend the activity to other parts of the Kingdom. In 1965 the WSSA was placed under the Ministry of Agriculture and Irrigation as the Water and Soil Survey Department (WSSD). Arthur O. Westfall arrived in March 1964 to head the project and Vito J. Latkovich came in July 1964. By 1966, activities were well underway in implementing a nationwide plan for surface-water investigations. Westfall summarized the surface-water investigations of the period 1952–69 in an open-file report published in 1969. Taylor (1976, p. 65) listed the 11 published reports generated by the Afghanistan mission.

##### Argentina

At the request of the Argentine Direccion Nacional de Geologia y Mineria (DNGM) to US ICA/Buenos Aires, Stuart L. Schoff was assigned for the period July to October 1959 to evaluate several aspects of the DNGM's Hydrogeologic Service. His evaluations were contained in an administrative report of April 1960. He also participated in reconnaissance ground-water studies of three areas (Taylor, 1976, p. 13). In 1962 US AID/Buenos Aires responded to an Argentine request for assistance in a ground-water study in the lower Rio de La Plata area. William W. Doyel, assigned to work with the local agency during July and August 1962, designed a 4-year project designated "Ground Water in the Northeast of Buenos Aires Province."

##### Australia

Most of the activities in Australia were conducted under bilateral arrangements with Australian Federal or State agencies.

In September 1963, at the request of the Commonwealth Scientific and Industrial Research

Organization (CSIRO), Walter B. Langbein participated in a National Symposium on Water-Resources Use and Management at Canberra. He later consulted with CSIRO officials on hydrologic research and water-data programs.

Under provisions of Public Law 87–626 enacted on September 5, 1962, allowing wider scientific and information exchange and allowing certain hydrologic investigations and research outside the national domain, Stanley A. Schumm, during October 1964 to July 1965, studied the ancient and recent slopes and channels of the Murrumbidgee River system in New South Wales.

At the request of the Australian Water Resources Council, Stanley W. Lohman lectured on ground-water hydraulics in May 1967. He also advised the Australian Bureau of Mineral Resources, Geology and Geophysics in Canberra on the organization of a proposed Hydrogeological Branch.

In the first of a series of consultancies, Dan A. Davis visited the U.S. Naval Communications Station at Northwest Cape in May 1966 to advise on water problems and development. This was at the request of the U.S. Naval Facilities Engineering Command—not a bilateral activity as such.

***Belgium***

Under the auspices of the AEC, Eugene S. Simpson, from December 1960 to August 1963, assisted the Belgian Center for Nuclear studies in developing long-term hydrologic and hydrogeologic investigations at Mol, about 80 kilometers north of Brussels.

***Brazil***

Brazil has been the home-away-from-home for many WRD personnel. The first, during the period 1957 to 1966, was the assignment, under the auspices of US ICA, of Robert Schneider to make the first appraisal of the status of investigating and developing Brazil's ground-water resources. In the course of defining the principal ground-water provinces and their development potential (WSP 1663-A, 1963), and in reports to the counterpart agency, he set the stage for systematic operation of ground-water data networks and for areal investigations.

From July 1961 to January 1964, Dagfin J. Cederstrom assisted an educational project sponsored by the Departamento Nacional de Producao Mineral (DNPM) under US AID auspices in a study of ground-water geology and hydrology. A number of students received training and many more benefited from a general text "Agua Subterranea," which he wrote in Portuguese. It was published by US AID and widely distributed. Cederstrom also made a reconnaissance of the ground-water resources in northeastern Brazil early in 1962, identifying problem areas and development potential, later to be included in the regional investigations program.

As part of a general long-term US AID-sponsored development program for northeastern Brazil, a field investigation involving WRD personnel began in June 1962 with the arrival of Stuart L. Schoff in Recife to develop a proposal for a ground-water study of the region during a 3-month assignment. His proposal was soon expanded by US AID to include surface-water investigations. Leonard J. Snell arrived in January 1963 to become surface-water project chief and advisor to the principal counterpart agency, the Hydrology Division, Natural Resources Department of the Superintendency for Development of the Northeast (SUDENE). Schoff returned to Recife in June 1963 to become project chief for the ground-water studies and also an advisor to SUDENE.

William C. Sinclair was assigned to the ground-water study from December 1963 to November 1968. Harry G. Rodis participated in it from June 1964 to August 1966. Schoff returned to the U.S. in September 1967 leaving Sinclair in charge of the ground-water investigations. Robert O.R. Martin was assigned to the project from March 1964 to March 1966, overseeing computing and publishing an enormous backlog of rainfall and streamflow data. George E. Philipsen assisted him in this effort on a 3-month detail in early 1965. Snell returned to the U.S. in October 1965 and was replaced in August 1966 by William F. Curtis.

Elsewhere in Brazil, other projects were underway. In June 1964, during Snell's assignment to SUDENE, he reviewed hydrologic-data activities and requirements for the Interstate Commission for the Araguaia-Tocantins Valley (CIVAT), covering 770,000 square kilometers in east-central Brazil. In July 1964, he made a preliminary assessment of a national program of surface-water investigations. The organizational needs were detailed by Adrian H. Williams during an assignment in the first 3 months of 1966 during which the new Brazilian National Department of Water and Electrical Energy (DNAEE) became operational. Active technical support of the new agency began under interim US AID funding in February 1966 when Floyd F. LeFever arrived in Rio de Janeiro to become senior advisor in hydrology to DNAEE. He remained in this position until September 1966.

Measuring the Amazon River flow in 1963 and 1964 attracted worldwide attention. This began with an effort by the International Association of Scientific Hydrologists in 1957 to assess world production of river-borne dissolved solids. There was little information on the Amazon. In May 1961, Luna B. Leopold, Walter B. Langbein, and Professor H. O'R. Sternberg, University of Brazil, developed a joint proposal for measuring the flow, solute load, and sediment concentration of the river. With the backing of the Brazilian Navy and using one of their vessels, three expeditions were made in July 1963, October and November 1963, and August 1964 by a team led by Roy E. Oltman and assisted by Frank C. Ames, Luther C. Davis, Leonard J. Snell, Professor Sternberg, and several Brazilian naval officers. The results were summarized in USGS Circulars 486 and 552.

***Cambodia***

At the request of US ICA/Phnom Penh, Robert V. Cushman was assigned to Cambodia in March to May 1958 to advise on current ground-water problems and to recommend a long-term program of investigations. A program began and a 1,065-hole drilling program was completed over a 3-year period.

Leonard Snell, during his ICA assignment in the Philippines, was detailed to ICA/Phnom Penh during January and March 1959 to organize a stream-gaging program for the Cambodian Ministry of Agriculture. After a field reconnaissance of central Cambodia, he provided training for 10 technicians of the Irrigation Service, selected sites for a dozen gaging stations, and developed detailed plans for training and organization.

William C. Rasmussen arrived in Phnom Penh in November 1963 to evaluate the results of Cushman's ground-water exploration program and to recommend future work and training. However, the Cambodian government terminated U.S. technical assistance and Rasmussen was reassigned to South Vietnam in January 1964.

***Chile***

In 1957, Robert J. Dingman was in Chile on a long-term assignment sponsored by US AID and in the midst of a program of ground-water investigations. The principal counterpart agencies were the Corporacion de Fomento de la Produccion (CORFO) and Instituto de Investigaciones Geologicos (IIG). The scope of ground-water investigations was expanded in 1958 and William W. Doyel and Robert W. Devaul arrived in Santiago in February 1959. Devaul returned to the United States in December 1961, Doyel in April 1962, and Dingman in June 1962, on termination of WRD technical assistance. The results of this program were summarized by Taylor (1976, p. 25, 26).

***Costa Rica***

After the eruption of Irazu Volcano in March 1965, the government of Costa Rica, through US AID, requested technical assistance in a variety of investigations. One of these was a short-term mission to advise the National Water Supply and Sewerage Service (SNAA) on problems related to ground-water development, protection, and program design. William D.E. Cardwell, assigned to Costa Rica from August to October 1964, reconnoitered several areas of the country and developed a 2-year program of hydrogeologic investigations. His recommendations were soon implemented in a program under the auspices of the United Nations, funded by the United Nations Development Programme.

***Cuba***

WRD studies in Cuba during this period were at the request of the U.S. Navy Department and concerned the water supply of Guantanamo Bay Naval Station. Horace Sutcliffe, Jr., and L.W. Hyde visited the Naval Station during September 1959 to June 1960 and provided recommendations on the construction of infiltration galleries, which were followed. From January to April 1963, Sutcliffe returned to the Station with Solomon M. Lang to assess the operation of the galleries and to recommend further measures.

***Egypt***

The United Arab Republic (UAR) formed the General Desert Development Authority (GDDA) in 1959 and requested US ICA assistance in designing a program of ground-water investigations in an area encompassing four large oases—Kharga, Dakhla, Bahariya, and Farafra, collectively designated as the New Valley of the Western Desert of Egypt. Philip E. LaMoreaux was assigned to Cairo in November 1959 to develop a ground-water program in the New Valley.

WRD technical field support began in June 1960 when Herbert A. Waite arrived in Cairo as principal project advisor to GDDA and to US AID/Cairo. In late 196l, GDDA was renamed the Egyptian General Desert Development Organization (EGDDO): Waite served until August 1962 and was succeeded by Raymond W. Sundstrom, who arrived in June 1962 and continued as principal advisor until his return to the United States in September 1964. His successor, Robert L. Cushman, arrived in Egypt in March 1965 and served as principal project advisor until the planned phaseout of WRD support in May 1967. During the 7 years of technical assistance, the following WRD personnel also contributed to the program: Raymond W. Sundstrom, June to October 1961, trained EGDDO hydrologists and engineers in quantitative methods of aquifer evaluation; Frank E. Clarke, May to July 1962, May 1963, May 1964, and March and April 1965, advised EGDDO on corrosion problems with wells and pumping equipment; Paul P. Bieber, January 1962 to

July 1964, assisted Waite and Sundstrom; Herman R. Feltz, March to June 1963 and June to July 1965, evaluated water-quality assessment facilities and procedures; Leopold A. Heindl, June to August 1963, resolved problems of preparing and publishing reports; George A. LaRocque, October to December 1963, trained EGDDO engineers in quantitative methods of aquifer testing and analysis; Herbert E. Skibitzke and Russel H. Brown, March 1964, advised on aquifer analysis and analog modeling; Albert E. Robinson, March to June 1964, assisted EGDDO in constructing an analog model of the New Valley; and Joseph S. Gates, March 1965 to May 1967, replaced Bieber and assisted Cushman until the planned phaseout of the program.

***Ethiopia***

WRD technical assistance in Ethiopia began in February 1966 when David A. Phoenix was assigned to that country for that month at US AID request to complete ground surveys and airborne reconnaissance of 52,000 square kilometers in southern Sidamo Province. He classified the favorability of areas for development and outlined a long-term program of investigations and pilot development. Ground- and surface-water programs were begun after 1966.

***Ghana***

The Volta River Authority of Ghana requested that US AID/Accra provide a specialist to evaluate the status of ground-water exploration and development in Ghana and to recommend measures for strengthening the existing program of the Ghana Division of Water Supplies. Harold E. Gill was assigned to Ghana from February to May 1964 and completed a nationwide reconnaissance assisted by personnel of that Division and of the Ghana Geological Survey. In addition to making recommendations on organization and operations, Gill reported on the availability and use of ground water in Ghana and described the major geohydrologic provinces in WSP 1757–K, 1969.

***Guyana***

George F. Worts, Jr., made a brief study of ground-water conditions in the coastal artesian basin of then British Guiana at the request of US AID from February to April 1957. His report, proposing further investigations, was published in 1958 by the Guyana Geological Survey as Bulletin 31 and as WSP 1663–B in 1963.

***Haiti***

After a Haitian request to US ICA, Herbert A. Waite, in August and September 1959, assayed the sources of water for Port-au-Prince and 12 towns and villages in the Department du Nord and recommended ways of improving the supplies.

***India***

In early 1966 US AID/New Delhi requested the services of WRD to evaluate the status of hydrologic knowledge and water-resource development in the Ganges Plains, where extensive tubewell installations had been made to supplement irrigation from canals. Paul H. Jones and Walter Hofmann were assigned to this mission after 1966.

***Iran***

Following earlier work by Karl Jetter, John A. Baumgartner continued to develop a program for collecting and publishing streamflow data in Iran. Baumgartner died in February 1959 and was succeeded by Alvin F. Pendleton, Jr., who guided the project until its termination in August 1963.

Joseph W. Lang's 1952 reconnaissance of ground-water conditions and problems resulted in a series of observations and recommendations that were acknowledged by the 1959 establishment of a Ground Water Division of the Hydrographic Service. In 1960, Pendleton assumed the additional responsibility for advising the Division until he departed Iran in 1963.

By 1963, the national stream-gaging program had been expanded to 230 fully equipped stations, administrative and technical operations were being carried out in nine district offices, an Iranian staff of 200 hydrologists and technicians were given training in surface-water data collection and analysis, 100 precipitation and evaporation measuring sites were equipped, three sediment labs and a central soils and water lab became operational, a hydrological yearbook series was firmly established, and a ground-water staff grew to number 135 professionals and technicians. Expansion and progress by Iran continued after 1963.

***Iraq***

In March 1959, at the request of US ICA/Baghdad, Edward Bradley was assigned to Iraq to advise the Iraqi Development Board on designing a long-term program of ground-water investigations. However the United States bilateral assistance program was soon terminated and Bradley was reassigned to Jordan the following May.

***Israel***

US AID/Tel Aviv was requested by Water Planning for Israel, Ltd. (TAHAL), to provide a specialist to evaluate the Cenomanian-Turonian aquifer in central Israel. Robert Schneider was assigned to this work from April to June 1962. Schneider reported his results and recommendations in WSP 1608–F, 1964.

#### Japan

At the request of the U.S. Air Force, Joseph T. Callahan made a brief evaluation of ground-water development problems at Misawa Air Base on northern Honshu Island in October 1964. This was one of a series of technical consultation services on water-supply problems at U.S. Air Force installations in Japan.

#### Jordan

Edward Bradley was assigned to US ICA/Amman from May 1959 to June 1960 to serve as a ground-water technical advisor to the Jordan Development Board's Water Resources Department (JWRD), later the Central Water Authority (CWA). He provided training to several JWRD professionals and in collaboration with other, non-WDR hydrogeologists, completed a nationwide well inventory and made 22 site studies, chiefly near Amman and in the West Bank. Floyd F. LeFever was assigned to this mission as surface-water specialist from March to May 1962. C. Richard Murray was assigned to Amman from March to August 1962. He recommended studies needed in the Jordan Valley and elsewhere in the country, encompassing areal and subsurface geology, ground-water occurrence, recharge and discharge, test drilling, water-quality analyses, ground-water law, and training. Ground-water studies in two areas of the Jordan Valley were started under Murray's direction and completed by the CWA.

Edward S. Davidson was assigned to the mission from January to March 1966. He studied the problems of the West Bank irrigation system near Jericho and suggested ways to stabilize the fresh-water levels, arrest saline-water intrusion, and recharge the productive aquifer. Remedial measures were undertaken but later suspended because of the hostilities of June 1967.

#### Korea

The WRD first participated in the water-resources sector of the US/South Korean bilateral technical assistance program in January 1963 when Dingman and Doyel were assigned, at US AID/Seoul request, to make a preliminary survey of the ground-water resources of South Korea and to recommend an exploration and development program. They completed a reconnaissance and a report during their three-month mission and provided alternative 5-year and 4-year plans for investigations and training. Neither plan was adopted and in September 1964, Callahan was again assigned to Seoul to reevaluate the Dingman/Doyel proposals and to assist Republic of Korea officials in reaching a decision on a plan. Implementation stalled in a change of policy by US AID/Seoul favoring integrated river-basin development. US AID/Washington then requested the services of a DOI team to develop a comprehensive plan of study of the Han River Basin. In April to June 1965, Callahan and two BOR employees prepared a plan that was implemented in February 1966. Callahan then returned to Seoul to head the Ground Water Division of a joint survey team.

#### Kuwait

At the request of the Government of Kuwait, WRD provided the services of Harold E. Thomas to assess several aspects of Kuwait's water resources and to evaluate consultants' proposals for ground-water development and for desalting plants. With funding by the Kuwait government, he visited the country during November and December 1965. His Open-File Report 75–630 quantified the prospects of importing water from Iraq, underground storing and withdrawing water, developing fresh or brackish ground water, expanding desalinization, and integrating the development of the several resources.

#### Libya

Under an agreement between the U.S. TCA and the Government of Libya, a program of long-term technical assistance in ground-water exploration and pilot development with WRD support became operational in 1952. Assignments during the early years (1952-57) were documented in Ferguson (Volume V, p. 67). The broad objectives of the "Ground-Water Geology Project" were investigating, reporting, collecting and managing data, promulgating water legislation, developing a water-resources organization, training counterparts, and providing advisory services to the Libyan government, US AID, and others.

Cederstrom who began his assignment in Libya in July of 1955, completed his assignment in the Tarabulus (Tripolitania) area and left in July 1957. Robert C. Vorhis was assigned to Libya in January 1956 and remained until September 1960, first working with Cederstrom in coastal Tripolitania and later continuing his own studies in that area. He also trained Libyan counterparts and established data-management procedures in their Department of Agriculture. G. Chase Tibbitts, Jr., who had arrived in Libya in April 1956 and remained until October 1962, engaged mostly in exploratory drilling and investigations in the Fezzan region of southwest Libya. Doyel came to the Wilayat Barqah (Cyrenacia) region of northeast Libya in August 1956 and remained until September 1958 doing exploratory drilling and areal ground-water investigations in the Benghazi, Derna, and Tobruk areas.

Doyel's work in the Cyrenacia region was taken up by Thomas G. Newport during the period March 1959 to June 1961. James R. Jones, assigned to Benghazi as team leader in March 1958, supervised exploratory drilling and investigations in the coastal plain and littoral zone.

During January 1960, Wilbur T. Stuart made a study of water-level declines in the Tripoli area. William Ogilbee continued the work of Vorhis in the Tripolitania region from November 1960 to December 1962, complementing Tibbitts' activities in that region.

In 1960, Jones, Tibbitts, and Newport, along with Libyan counterparts, conducted a regional ground-water reconnaissance of the vast desert region of eastern Libya from the Mediterranean coast south to the central Sahara, leading to the discovery of extensive aquifers in the Kufra Basin. In 1962, Jones' headquarters was transferred from Benghazi to Tripoli for more effective management of the remanent project field activities. He continued there until June 1964, guiding the organizational development of a Water and Soil Department, and also the development of a national water law, in addition to providing advisory services on ground-water development and management to the government of Libya, US AID, international agencies, and others.

### Nepal

The Government of Nepal requested US AID/Kathmandu to arrange for a nationwide hydrologic survey including recommendations for a water-data collecting network and an organization to perform the work. Fred M. Veatch (May to August 1961) and Harry Hulsing (June to October 1961) completed a reconnaissance of the river basins in the Kingdom and proposed an agency organized to perform water-resources investigations.

A nationwide Hydrologic Investigations Project began in May 1962 with the arrival of Daniel E. Havelka. During the next 2 years, he trained Nepalese engineers in basic field methods, established a number of gaging stations, and organized a Department of Hydrology and Meteorology. William F. Curtis succeeded Havelka from June to November 1964 and began collecting sediment-data at key gaging stations, established a sediment lab, and trained Nepalese counterparts. Woodrow W. Evett reported to Nepal in December 1964 to continue and expand on the activities of his predecessors during a 4-year stay.

### Netherlands

Joseph E. Upson, II, was stationed at The Hague for 10 months between July 1958 and July 1959, supported by a Rockefeller Foundation Public Service Award. He observed Dutch methods of ground-water utilization and management that might be applied to investigations in the U.S. coastal zones and studied the effect of glacial and postglacial sea-level fluctuations on fresh and saline ground-water zones.

### Nigeria

WRD's assistance in water-resources investigations in Nigeria (supported by US AID/Lagos) began in June 1961 when Harold E. Thomas and Lee C. Dutcher made a one-month review of requirements for ground-water investigations in the northern region of the country. Their review and recommendations led to the assignment of David A. Phoenix to Kaduna from November 1962 to November 1966 as senior advisor to US AID and the Geological Survey of Nigeria (GSN). He advised US AID and GSN and provided general direction and logistical support to the Chad and Sokoto Basin projects and to the water-quality laboratory operations in Kaduna. He also made reconnaissance ground-water studies at six sites and lectured at the university centers at Ibadan and Zaria.

Chad Basin studies began in January 1963 with the assignment of Raymond E. Miller to Maiduguri, northeastern Nigeria. He was joined by Richard H. Johnston in March 1963 and effectively completed the first phase of the 65,000-square-kilometer basin study with the assistance of Nigerian hydrogeologists and technicians who were given on-the-job training. Frank E. Clarke visited the project in March 1965 to evaluate corrosion problems and to suggest control measures. Johnston returned to the United States in April 1965 and Miller, in May 1965. Chase Tibbitts was assigned to Maiduguri in January 1966 for a second phase of studies in the Chad Basin.

Another ground-water exploration, that of the 65,000-square-kilometer Sokoto River Basin in northwestern Nigeria, began with the arrival of William Ogilbee in Sokoto in March 1963. Henry R. Anderson joined Ogilbee in June 1964. Ogilbee returned to the United States in July 1965 and Anderson in October 1966. Raymond T. Kiser was assigned to Kaduna in June 1965 to expand the activities of the GSN Laboratory.

The Federal Ministry of Economic Development requested further US AID assistance to conduct a comprehensive inventory of Nigeria's water resources. William H. Robinson was assigned to this task from January to April 1963. His recommendations were implemented only to pursue surface-water investigations in the northern and eastern regions. Billy E. Colson was assigned to Kano in north-central Nigeria in July 1964 to assist the local agencies in developing a long-term surface-water program and in training

Nigerians in stream-gaging methods and in sediment and water-quality sampling techniques. Colson returned to the United States in November 1968. Charles R. Sieber was assigned to Kaduna from September 1964 to October 1966 to help establish a regional hydrologic office where all northern Nigeria records could be centrally managed. For a variety of reasons this did not come to pass. Several Nigerians were trained in basic stream-gaging methods. Elizardo D. Lucero was posted to Enugu in southern Nigeria from November 1965 to August 1967 to organize a Surface-Water Hydrology Department in the Regional Ministry of Works. With a high degree of counterpart support, he trained 30 Nigerians in basic field methods and techniques and left a competent organization in operation.

Harold Thomas revisited Nigeria in April-May 1966 to review progress on USGS-assisted water-resources investigations and to present recommendations for continuation of activities. Political instability precluded a workable extension of WRD assistance which ended with Colson's departure in November 1968. Taylor (1976, p. 57) lists 21 formal reports generated during the 1961–68 period of active engagement. A number of these were published by the GSN.

***Pakistan***

The "West Pakistan Ground Water Survey—Project 035" was very active and productive during the years 1957 to 1966, during which the following WRD personnel, in approximate chronological order, provided a wide variety of services to the project: G.A. LaRoque, December 1953 to July 1958; C.C. Yonker, June 1955 to June 1957; R.T. Kiser, July 1955 to April 1958; R.L. Cushman, January 1957 to January 1959; A.N. Sayre, November and December 1957; G.W. Caughran, October 1957 to January 1960; D.W. Greenman, December 1958 to September 1960; E.W. Patten, April 1960 to April 1962; W.V. Swarzenski, June 1961 to October 1965; G.D. Bennett, January 1962 to December 1966; M.W. Mundorff, September 1962 to December 1966; J.W. Hood, September 1962 to September 1964; H.L. Young, August 1963 to December 1966; F.E. Clarke, March 1964, March and April 1965, October and November 1966; and G.T. Malmberg, June 1965 to July 1969.

After 13 years, Project 035 was terminated in June 1967 and WRD technical support was redirected toward hydrologic monitoring and research.

An important ancillary activity was the work of a DOI Panel of Experts convened at President Kennedy's request to address the technical and socio-economic problems associated with waterlogging and salinity in the Indus Plain. The Panel, which included Walter B. Langbein, Thomas Maddock, Jr., and Herbert E. Skibitzke, did its work during 1961–63, producing a report in 1964 from President Johnson to the President of Pakistan titled "Report on Land and Water Development in the Indus Plain."

***Panama***

At the request of the Panamanian Instituto de Recursos Hidraulicos y Electrificacion (IRHE) to US AID, Joseph T. Callahan, in February 1962, evaluated the needs for a ground-water investigation program in the west-central region of Panama and proposed a long-range program. In July and August 1962, Harold Thomas assisted officials of IRHE and governmental groups in developing a National Water Code that later resulted in government decrees regarding water uses and rights and in establishing a National Water Commission.

Callahan's proposals of 1962 were incorporated in a comprehensive 5-year "Cadastro Rural de Tierras y Aquas de Panama." As part of that program, Dingman was assigned to Panama from October 1964 to January 1965 to train IRHE professionals in geohydrologic and geophysical field methods and to recommend program and institutional arrangements.

***Peru***

In 1957, Stuart Schoff was at the midpoint of a 4-year, US AID-supported assignment to carry out ground-water appraisals of critical areas throughout the arid coastal region of Peru. Working with a Peruvian engineer-geologist, Juan L. Sayán M., a comprehensive investigation of the Lambayeque Valley in northern Peru was completed in 1958 (WSP 1663–F, 1969). Between August and November 1958 Schoff and Sayán conducted a general reconnaissance of ground-water conditions in seven provinces of southern Peru which had been subjected to a severe drought in 1955–56. Their findings were published in 1959 as part of a 30-volume report "Plan Regional para el Desarrollo del Sur del Peru."

***Philippines***

Richard Murray arrived in Manila in January 1957 to advise a new Ground Water Unit of the Irrigation Division, Bureau of Public Works (BPW). He helped develop its organization, guided the purchase of instruments and equipment, and trained their personnel in techniques of ground-water investigations and report writing.

Assistance from WRD also was requested in reviewing a prospective national stream-gaging, water-quality, and precipitation-data program. Fred Veatch was assigned to this task from February to June 1957.

His recommendations were accepted and implemented with the arrival of Leonard Snell in May 1957. Records for the postwar years were recomputed, compiled, and published by the BPW under Snell's direction. He and Murray also helped to establish a laboratory for sediment, water quality, and soils analysis. Snell returned to the domestic program in May 1959 and Murray returned in 1961.

At the request of the Navy Department, George F. Worts conducted a hydrologic reconnaissance of the Poro Point area on Luzon Island in October 1961 to assist in the development of a water supply for Wallace Air Force Station. An administrative report was given to the Navy in 1961 and technical findings were published in WSP 1608–E (1964).

***Saudi Arabia***

Beginning in 1950, Glen F. Brown planned and directed a massive effort of geographic and geologic mapping of the Arabian Peninsula, assisted by Roy O. Jackson, geologist, Simon H. Kfoury, cartographic technician and translator, both assigned to WRD, and many others. Between 1955 and 1963, USGS geologists worked on the Saudi mapping project in Washington. The twin maps for each of the 22 quadrangles were published between 1958 and 1964 at a scale of 1:500,000. The data were also compiled on two, 1:2 million scale, geographic and geologic maps published by the USGS in 1958 and 1963. After 1963, Brown was involved with a joint USGS-Saudi Arabian Government (SAG) project to assess the mineral-resources potential of the Precambrian Shield region of central and western Saudi Arabia.

Throughout the 1950's and 1960's, Brown also provided water-resources advice to the SAG Ministry of Agriculture and Water on several irrigation schemes and municipal supplies. He then assisted the SAG in developing a nationwide plan to explore and develop ground water.

***Sudan***

Following program recommendations by Waite in 1955, the Geological Survey of Sudan (GSS) requested technical assistance from US AID/Khartoum in implementing Waite's proposals. Harry G. Rodis was assigned to Sudan from May 1961 to May 1963. His tour resulted in the organization of a Ground Water Section in the GSS, systematic managing of nationwide hydrogeologic data, and training a 15-man Sudanese staff in areal ground-water investigations. Studies of ground water in the Kordofan Province, central Sudan, and other areas were made. Results of the Kordofan Province studies were published in PP 475–B (1963) and in WSP 1757-J (1968).

***Thailand***

In 1954 Philip E. LaMoreaux provided the Thai government and US AID/Bangkok with recommendations for organizing and training a ground-water staff and for expanding ground-water exploration and development in the Khorat Plateau region of northeastern Thailand. His recommendations were acted on with the assignment of a US AID hydrogeologist to the project. At US AID/Bangkok request, LaMoreaux revisited the Khorat Plateau in May 1961 to review the results of his 1954 recommendations. His administrative report provided recommendations for additional investigations and well drilling. The US AID hydrogeologist and his Thai colleagues carried out the Khorat Plateau work until the project was terminated in June 1965.

***Tunisia***

Late in 1958, Robert Vorhis was detailed from Libya to make a ground-water reconnaissance of the island of Djerba and the adjacent Zarzis peninsula to evaluate the availability of water in brackish aquifers to supply a desalinization plant. Subsequently, US ICA/Tunis was requested to provide long-term technical assistance in geohydrology. Harold Thomas arrived in Tunis in December 1959 and directed the project until January 1962. Lee Dutcher reported to Tunisia in June 1960 to assist Thomas and remained there until September 1963. Four deep test wells were drilled in the Tabulbah area, enabling a special study of the 13,600-square-kilometer Sahel de Sousse region of central Tunisia; and in the process provided advisory services to the government's well-drilling section as well as field training to six Tunisian technicians. They also prepared a feasibility study on a 3-year US AID development grant project for drilling and equipping 50 production wells. That project was partly implemented by the assignment of Vinton C. Fishel to Tunis from January 1964 to July 1965. Dutcher, Thomas, Fishel, and Vorhis reported on their projects in WSP 1757–E, F, and G, in eight duplicated reports in French and English issued by the Tunisian collaborating agency, in two journal articles, and in an open-file report.

***Turkey***

Kenneth N. Phillips was assigned to Ankara from April to June 1957. With hydrologists of the Electric Power Resources Survey Administration (EIEI), he visited field sites and reviewed the office procedures of the stream-gaging program. On the basis of Phillips' recommendations on training and improving equipment, US ICA supported a 4-year project under which Carl C. Yonker guided the effort from December 1958 to April 1961. Leonard Snell continued the project from June 1961 until its termination in December 1962.

In 1962, the Ground Water Division (GWD) of the State Hydraulic Works (DSI) requested US AID/Ankara to provide the services of a ground-water adviser to assist in designing and conducting more intensive areal studies. Richard Murray was assigned to this task from January 1963 to May 1965, during which pilot ground-water development projects were begun in a dozen areas. Additional requests by DSI to US AID/Ankara for short-term assistance in the mid-1960's were accommodated by Robert L. Cushman who, from May to August 1964, demonstrated methodologies of aquifer tests and quantitative analyses and directed field seminars in applied ground-water hydraulics; Frank Clarke, in March 1965, advised on well-corrosion and encrustation problems; and Paul Jones, in May and June 1967, reviewed GWD activities in borehole geophysics and directed a seminar on electric-log interpretation.

*Vietnam*

At the request of US AID/Saigon, William C. Rasmussen assisted in designing a program for developing ground-water supplies for villages and towns in South Vietnam during January to March 1964. In April 1964 he returned to implement the program as Acting Associate Chief of a Rural Water Supply Task Force. In October 1964 operational activities were turned over to the Vietnamese and reduced to secure areas of the country which by then was in conflict with North Vietnam. Rasmussen then became chief adviser to US AID/Saigon in surface- and ground-water investigations and in training counterparts in the South Vietnamese Directorate of Water Supply. Eugene Shuter directed a seminar in borehole geophysical logging during August and September 1965. Rasmussen's tour ended in April 1966. (Author's note: Bill Rasmussen resigned from the USGS after this period of WRD history ended, returned to Vietnam as a consultant, and was killed May 11, 1973, when the jeep in which he was riding detonated a land mine.)

*Zimbabwe (Rhodesia)*

Under US ICA sponsorship, P. Eldon Dennis, from May to October 1959, made a ground-water reconnaissance of Zimbabwe (then Southern Rhodesia), particularly of the irrigation potential of the Sabi River valley in the southeast, the Kalahari sands and basalt beds of the Gwaii region in the West, and an artesian belt in the Sebungwe region. His recommendations were carried out by the Rhodesian Division of Irrigation and Lands. Technical findings were given in a 1960 administrative report and in WSP 1757–D (1964).

*Scientific and Technical Exchange and External Research*

The U.S. National Academy of Sciences (NAS) National Research Council (NRC) sponsored numerous activities in collaboration with foreign counterpart organizations in which WRD was asked to participate. For example, Walter Hofmann was a member of the NAS-NRC Latin America Science Board's Task Force which visited a number of Central and South American countries during October to December 1964 to identify the needs for regional research-training institutions. In August 1965, Harold Thomas participated in an NAS-NRC Africa Science Board Workshop on Science and Development in Africa, convened in Bellagio, Italy. Nicholas C. Matalas presented a paper at the February 1966 Symposium on Statistical Methods in Hydrology in Montreal, jointly sponsored by the NAS-NRC and the Canadian NRC. The Committee on Polar Research of this U.S./Canadian group also held a meeting in St. Helaire, Quebec, in April 1966 at which Mark F. Meier was a member of the panel on glaciology.

Negotiations by the U.S. Department of State to initiate formal bilateral agreements for scientific and technical exchange and cooperation began in the 1960's, but WRD participation in the water-resources sector of resultant programs did not begin until after 1966.

Public Law 87–626, enacted on September 5, 1962, broadened the scope of allowable activity beyond the national domain, facilitating participation in the International Hydrological Decade and enabling WRD personnel to pursue research and collaborative efforts abroad to benefit the domestic program. See, for example, the brief account of Stanley Schumm's work in Australia, cited heretofore.

WRD personnel also accomplished short missions as follows: I.S. Papadopulos conferred with Dutch and French specialists in October 1965 on problems in the quantification and mechanics of ground-water flow. Raymond M. Turner studied the hydrologic implications of plants in the Sonoran Desert of northern Mexico in October 1965. Francis A. Kohout observed submarine springs in the eastern Mediterranean in February 1966 and consulted with hydrologists in Israel, Greece, and Lebanon on these springs. William Back and Bruce B. Hanshaw did geochemical studies of the ground-water system of Mexico's Yucatan Peninsula in March and April 1966. Ranard J. Pickering consulted with scientists at the Laboratory of Marine Radiohydrology, International Atomic Energy Agency, in Monaco in May 1966.

#### *Multilateral Activities*

WRD personnel participation in international conferences, seminars, training courses, working groups, and the like was largely under the aegis of United Nations constituent agencies (UNESCO, for example) or, to a lesser extent, regional intergovernmental agencies such as the Organization of African Unity. They are all categorized as multilateral activities even though many involved missions to specific countries. They are reported here in terms of principal sponsorship although the activities often involved more than one organization.

#### *Economic Commission for Asia and the Far East (ECAFE)*

WRD participation with ECAFE began in December 1957 when Richard Murray and Leonard Snell served as advisors to the Philippine delegation at the Third Regional Conference on Water Resources Development, held in Bangkok, Thailand, ECAFE headquarters. Walter Langbein was a lecturer in July 1959 at an Interregional Seminar on Hydrologic Networks and Methods, also in Bangkok. Roy E. Oltman was a lecturer on field methods in hydrology in Bangkok in November and December 1961. Arthur O. Westfall served as an advisor to the Afghan delegation at a seminar on use and interpretation of hydrologic data, held in Kabul in January and February 1966. Vito Latkovich advised the Afghan delegation and Woodrow Evett advised the Nepalese delegation at a flood-frequency seminar in Bangkok in April 1966.

#### *Food and Agricultural Organization of the United Nations (FAO)*

In Afghanistan, P. Eldon Dennis assisted the Afghanistan Government from June to August, 1961 in preparing a ground-water development project proposal.

In Israel, George F. Worts, Jr., in February 1964 did research on artificial recharge and coastal-collector systems; William Back, in February and March 1964, worked on geochemical aspects of pumping and recharge operations; Solomon M. Lang, in April and May 1965, made a geohydrologic evaluation of a watershed pilot project; and Joseph F. Poland, in May 1965, reviewed a coastal-collector system and a watershed pilot project.

In Pakistan, in November 1964, Thomas Maddock, Jr., Herbert E. Skibitzke, Wolfgang V. Swarzenski, and Gordon D. Bennett lectured at a FAO-sponsored seminar on waterlogging and salinity in Lahore, Pakistan.

In Jamaica, Victor T. Stringfield, in September 1965 and in July and August 1966, reviewed plans and progress on several ground-water investigations in karst areas.

#### *International Atomic Energy Agency (IAEA)*

WRD personnel have participated since 1961 in numerous symposia, training courses, and working groups sponsored by the IAEA. Leland L. Thatcher and Eugene Simpson, in May 1961, as panelists at meetings on applications of tritium in the physical and biological sciences and on radioactive waste disposal; R.M. Richardson, in November 1961 and December 1962, and C.V. Theis, in March 1963, were consultants at symposia on applications of radioisotopes in hydrology; and Ranard Pickering, in May 1966, presented a paper on radioactivity in bottom sediments.

The WRD provided technical support to IAEA's hydrology program by a series of long-term assignments of specialists in radiohydrology to the IAEA Secretariat in Vienna, Austria. Alan E. Peckham was the specialist assigned from July 1963 to July 1965. He was succeeded by George H. Davis from March 1966 to March 1968.

#### *International Bank for Reconstruction and Development (IBRD)*

From April to June 1960, Glen F. Brown, ground-water hydrologist, was a consulting member of the World Bank Economic Mission to Saudi Arabia. During January and February 1966, Paul Jones, a consultant to a World Bank Mission to India, reviewed progress and plans of IBRD-funded projects involving irrigation tubewells in the Ganges Plains.

#### *United Nations Education, Scientific, and Cultural Organization (UNESCO)*

The chief focus of UNESCO involvement in scientific and applied hydrology between 1951 and 1964 was on its Committee on Arid Zone Research (CAZR) which promoted worldwide cooperation and research in the natural resources of arid zones. This emphasis was absorbed largely in the activities of the International Hydrological Decade (IHD) which began formally in January 1965.

Between 1960 and 1964, members of WRD who participated in CAZR symposia, committee meetings, seminars, conferences and training courses, many of which were co-sponsored by the UN's regional commissions, were W. B. Langbein, May 1960, symposium in Paris, France; L.B. Leopold, May 1960, annual session in Paris, France and October 1961, symposium and annual session, Rome, Italy; H. E. Thomas and L.C. Dutcher, October and November 1961, training course in Tunis, Tunisia; W.T. Stuart, March and April 1962, training course in Lahore, Pakistan; L.B. Leopold and R.L. Nace, August 1962, seminar and annual session in Tashkent, USSR; R.L. Nace, H.E. Skibitzke and J.A. da Costa, September 1963, conference in Buenos Aires, Argentina; J.A. da Costa, September and October 1963, training course, Antofogasta, Chile; R.L. Nace, September 1963, annual session, Santiago, Chile; D.A. Phoenix and V.C. Fishel, May 1964, conference, Tunis, Tunisia; H.E. Thomas and D.A. Phoenix, July and August 1964, conference in Lagos, Nigeria; S.A. Schumm and S.W. Lohman, September 1964, conference in Toulouse, France; and R.L. Nace, November and December 1964, final annual session, Jodhpur, India. From March through June 1965, P.E. Dennis provided technical support to the Central Arid Zone Research Institute at Jodhpur, India.

Apart from the CAZR activities in this pre-IHD period, UNESCO sought longer-term assistance in two projects. In March and April 1963, Vinton C. Fishel made a reconnaissance study preliminary to regional studies of artesian basins in 11 North African countries. During October and November 1964, O. Milton Hackett assisted the UNESCO/UNDP Project for Development of Natural Resources in Jordan by a study of the organization of scientific research in that country.

Raymond L. Nace, Luna B. Leopold, and Walter B. Langbein, in the early 1960's, envisioned an International Hydrological Decade (IHD). At the September 1961 IASH Symposium on Ground Water in Arid Zones held in Athens, Greece, Nace presented the position of the U.S. scientific community on a proposed IHD. The proposal was spelled out in the December 1961 Bulletin of the International Association of Scientific Hydrology (IASH Bull., vi annee, no. 4, p. 5–9) as: "A Proposal for International Cooperation in Hydrology" by a panel of U.S. hydrologists, of which Langbein was the chairman.

The concept was implemented in the United States by the National Academy of Sciences (NAS) and the American Geophysical Union (AGU), and internationally by the IASH. With the cooperation of the U.S. Department of State and similar entities in other countries, UNESCO assumed responsibility for planning, coordinating and guiding a worldwide IHD program. Nace was a consultant to the April 1963 Paris Conference of Inter-Governmental Experts, convened to plan for the IHD, and at the IASH General Assembly of Berkeley in August 1963, he promoted the general sponsorship of the IHD by the International Union of Geodesy and Geophysics, parent body of the IASH. The NAS formed a U.S. National Committee for the IHD on which Nace served as Chairman from 1964 to 1967 when he was succeeded by Dean F. Peterson of Utah State University. Jose A. da Costa was assigned to UNESCO headquarters in Paris in 1964 as Secretary of the IHD Coordinating Council. Leo A. Heindl was detailed to the NAS in 1966 as the Executive Secretary of the U.S. IHD Committee.

The years 1965 and 1966 were largely occupied with the massive task of implementing the multifaceted program, for the most part following the plan outlined by Nace. Nace was the U.S. Delegate to the First Session of the Coordinating Council of IHD from May 24 to June 3, 1964. In January 1966, while attending the Thirteenth General Assembly of IASH in Paris, Nace assisted UNESCO in planning for the IHD and was a member of the First Session of the IHD Working Group on Exchange of Information. In April 1966, he chaired the First Session of the IHD Working Group on the World Water Balance. Following this meeting he was the U.S. Delegate to the Second Session of the Coordinating Council which established other working groups.

In 1965 William J. Drescher became co-chairman of the Steering committee for the International Field Year for the Great Lakes, a collaborative effort of the U.S. and Canadian National IHD Committees that commenced in earnest in 1971. Alfonso Wilson, fulfilling one of the educational objectives of the IHD, was a co-director and lecturer at a regional training course in surface-water hydrology in Lima, Peru, in October and November 1964, and in February 1966 was a lecturer at a Symposium on Hydrological Networks in Belo Horizonte, Brazil. A. Ivan Johnson assisted the IHD program in Turkey in January 1965 by developing a curriculum in hydrology and establishing an Irrigation and Arid Zone Research Laboratory at the Middle East Technical University in Ankara. John D. Winslow co-directed and lectured at a regional training course in ground-water hydrology in Buenos Aires, Argentina in October 1965. Richard F. Hadley was a member of the first session of the IHD Working Group on Representative and Experimental Basins in Budapest, Hungary, from September 29 to October 2, 1965. Leland Thatcher served as Technical Secretary at the First Session of the IHD Working Group on Nuclear Techniques in ground-water assessment, held in Vienna, Austria, in March 1966. From March to July 1966, Thad G. McLaughlin reviewed past hydrologic work in Greece and guided Greek preparation for active participation in the IHD. His 50-page report entitled "Greece - hydrology," was published by UNESCO in August 1966.

***United Nations Development Programme (UNDP)***

Among the projects instigated by the UN and managed by UNDP from 1957 to 1966 that involved WRD were: water-resources investigations in Jamaica to which Glenn P. Prescott was assigned from May 1956 to May 1957 to do type-area ground-water investigations in the Clarendon Plain and to train Jamaican personnel in methodology; ground-water investigation of the Azraq Basin, Jordan, in which Thad G. McLaughlin advised the project managers and Jordanian government personnel on hydrogeologic problems during September and October 1963; ground-water investigations in Lebanon in which John G. Ferris, during November and December 1964 and again in June 1965, consulted with UN/UNDP personnel on problems in ground-water hydraulics and well construction in the karstic terranes of the Coastal Plain and the Bekaa area.

***United Nations (UN)***

Thomas Eakin served from 1958 to 1960 as a member of the UN Working Group on Large-Scale Ground-Water Development. Also, Walter B. Langbein and George C. Taylor, Jr., were members of the U.S. Technical Advisory Group on Water and River Basin Development during 1962 and 1963; both were domestic assignments. The work of the advisory group was a prelude to a United Nations Conference on the Applications of Science and Technology (UNCAST) for the Benefit of the Less Developed Countries. Ernest L. Hendricks was the U.S. delegate to this Conference held in Geneva, Switzerland, in February 1963.

***World Meteorological Organization (WMO)***

Walter B. Langbein, Rolland W. Carter, and Manuel A. Benson were consultants to the first session of the WMO Commission on Hydrometeorology held in Washington in 1961. From 1961 to 1966 they, and some 15 other members of WRD, participated in working groups and technical symposia promoted by the WMO's Commission on Hydrometeorology and the Commission for Instruments and Methods of Observation. Between 1964 and 1968, Langbein, Benson, and G. Earl Harbeck, Jr., were principal contributors to the preparation of several WMO technical notes and reports. Since 1965, WMO has been active in a number of working groups supporting the program of the IHD.

***Water for Peace Program***

On May 23–31, 1967, the International Water for Peace Conference was held in Washington, D.C., attended by some 6,400 participants, including 94 country delegations, and representatives of 24 international organizations.

The program began on October 7, 1965, when President Johnson pledged U.S. participation in a "massive cooperative international effort to find solutions for man's water problems." A Committee on Water for Peace was created by the Departments of State and Interior to survey world water problems and to recommend actions to be taken to advance international cooperation in finding solutions for these problems. The Committee (and its 14 working groups) was active through 1966 and published its recommendations in March 1967. Among those from WRD active in the working groups and in the preparation of the report were Thomas E. Eakin, George C. Taylor, Herbert A. Swenson, William J. Schneider, and Leopold A. Heindl.

One of the Committee objectives was to organize the International Conference on Water for Peace. WRD was represented at the conference by Walter B. Langbein, Raymond L. Nace, S. Kenneth Love, and Leopold A. Heindl as rapporteurs or as session chairmen. Swenson was vice-chairman of the Conference Program Committee. George H. Davis, Frank E. Clarke, George W. Whetstone, Thomas W. Robinson, and Charles J. Robinove presented papers. O. Milton Hackett, Walton H. Durum, and C. Lee McGuinness served as summation officers for the Conference Secretariat. The conference proceedings were published in late 1967.

***Regional Intergovernmental Organizations***

George H. Taylor, Jr., presented a report on water resources and economic development at a May 1961 meeting of the Working Group on Hydrology of the Pan-American Institute of Geography and History (PIAGH), an affiliate of the Organization of American States (OAS), in Caracas, Venezuela.

The Organization for Economic Cooperation and Development (OECD) was established in 1960 to promote economic growth and world trade among the countries of Western Europe and Australia, Canada, Japan, New Zealand, and the United States. OECD sponsored meetings of an Expert Group on Scientific Research in Water Pollution were held in Paris in March 1961 and November 1962. Herbert A. Swenson was the U.S. representative at those meetings as well as the U.S. delegate to meetings on Cooperative Water Pollution Research held in November and December 1964.

In April 1964, David A. Phoenix advised the Nigerian delegation at a Drafting Convention in Maiduguri sponsored by the Organization for African Unity (OAU).

The Central Treaty Organization (CENTO) was a former mutual security alliance of the U.S. and Southwest Asian countries. Under the stimulus of the International Hydrological Decade, a CENTO Symposium on Hydrology and Water Resources was held in Ankara, Turkey, in February 1966. Raymond L. Nace delivered the keynote address and Francis A. Kohout and Thomas Maddock, Jr., presented technical papers.

***Nongovernmental International Organizations***

Foremost among the international scientific and technical groups with which WRD scientists and engineers have been associated is the International Association of Scientific Hydrology (IASH), a constituent body of the International Union of Geodesy and Geophysics (IUGG). National delegates to or participants in symposia, assemblies, commissions, and working groups were organized through the National Academy of Science's U.S. National Committee for IASH in which senior WRD personnel played leading roles.

Major IASH meetings at which members of WRD presented papers during 1957 to 1965 were: General Assembly of Toronto, Canada, September 1957; General Assembly of Helsinki, Finland, July and August 1960; Symposium on Ground Water in Arid Zones, Athens, Greece, September 1961; General Assembly of Berkeley, California, August 1963; Symposium on Representative and Experimental Basins, Budapest, Hungary, September and October 1965; and Symposium on the Hydrology of Fractured Rocks, Dubrovnik, Yugoslavia, October 1965.

WRD hydrologists and hydrogeologists have been intermittently active in a number of other nongovernmental organizations including the International Association of Hydrogeologists, International Geographical Union, International Union for Quaternary Research, and others. WRD personnel have participated also in international meetings of U.S.-based organizations such as the American Geophysical Union and the Geological Society of America.

## Land Subsidence

*By* George H. Davis

Although land subsidence due to ground-water withdrawal had been known since the mid-1930's in California, it was first recognized as a major engineering problem in the mid-1950's when the Bureau of Reclamation's Delta-Mendota Canal, a key feature of the California Central Valley Project, suffered a loss of almost one-third its design capacity through differential subsidence before it was placed in operation. About the same time similar land subsidence was manifesting itself in the Houston, Tex., area, in the form of tidal flooding of low-lying areas.

An Inter-Agency Committee on Land Subsidence in the San Joaquin Valley, chaired by Joseph F. Poland of WRD, was formed in 1954 to investigate the land subsidence problems in the Central Valley. As one result of the interagency planning, an intensive investigation of subsidence was begun by WRD in 1956 in cooperation with the California Department of Water Resources. The objectives were to determine the extent, rate, and causes of the subsidence, to develop criteria for estimating subsidence, and to suggest methods for its alleviation or control. This applied program was complemented by a USGS-funded research program directed toward determining the principles controlling the deformation of aquifer systems resulting from change in grain-to-grain load, caused chiefly by change in internal fluid pressure.

Initial results of the interagency investigation were published in "Progress report on land-subsidence investigations, San Joaquin Valley, California, through 1957," authored largely by Poland, George H. Davis, and Ben E. Lofgren of WRD. The results of the applied research under the cooperative program were published mainly in Professional Paper 437 (1964–75), chapters A through I, by various permutations of joint authorships by Poland, William B. Bull, Lofgren, Raymond E. Miller, Robert L. Klausing, Francis S. Riley, Richard L. Ireland, and Robert G. Pugh. The results of the fundamental research program were published chiefly in Professional Paper 497, chapters A through G, by A. Ivan Johnson, Robert P. Moston, and Donald A. Morris (A); Robert H. Meade (B,C,D); Raymond Miller, Jack H. Green, and George Davis (E); Poland and Richard Ireland (F); and Francis Riley (G). Concurrently with these studies in the Central Valley, Poland and Green were carrying out subsidence studies in the Santa Clara Valley at the south end of San Francisco Bay (WSP 1619-C, 1962).

Elsewhere in the country, land subsidence in the Houston, Tex., area was investigated by Allen G. Winslow and Leonard A. Wood (Mining Engineer, v. 11, 1959); and by Robert B. Anders and Wellborn L. Naftel (Texas Water Commission Bulletin 6211, 1962); at Las Vegas, Nev., by Glenn T. Malmberg; at Denver, Colo., by George H. Chase and Stanley W. Lohman (PP 424–A, 1961); in the Eloy-Picacho area, Arizona, by Geraldine M. Robinson and Dennis E. Peterson (Circular 466, 1962); and at Savannah, Ga., by George Davis and Harlan B. Counts (Engineering Geology Case Histories 4, 1963). In nearly all these areas noted above the subsidence studies were long-range studies that extended beyond 1966 and some are continuing in the 1990's.

## Marine Geology and Hydrology

*By* Joseph E. Upson, II

Although some activities of the USGS and of the WRD in particular had been carried on in the ocean-marginal areas of the United States for several years, about 1960 national attention came to be focused on the coastal areas as well as the open ocean. This attention was stimulated by several reports: House Report No. 2078, "Ocean sciences and national security," a report of the Committee on Sciences and Astronautics; another report of the Committee on Oceanography, National Academy of Sciences—National Research Council (NAS/NRC), "Oceanography 1960–1970, Chapter 1, pages 1–8; and a special report by the same body, "United States participation in the International Indian Ocean Expedition," September 1961. These resulted in Senate Bill 2692, 86th. Congress, 1st Session introduced by Senator Warren Magnuson. The Geological Survey proposed a program which Preston E. Cloud, Jr., Geologic Division, had begun to develop about 1961, and it became part of an oceanographic program of the DOI proposed for 1963–72.

In a memorandum dated July 7, 1961, Raymond L. Nace announced the interest of the WRD in this research, and asked for project suggestions and indication of interested personnel. Joseph E. Upson worked with James V.A. Trumbull of the Geologic Division in developing the 1963–72 proposal. WRD's part in this was largely included under the category of research, for which $1,640,000 was requested in FY 1963. Later, Upson prepared a more specific and detailed proposal for a WRD program in oceanography. This consisted of a number of new projects assembled from various sources, as follows: individual proposals submitted by Branch personnel; the internal document, "Some suggested topics in oceanographic research" prepared by the SWB, similar but less formal statements prepared by Robert R. Bennett and Walton H. Durum for the GWB and QWB, respectively; discussions with Bennett, Rolland W. Carter, and Durum; and suggestions and ideas resulting from visits to some oceanographic institutions and marine laboratories on the Atlantic Coast. In addition to new projects, the proposal also recognized that much work, especially in the GWB, would best be extensions of existing activities.

General topics of primary concern were circulation patterns of water in estuaries and lagoons, the transfer of salts to coastal waters, and the interaction of freshwater and saltwater both in estuaries, lagoons, and river mouths on the one hand, and in the geologic formations underlying shore areas and coastal waters on the other. These topics were all pertinent to the increasingly acute problems of estuarine pollution and potential saltwater degradation of coastal ground-water supplies.

Given the essential role of estuaries and coastal waters in the life cycles of fish and bird life, water quality was of prime importance. In this connection, the Interior Department appointed a Task Force on Estuarine Pollution which produced a report with recommendations late in 1966. Robert L. Cory was the WRD representative on this Task Force.

The WRD never received specific funding for a designated marine hydrology program. Personnel of the Division, however, did participate in the Survey program, "Marine Geology and Hydrology" begun in FY 1964 and carried on under the overall direction of K.O. Emery, Geologic Division, at Woods Hole Oceanographic Institution. This was a line item in the Survey's FY 1965 budget. WRD personnel were Robert H. Meade (GWB), project chief, Edward Bradley (GWB), Frank T. Manheim (QWB), Conrad D. Bue (SWB), Donald J. Casey (SWB), and Francis A. Kohout (GWB). Funding was from the Marine Geology and Hydrology Program. Woods Hole provided space, ship time, and other facilities. Studies dealt with (1) mixing of freshwater and saltwater, both ground water and surface water, (2) seaward dispersal of dissolved and particulate matter, and (3) changes that sediments undergo during and after their entry into the marine environment. Many specific projects were begun during these years, but it was 1968 and later before comprehensive results were published.

In addition to this major Survey-wide thrust, modest amounts of money from the WRD Federal program supported several projects in estuaries and other coastal waters. In 1962, Robert L. Cory began a study of the effects of heated water in the Patuxent Estuary, Maryland. Francis A. Kohout concluded that dilution of the saltwater of Biscayne Bay, Fla., was due largely to the discharge of fresh ground water. Arvi O. Waananen, with Vance C. Kennedy and Holly C. Wagner, Geologic Division, worked on stream discharge and chemical constituents entering Willapa Bay in Washington.

In fiscal year 1964, Robert A. Baltzer, Nobuhiro Yotsukura, and others began to develop mathematical models of salinity intrusion under unsteady flow conditions in estuaries. This work later bore much practical fruit in outlining water movements in Tampa Bay, Fla.

One of the outstanding activities during the 1960's was that carried on in the Columbia River, Washington and Oregon, between Pasco and Vancouver, Wash., and on into the estuary. This work was in two interrelated projects, one, beginning in 1962 dealing with the distribution and movement of radionuclides in suspended and bottom sediments, and the other begun in 1963 which extended the study below Vancouver to the river mouth. The first, called the "River study," was under the direction of William L. Haushild and continued until the end of FY 1967 when funding was discontinued. The second, referred to as the "Estuarine study," was under the direction of David

W. Hubbell, and continued until the fall of 1971. (See "Columbia River Radionuclide Studies.")

These projects were funded by the AEC and the Corps of Engineers in total amounts on the order of $225,000 annually. The research findings in both projects have served as primary sources of information on the flow and sediment regimes, as well as on the levels and distribution of radionuclides, in both the Columbia River and its estuary. Also, new techniques were developed for measuring the discharge of a large river and for collecting suspended-sediment and bottom-sediment samples, and knowing their spatial distribution. Many reports were published in later years, and much of the information went into open-file reports or internal reports to funding parties (see "Columbia River Radionuclide Studies").

In 1958–59, Upson had spent a year in the Netherlands under a Rockefeller Public Service Award, observing and studying with Dutch hydrologists and geologists the occurrence of salty ground water in Holland, and Dutch methods of managing freshwater resources in essentially a saltwater environment. He continued this interest in making, along with William Back, regional analyses of the distribution of salty ground water along the Atlantic Coast (PP 550–C, 1966). But work on saltwater encroachment in coastal aquifers had been going on for many years in the GWB, under the cooperative program. (See "Geochemical Processes in Ground Water.") Men who pioneered much of that work were Henry C. Barksdale in New Jersey, Robert R. Bennett in Maryland; Garald G. Parker, Sr., followed by Hilton H. Cooper and Francis A. Kohout in the Miami area, Florida; Harlan B. Counts in Savannah, Ga., and South Carolina; Robert L. Wait, Georgia; and Norbert J. Lusczynski, Nathaniel M. Perlmutter, Wolfgang V. Swarzenski, and J.J. Geraghty on Long Island, N.Y. Aside from numerous reports as the work progressed, conclusive results appeared in WSP 1613 A–F, published in 1963. Results of estuarine studies by other investigators were published between 1962 and 1966 as separate chapters of WSP 1586, "Hydrology of tidal streams."

Thus the early 1960's saw the beginnings of significant work in what was thought of as "coastal hydrology." Except for Water-Supply Papers on saltwater encroachment, the completion and publication of most results had to await the next decade.

## Phreatophytes

*By* Richard C. Culler *and* reviewed *by* Robert M. Wyrick *and* Arvi O. Waananen *and* typing assistance *by* Dorcas Culler

The increasing population of the arid and semiarid Southwestern United States and the accompanying need for more water continued to focus the attention of hydrologists and water managers on phreatophyte control as a conservancy measure. Phreatophytes are defined as plants which depend on the ground-water reservoir for their water supply and can transpire large quantities of water. Water consumed by phreatophytes generally produces benefits of lower economic value than would be produced if the water were used for agriculture or domestic purposes. The rapid infestation of river flood plains by the prolific saltcedar was also a matter of concern.

The Phreatophyte Subcommittee of the Pacific Southwest Inter-Agency Committee represented the interest of many Federal and State agencies in the phreatophyte problem. Thomas W. Robinson (Mr. Phreatophyte to many of his associates), represented the Geological Survey on the committee. He prepared USGS Circular 495 (1964) which listed and briefly described 48 ongoing phreatophyte research projects involving 9 Federal and 21 State or local agencies. These projects included studies of consumptive use, areal extent and density at specific sites, methods of chemical and mechanical control, and revegetation.

Robinson compiled a list of 70 plant species classified as phreatophytes and described their characteristics, location of occurrence, and available data on consumptive use. (WSP 1423, 1958). He assembled data on the introduction, spread, and areal extent of saltcedar. In addition to field mapping, information was collected from Federal and State agencies and published in Professional Paper 491–A (1965). He also assisted in the preparation of a guide to surveying phreatophyte vegetation published as Agriculture Handbook No. 266. Robinson was also involved in the design of evapotranspirometers—excavations up to 30 x 30 feet and 14 feet deep with vertical sides lined with a continuous sheet of plastic and equipped with water supply and observation pipes. These refilled tanks could be planted with phreatophytes and the consumptive use measured by metering the quantity of water required to maintain the water table at a constant depth. Corrections for changes in moisture storage in the unsaturated zone were computed from neutron soil-moisture meter observations. This method of collecting consumptive-use data for various species of phreatophytes was applied by the Geological Survey at three locations.

In 1959, six large tanks were constructed in the saltcedar-covered flood plain of the Gila River near Buckeye, Ariz. Five additional smaller tanks were added in 1962. Three tanks were kept free of vegetation to observe evaporation rates from bare soil. The other tanks were planted with saltcedar and the water table was maintained at various levels to determine the effect of depth to water on transpiration rates. All tanks were surrounded by saltcedar except two tanks, which were used to measure the "oasis" effect. The water-budget method as represented by tank data was supplemented by use of the energy-budget method. The instrumentation for this method was similar to that used for lake-evaporation studies. The tanks were constructed by the BOR. Data were collected from 1963 to 1967. T.E.A. Van Hylckama instrumented the site, operated the equipment, and reported the results.

A study of the phreatophytes typical of the Humboldt River Valley was started in 1960 near Winnemucca, Nev. Twelve tanks of various sizes were constructed. Three tanks were planted, each with species of willow, wildrose, and rabbitbrush. Greasewood was planted in two tanks, and one tank was kept free of plants. The evapotranspiration was observed from 1962 to 1967. This was a cooperative project with the BOR and the State of Nevada. Robinson supervised the installation and operation of equipment and the analysis of data.

The flood plain of the Lower Colorado River contained phreatophytes not found at the other sites. In 1960 nine tanks were constructed at the Imperial camp site near Yuma, Ariz. Three tanks were planted to arrowweed, one tank to fourwing saltbush, and two tanks to quailbrush. The other three tanks were kept vegetation free from 1962 to 1964 and planted with bermuda grass in 1965. An additional four tanks were constructed on the banks of Mittry Lake. Three tanks were planted with cattail and the other tank was used to measure evaporation from open water. The tanks, constructed by the BOR, were instrumented and operated by Gilbert H. Hughes from 1961 to 1965, Rudolph H. Westphal in 1965 and 1966, and O.M. Gross in 1966, under the general supervision of Charles C. McDonald, Project Chief of the Survey's Lower Colorado River project.

The water-budget method was applied to a 4.1-mile reach of Cottonwood Wash, Mohave County, Ariz. The narrow flood plain contained cottonwood and willow. The reach was divided into two subreaches with gaging stations at each end of the subreaches at locations where bedrock outcrops forced all flow to the surface. Concrete flumes capable of measuring the base flow were constructed at each location. The evapotranspiration was measured during base-flow periods using the upstream subreach as a control and the lower subreach for applying methods of vegetation change. January 1959 to June 1960 was a calibration period. A chemical defoliant was applied to the vegetation in the lower subreach in June 1960, and all vegetation in this subreach was eradicated in February 1961. Data were collected until August 1963. The project was instrumented and operated by James E. Bowie and William Kam of the Arizona SWB and GWB Districts.

In 1961, Senator Carl Hayden, Chairman of the Senate Appropriations Committee, wrote to the Director, Geological Survey, stating that the increased requests for phreatophyte-control projects indicated the need for additional data on the effect of these measures and that supplemental appropriations would be made available for the needed research. Thomas Maddock, Jr., prepared the Director's reply, described the existing research projects, and requested that $100,000 be made available for FY 1962, as the first year of a 10-year program totaling $900,000. An 11-man committee, with G. Earl Harbeck, Jr., as chairman, was created including persons involved in previous and current phreatophyte research. Suggestions regarding the planning of the project were obtained from each member. After considering these suggestions and reviewing the available data, it was decided that a project which measured the evapotranspiration, before and after clearing phreatophytes from a flood plain typical of the areas of proposed phreatophyte control, was required.

A reconnaissance of available sites indicated that a 15-mile reach of the Gila River flood plain within the San Carlos Indian Reservation, Arizona, was the best available. The site included a wide, naturally developed flood plain and extended into the sediment deposits at the head of the San Carlos Reservoir. A homogeneous cover of varying heights and densities of saltcedar covered most of the area with mesquite along the edges of the flood plain. An agreement for access to the study area and consistent land management during the before- and after-clearing periods was signed with the San Carlos Tribal Council on May 28, 1962.

A water budget of the flood plain was selected as the primary method of measuring the evapotranspiration. The equation, including 12 components defining the inflow, outflow, and change in storage, was developed with evapotranspiration to be the residual. The study area was divided into three reaches with gaging stations at the ends of each reach. Thirteen cross sections at about 1-mile intervals were cleared to provide access to three ground-water wells and three pipes for neutron soil-moisture meters on each side of the Gila River channel. The installation of equipment was started on the upstream reach, and all data were available by March 1963. Instrumentation was completed in August 1963 on the intermediate reach and in January 1964 on the lower reach. Clearing of phreatophytes was completed on the upper reach in 1967.

Digital computers were becoming available and the project was instrumented for their use. Digital water-level recorders had recently been introduced and 90 were obtained to equip all recorded-data sites. A portable card punch was used in the field for recording soil-moisture data. The computer facilities of the University of Arizona were used for storing, analyzing, and computing data during the early years of the project. All surface-water, ground-water, and precipitation data were continually recorded. Water storage in the unsaturated soil zone could be measured only by logging the soil-moisture meter pipes. Soil-moisture measurements were made in one reach each week which determined 3 weeks as the length of the water-budget period. The evapotranspiration, as computed by the equation for a budget period, could be considered an independent data point to define seasonal trends and to establish relations with descriptions of vegetation and climate. Data for budget periods containing erroneous or incomplete observations could be deleted. The energy budget was used as a secondary method of measuring evapotranspiration. Observation sites were selected with vegetative cover typical of the flood plain.

Herbert E. Skibitzke provided aerial photographs of the study area. An application of the mass-transfer method was made using an airplane carrying meteorological instruments. A pattern of the flights across the flood plain was flown at the top of the vegetation and at higher levels. The airplane was tracked by radar and the path was plotted on a map of the area.

The scope of the Gila River Project required a staff and consultants having a wide range of experience. Richard C. Culler was appointed project chief. Robert M. Myrick served as computer programmer and planned the collection and computation of data, and with the assistance of Michael R. Collings, supervised the installation of equipment. Streamflow records were provided by the Arizona WRD District and analyzed by Durl E. Burkham. Oliver E. Leppanen was in charge of the application of the energy-budget method. The description and observation of vegetation was provided by Raymond M. Turner. Quality-of-water studies were made by Robert L. Laney. Edward S. Davidson and William G. Weist provided a geohydrologic description of the project site. Irel S. McQueen and Reuben F. Miller provided soil analyses. Nicholas C. Matalas assisted with the statistical problems of the study, and David R. Dawdy served as a consultant on computing and analyzing the data.

Among the many publications that resulted from the several research projects described above were PP 655–A, "Objectives, methods, and environment—Gila River Phreatophyte Project, Graham County, Ariz.," by R.C. Culler and others, 1970; PP 655–P, "Evapotranspiration before and after clearing phreatophytes, Gila River flood plain, Graham County, Arizona, by R.C. Culler, R.L. Hanson, R.M. Myrick, R.M. Turner, and F.P. Kipple, 1982; PP 486–F, "Studies of the consumptive use of water by phreatophytes and hydrophytes near Yuma, Ariz.," by C.C. McDonald and G.H. Hughes, 1968; PP 655–H, "Quantitative and historical evidence of vegetation changes along the upper Gila River, Ariz., by R.M. Turner, 1974; and PP 491–E, "Water use by saltcedar as measured by the water-budget method," by T.E.A. Van Hylckama, 1974.

## Radiohydrology

*By* George D. DeBuchananne *and* Alfred Clebsch, Jr.

[Note: This chapter was assembled in the following steps: (1) An initial draft by DeBuchananne (deceased April 25, 1991) with revisions and additions by Alfred Clebsch, (2) a brief writeup by Eric L. Meyer describing the reactor-site review process, (3) a brief writeup by Leland L. Thatcher on the tritium program, (4) a review by Clebsch of periodic reports of the Radiohydrology Section and other documents in the files of the late C.V. Theis, and (5) this draft, which combines the four. The contributions of Meyer and Thatcher, plus reviews by Meyer and Harry E. Le Grand prior to step four, are gratefully acknowledged as are helpful reviews of the final draft by Meyer and Alan E. Peckham.

The agency and facility names are those in use at the time. The Atomic Energy Commission (AEC) subsequently became Energy Research and Development Administration and later the Department of Energy. Facility names have also been changed; indeed, some may no longer exist. Responsibility for omissions and other errors is mine. (A.C. 6/91)]

The initial work for the AEC, reaching back to the 1940's, dealt primarily with the availability of water supplies and secondarily with management of radioactive wastes. But as the working relationship with AEC developed, by 1957 both WRD and Geologic Division (GD) were conducting research on a variety of topics essential to an understanding of the interaction and aqueous transport of radioactive materials in geologic media. In that year, Survey work on radioactive waste disposal supported by AEC consisted of (1) field projects at AEC installations, (2) general research, and (3) program coordination, funded by AEC headquarters at $180,000 and supplemented in some cases by funds from AEC Operations Offices for work at the National Reactor Testing Station (NRTS) in Idaho, the Oak Ridge National Laboratory in Tennessee, Los Alamos Scientific Laboratory in New Mexico, and others. Total funding at all the sites is not available; but as an example, in 1957 at NRTS the headquarters funding totaled $22,500 and local funding amounted to $60,000.

Research in 1957 was related to the two major concepts underlying AEC's waste-management philosophy: "dilute and disperse" or "concentrate and contain." So-called low-level wastes (based on the level of their radioactivity) were discharged to streams or to the ground, whereas those wastes deemed to be far too radioactive for safe discharge to the environment were the subject of studies aimed at reducing their volume so that they could be economically stored in a manner that would isolate them permanently from the environment. Overall direction to the program was derived from the report of a 1955 conference of the Earth Sciences Division of the National Academy of Sciences/National Research Council (NAS/NRC) (1957) at which WRD was represented by John G. Ferris, Arthur M. Piper, and C.V. Theis. The Geologic Division sent seven participants. Theis became the Survey's sole member of the advisory committee that succeeded the conference.

Most of the site-specific hydrologic investigations such as the work at NRTS, Los Alamos, and Oak Ridge attempted to determine the fate of low-level wastes moving under natural hydrologic gradients away from some point or points of release (Abrahams, Weir, and Purtymun, PP 424–D, 1961; Jones and Shuter, PP 450–C, 1962). Much of the topical research focused on the problems of defining and understanding geologic media or environments that would prevent or inhibit movement (Roedder, Bull. 1088, 1959; Skibitzke, PP 386–A, 1961). Geologic Division work on the physical properties of salt and the geographic distribution of large-scale salt deposits in the United States (Pierce and Rich, USGS open-file rept., 1959) was characteristic of this effort, as were the studies of sedimentary basins, in which both Divisions were involved (LeGrand, USGS open-file rept., 1962, and Repenning, USGS open-file rept., 1959). On the other hand, the surface-water research of Richard G. Godfrey, Bernard J. Frederick, and others on dispersion and time-of-travel was aimed at being able to predict the fate of deliberate or accidental release of waste solutions into surface streams, and the laboratory research on transport through the zone of aeration, conducted in the Hydrologic Laboratory in Denver, were both relevant to the problems of low-level waste management.

The work of WRD personnel at selected AEC sites was noteworthy, (some of it due to the personal characteristics of the individuals) because of the combination of complexity of the hydrologic system involved and the waste-management practices at the facility. The work at NRTS had been under the leadership of Raymond L. Nace, who developed a deep interest in the overall subject, and the close technical interest of C.V. Theis and Herbert E. Skibitzke, both of whom were challenged by the unusual properties of the basaltic aquifer underlying the Snake River Plain. When Nace became associate Division chief, his interest continued and indeed he is credited with coining the term radiohydrology. At Oak Ridge, Raymond M. Richardson, who was assigned there in late 1957, developed a close working relationship with personnel of Union Carbide, the prime contractor for operating the Oak Ridge facility, who were influential with AEC in guiding the research. Richardson's imaginative influence therefore extended well beyond the Oak Ridge site, as illustrated by his 1963 paper on climate and radionuclides migration (Proceedings International Colloquium on Migrations of Radioactive Ions, Saclay, France). At Los Alamos, John H. Abrahams, trained in soil science, brought that discipline to bear on the physical and chemical problems of movement and sorption of wastes in rhyolite tuff, which underlies the area to depths measured in hundreds of feet (Abrahams, Baltz, and Purtymun, PP 450–B, 1962).

The need for coordination of AEC-funded work that comprised the foregoing activities led to the establishment in April 1957 of the Radiohydrology Section under the leadership of Victor T. Stringfield. Theis continued to be funded under the program and to provide technical guidance to projects. A few months later WRD work at the Nevada Test Site began as an addition to GD's program on the geophysical, and engineering-geologic studies related to contained underground testing of nuclear explosives. Because of the interlocking nature of these two major efforts, Luna B. Leopold, Chief Hydraulic Engineer, and Wilmot H. Bradley, Chief Geologist, agreed formally that WRD would be the principal spokesman with AEC for the "waste-disposal" program and GD would be the principal spokesman for the "weapons-test" program, later broadened to include all nuclear explosions. WRD's role in the latter is discussed in more detail under "Hydrologic Studies Related to Nuclear Explosions."

The AEC group with which WRD worked most closely was the Division of Reactor Development, which had the responsibility for research and development in radioactive-waste technology as well as for construction of research and demonstration reactors. The application of nuclear energy to the generation of electricity provided the impetus for much of this work, and the Survey conducted investigations of the geology and hydrology of many of the sites. A number of these studies were published in Geological Survey Bulletin 1133 (for example, Keech, 1962).

Work that was under the purview of the Radiohydrology Section was not confined to waste disposal and reactor sites, however, although these components dominated the funding. The work of Robert C. Scott and Franklin B. Barker (PP 426, 1962), funded through the Survey's Federal appropriation and originally organized in Idaho under Nace, investigated the occurrence of radioactivity and of selected radioelements in natural waters. Work supported by the AEC Division of Isotopes Development included the use of radiotracers in surface- and ground-water hydrology, sediment transport, and geophysical logging (Frederick and Godfrey, PP 424–D, 1961; Skibitzke and others, International Journal Applied Radiation and Isotopes, 1961; Hubbell and Sayre, Proc. Hydrologic Division, ASCE, 1964; Keys, Proc. International Atomic Energy Agency, 1967). Following the discovery of naturally occurring tritium by Willard F. Libby and his co-workers at the University of Chicago, and the disturbance of the natural tritium regime in 1954 by thermonuclear (hydrogen) bomb testing, WRD set up a tritium hydrology project aimed at integrating studies conducted along more conventional lines with support from this new technology. Charles W. Carlston led field investigations and an analytical laboratory was established in Washington, D.C., by Thatcher, first at the Carnegie Institution's Geophysical Laboratory and later in the Old Post Office Building at 12th and Pennsylvania Avenue. A nationwide tritium-monitoring network was established, with advice and consultation from Lester Machta of the U.S. Weather Bureau, staffed by WRD personnel in the field and sample analysis performed by the new WRD laboratory (Thatcher and Hoffman, Journal of Geophysical Research, 1963). Because of the network capabilities and high degree of analytical precision, other Federal agencies that were interested in detecting evidence of thermonuclear testing around the world provided funding for this work, and submitted samples from a geographically broad network. The role of the Radiohydrology Section in this work derived in part from its classified nature and from the fact that the Section Chief served as WRD Security Officer. The WRD tritium network is described by Thatcher and Hoffman (1963), and hydrologic applications of tritium in precipitation as well as its use as an introduced tracer are discussed in "Tracers in Hydrology." The monitoring network was continued for many years, with analytical and interpretive work by Theodore A. Wyerman and Gordon F. Stewart; the data were published in the Environmental Isotope Data series of the International Atomic Energy Agency (1969).

In 1959, in anticipation of nuclear power-generating stations operated by utility companies, the Atomic Energy Act was amended to provide for AEC to regulate and license such facilities. In addition to internal safety evaluations, site safety evaluations were to be made and license applications were presented to the Advisory Committee on Reactor Safeguards (ACRS). Survey comments on the geology and hydrology of a site, as they might affect nuclear safety, became progressively more formal. Somewhat similar procedures were followed for the licensing of sites for the disposal of low-level (or "low-hazard potential") solid radioactive wastes being proposed in several States. Somewhat later, with the creation of the Nuclear Regulatory Commission, Atomic Safety and Licensing Boards replaced ACRS and their "hearings" became quasi-judicial proceedings in which Survey reports were formal depositions as expert testimony.

In order to fulfill this need for close consultation with AEC technical staff, and for virtually day-to-day advice on its geologic and hydrologic research in industry and academia, AEC asked that WRD establish a "liaison" position at AEC headquarters in Germantown, Md. The first incumbent to this position was Eugene S. Simpson.

As the AEC-funded program expanded, each of the three WRD operating Branches was asked to assign a man to serve as a point of contact with the Radiohydrology Section to coordinate and provide a focal point for the work of that branch. George DeBuchananne was the first so designated by the GWB because most of the work at AEC facility sites was by GWB personnel.

By 1961 financial support from the Division of Reactor Development had grown to $450,000; (approximately) $138,000 to GD and $312,000 to WRD. WRD funds were distributed to: Radiohydrology Section, $49,500; GWB, $130,500; SWB, $45,000, QWB, $48,500; and $38,500 to Division and Bureau overhead.

Harry LeGrand had replaced Stringfield as Chief of the Section in 1960, and Alan E. Peckham, who had been reassigned from work at NRTS to assist Stringfield, was temporarily assigned to AEC headquarters to replace Simpson, who had taken an assignment to Mol, Belgium, one of several European atomic-energy installations.

In addition to the ongoing field investigations at NRTS, Idaho, Oak Ridge, Tenn., and Savannah River, S.C., Charles L.R. Holt was completing work at Argonne National Laboratory near Chicago and Joseph T. Callahan and Joe W. Stewart were finishing work on a report on the Georgia Nuclear Aircraft Laboratory operated by Lockheed in the Georgia Piedmont. Zone of aeration investigations were being pursued in the laboratory by Wilbur N. Palmquist and A. Ivan Johnson (PP 450–C, 1960), with technical guidance from Theis, and field investigations were being made at NRTS and Los Alamos with local funding support.

WRD's water-quality work supported by AEC had to compete with "in-house" capabilities of the AEC laboratory complex, and although funding for the QWB might have been disproportionately low in comparison to both the significance of the problems and QWB's capabilities to conduct research, much of the work produced noteworthy results. By 1961 Marvin Skougstad had completed work on the occurrence and distribution of stable strontium (Skougstad and Horr, USGS Circ. 420, 1960), important for its potential role in isotopically diluting strontium–90 in biological systems, considered to be one of the most dangerous fission products because of its affinity for bone tissue and long half-life. Research by John D. Hem and Vance C. Kennedy (see Kennedy, PP 433-D, 1965) in Denver and Adrian R. Chamberlain, David W. Hubbell, and William W. Sayre at Colorado State University (CSU) attacked the important problem of the role of sediments in stream transport of radionuclides.

Surface-water research by Godfrey and Frederick continued, closely coordinated with a major interagency effort to assess the effect of waste discharges into the Clinch River downstream from Oak Ridge, to which P. Hadley Carrigan and Raynard J. Pickering were making major technical contributions on behalf of the WRD. (See "Clinch River study.")

AEC's sponsorship of ground-water research at Phoenix, Ariz., by Skibitzke, Akio Ogata, and their associates helped put the WRD in the forefront of work on dispersion theory, electrical analog models, and on the effect of geologic inhomogeneities on the dispersal of contaminants in sedimentary materials (Ogata, PP 411–B, 1961; Skibitzke, IASH Pub. 52, 1960; Theis, Proceedings, 2d AEC working meeting on ground disposal of radioactive wastes, Chalk River, Ontario, Canada, 1962).

Also in 1961 Eric L. Meyer was transferred from Denver to the SWB headquarters and Walton H. Durum was designated for the QWB as the contact with the Radiohydrology Section. Alfred Clebsch transferred from Albuquerque to the Radiohydrology Section for a 2-year assignment in the position at AEC headquarters initially held by Simpson; his assignment was to last until 1966.

Major redirection of work at the National Reactor Testing Station and at the Savannah River Plant (SRP) took place in 1960 and 1961. In Idaho Paul H. Jones, as chief of the WRD project, emphasized the application of borehole geophysics to the previously intractable problem of permeability distribution within the Snake River Basalts and associated interbeds. Jones, Eugene Shuter, and coworkers found a kindred soul at the site in W. Scott Keys of the AEC staff. By using inflatable packers to seal off thin permeable zones, they were able to study individual beds that were hydraulically connected and to sample the distribution of waste constituents in observation wells in a way previously infeasible (Jones, USGS open-file rept., 1961). At the SRP a project to study the feasibility of emplacing high-level wastes in mined cavities in the crystalline basement rocks enabled WRD to investigate the hydraulic characteristics of rocks with extremely low permeability to a degree that would have been prohibitively expensive under any other conceivable circumstances. The work at the SRP was led by I. Wendell Marine. (Proctor and Marine, Nuclear Science and Technology, 1965). Testing techniques involved the use of inflatable packers and tritium as a tracer. (See "Tracers in Hydrology.")

In 1962 the Division's work on the Columbia River below Hanford began. It was noteworthy because of the infusion of research results from the work at Fort Collins and Denver into the investigational methodology by William F. Haushild and Hubbell, and the cooperative working relationship among WRD, the AEC's site contractors, and nearby universities. (For more detail see "Columbia River Radionuclide Studies.")

Paul Jones replaced LeGrand as Chief of the Radiohydrology Section in 1962, and Donald A. Morris succeeded Jones as project chief at NRTS.

Also in 1962, Elmer H. Baltz and William J. Drescher were assigned to work on disposal by deep-well injection, which was still of great interest to the AEC. Members of the NAS/NRC committee with experience in the petroleum industry continued to advocate this disposal method, and a subcommittee of the Research Committee of the American Association of Petroleum Geologists was analyzing the subsurface geology of several sedimentary basins that appeared to have favorable hydrogeologic conditions. Baltz and Drescher provided a hydrologic perspective to that effort, and in addition, investigated potential sites for a field experiment in which simulated wastes might be injected into a sandstone aquifer, shallow enough to be able to afford a carefully designed network of monitoring wells so that studies of the rate and geochemical effects of waste migration could be made. This work was later abandoned because of difficulty in finding a site that would meet hydraulic, geochemical, and depth criteria and because the well-injection method of disposal was losing favor as a result of unsatisfactory results being experienced in the chemical and petroleum industries.

By WRD memorandum of July 24, 1963, the Radiohydrology Section was incorporated into the GHB, with the directive to "....move explicitly in the direction of concentrating on research." Jones continued to head the program from within the GHB until his departure in 1964 for graduate training at Louisiana State University. He was succeeded by Clebsch, who continued in the assignment at AEC headquarters as an extra duty until 1966, when Baltz was reassigned from Albuquerque to AEC headquarters.

With the Survey's study in 1963 (by Julius Schlocker, Manuel Bonilla, and others of GD's Engineering Geology Branch) of the controversial Bodega Bay reactor site in California, reactor-site analyses became more and more complex. Earthquake-hazards and hydrologic analyses became highly formalized and this led to a more formal agreement between the Survey and the AEC, documented by AEC Chairman Seaborg and Interior Secretary Udall.

By 1964 Kennedy's work on the mineralogy of stream sediments was winding down, and the work at CSU, Fort Collins, now being pursued by Sayre was becoming increasingly detailed, with the use of fluorescent dyes and polyethylene particles to study the effect of turbulent flow near a rough boundary. AEC interests moved toward the feasibility of injecting radioactive gases, such as might be released by a major reactor malfunction, into shallow permeable strata underlying a layer of low permeability. The rationale for this concept was that many of the radioactive gases are of fairly short half-life and might be retained long enough for the radioactivity to decay to innocuous levels, with the added advantage that radioactive particulate matter would be adsorbed onto subsurface granular materials. WRD personnel at NRTS (Jack T. Barraclough and coworkers) and at Los Alamos (Francis Koopman, William. D. Purtymun, and later J. L. Kunkler) developed fundamental information on the physical and chemical characteristics of entrained air, the transmission of pressure through slightly permeable material, and on the flow of air in the zone of aeration in response to atmospheric pressure changes; but the concept was set aside as a waste-management technique because of other developments in reactor engineering.

The reactor-site work continued to expand in 1964, with increased attention to the earthquake problem and concern over flooding that extended well beyond the reliability of customary flood-frequency estimates. At the SRP the discovery that fractures in the bedrock were hydraulically connected over distances of hundreds to thousands of feet led the NAS/NRC committee to oppose the concept of disposing of high-level wastes into mined cavities beneath the site. Attention then shifted to the near-surface ground-water hydrology of the "tank-farm" area, which became the subject of a detailed study, first by Marine, who later resigned to join the staff of the DuPont Company, and then by William E. Clark, who transferred in from the Florida District. This was in support of a detailed analysis of the safety of current methods of high-level waste management and sought an understanding of the flow system in three dimensions to a high degree of detail.

Ren Jen Sun joined the Radiohydrology Section about this time, and in response to an AEC request to evaluate data on ground-surface uplift around grout-injection wells at the Oak Ridge hydraulic fracture experiments, he developed a mathematical model that could predict thickness and lateral extent of a grout sheet at depth (Sun, Journal of Geophysical Research, 1969).

In response to Survey budget requests, the Congress appropriated in FY 1965 $1.0 million for the construction of a Nuclear Research Laboratory at the Denver Federal Center, whose functions were centered on a small "swimming-pool" reactor. This action followed an appropriation of $100,000 for planning and design of the facility in fiscal 1964. The facility was nearing completion by mid-1966, enabling both GD and WRD to utilize neutron-activation analytical methods in geologic and hydrologic studies. It was administered initially by the Regional Hydrologist and the staff operating the reactor were assigned to WRD. The acquisition of the facility is a tribute to the perseverance, dedication, and scientific acumen of Walton H. Durum, who planned, pushed, and prodded until the dream became a reality.

In 1966, as part of the reorganization of the WRD Headquarters, the organizational identity of the Radiohydrology Section was restored, recognizing its role in planning and coordinating for the Division as a whole rather than just for the research activities.

## Hydrologic Studies Related to Nuclear Explosions

*By* W. Arthur Beetem *and* William E. Hale with contributions *by* Ernest H. Boswell, Francis C. Koopman, Victor J. Janzer, Sam W. West, *and* Alfred Clebsch, Jr., *and* revised *by* Clebsch

### *Hydrologic Studies at the Nevada Test Site*

The participation of WRD in the underground nuclear test program at the Nevada Test Site (NTS) began in November 1957. Previously, Arthur M. Piper, Omar J. Loeltz, and other WRD personnel had assisted the AEC in developing ground-water supplies at the NTS during the period of atmospheric tests. The first contained underground nuclear explosion in the United States was detonated September 19, 1957, and the planning of more underground explosions provoked concern over the possibility of extensive ground-water contamination.

Geologists and geophysicists of the Engineering Geology and Geophysics Branches, GD, began work in 1956 on problems of rock strength, depth of burial necessary to ensure containment, and possible "triggering" of earthquakes by energy released in the explosion. The Albuquerque Operations Office of the AEC then had jurisdiction over the NTS, and Charles B. Read, a senior geologist with Fuels Branch, GD, was the Survey's contact with that office.

***Reconnaissance and Rainier Mesa***

Alfred Clebsch, Jr., a geologist with the New Mexico GWB District, was selected to study the test site and vicinity and to plan a program that would determine the likelihood of ground-water contamination. After a 3-month reconnaissance, a study plan was presented to a Survey review committee consisting of Edwin B. Eckel, Charles B. Read, Stanley W. Lohman, Arthur M. Piper, Harold E. Thomas, and Charles V. Theis.

There were half a dozen points of ground-water levels of questionable reliability in 1,400 square miles from which to estimate hydraulic gradients. Information on the geologic media was negligible; quantitative information on hydraulic parameters was not available, and drilling costs were high. The water table was 1,500–2,000 feet below Yucca Flat and 500–1,000 feet below Frenchman Flat.

Rainier Mesa, named after the first contained underground nuclear test, had tunnels being constructed for further tests and became the area of the first intensive work by WRD on the NTS. All Survey work including geologic mapping, studies of the geologic effects of the explosions, heat-flow studies, gravity and seismic surveys, and collection of hydrologic data, was closely coordinated. Several reports were authored jointly by GD and WRD personnel.

More than 5 miles of tunnels, drifts, and shafts were driven into the east face of Rainier Mesa. Mapping, sampling, and measuring the water discharge from tunnel drifts were allowed only during the graveyard shift of tunnel construction. In July 1958, Isaac J. Winograd joined the project. That summer, he and Clebsch studied the water-filled fractures in the rhyolitic tuff, a perched aquifer within the tuff, 2,000–5,000 feet above the regional water table.

Water samples and studies by Survey personnel and others documented the distribution of radionuclides in the perched ground water of Rainier Mesa after the Logan and Blanca events (code words for the tests). Reports of early studies closely related to the nuclear-test program were prepared quickly and transmitted to the AEC promptly in the Survey open-file series of trace-element investigation (TEI) reports and trace-element memorandum (TEM) reports. The TEI and TEM reports were continuations of series begun under the AEC-sponsored uranium program. Reports included data compilations and interpretations by Clebsch and Franklin B. Barker, TEI–763 (1960) and interpretive reports by Clebsch and Winograd, TEI–358 (1959), and Clebsch, PP 424–C, Art. 194 (1961).

***Yucca Flat Test-Hole Drilling Project***

An adequate understanding of the ground-water system for the NTS and vicinity could not be developed without more subsurface data. Although Clebsch, William E. Hale, and Winograd could scarcely conceive that the hydrologic information would be worth the drilling costs necessary, a deep drilling program to penetrate aquifers below Yucca Flat was proposed. An earth-science committee, advisory to the Chief of Albuquerque Operations Office, AEC, supported the deep-drilling program. George B. Maxey, formerly of WRD, was a committee member representing the Desert Research Institute, University of Nevada.

The six-well drilling program began in April 1960. At about that time, Clebsch was replaced by Stuart L. Schoff as Chief of the GWB project. Project headquarters was moved to Denver for better coordination with the Special Projects Branch, GD, which had operational responsibility for all geologic and hydrologic investigations relating to the testing, peaceful applications, and detection of nuclear explosions. Schoff was joined by John E. Moore, and the Las Vegas staff of Winograd and Charles E. Price was augmented by George E. Walker and William Thordarson in 1960, Murray S. Garber, Lewis R. West, and Richard A. Young in 1961, and Ralph F. Norvitch, George L. Meyer, A.C. Doyle, and Ralph E. Smith in 1962.

Five test holes were drilled in Yucca Flat and one in Jackass Flats with careful attention to geophysical surveys and estimation of geologic conditions. The geology of the ridges surrounding the valley was mapped concurrently by GD geologists. Holes ranging in depth from 1,700 to 2,300 feet were drilled, logged, cased, and tested in ways to maximize the amount, accuracy, and reliability of the geologic and hydrologic data acquired. Techniques for measuring of water levels in deep wells (particularly during test drilling) had to be devised and the contribution by Garber and Francis C. Koopman (TWRI, book 8, chapt. A–1, 1968) on this subject was a by-product of the test drilling program.

[Note: The results of work on this and subsequent phases of the program were reported in Technical

Letters (TL) which were identified by the major activity followed by a number such as TL–NTS–27, Gnome–15, and so forth. In the 1970's, all the TL's that had been released to the open file were renumbered and the TL designation was abandoned; for example, TL Dribble 9 became USGS 474–128. New dates on the USGS–474 series were assigned at the time of conversion.]

This drilling test program, a multimillion-dollar effort, was the most elaborate, expensive, and ambitious drilling program undertaken in support of a WRD hydrologic investigation. But the record was short-lived. The test-hole data indicated that further evaluation of the potential for contamination of ground water in and near the NTS was necessary, and a second drilling program was proposed and funded.

#### *Second Test-Hole Drilling Program*

The second test-hole drilling program, during 1962 to 1964, was under the field supervision of Winograd, assisted by others including Young, Price, Norvitch, Garber, and Thordarson. Ten test holes were drilled (eight of the holes to Paleozoic strata) at Yucca Flat, Frenchman Flat, Jackass Flats, and south and southeast of Mercury, Nev., adjacent to the NTS.

The test holes, some 6,000 feet deep, were difficult to test hydrologically. Construction data, lithologic and geophysical logs, water analyses, cores and cutting yields, production records, water levels, water yields, and pumping tests (when available) were utilized by the field personnel to describe the hydraulic conditions present at each test hole.

#### *Interpretation of Ground-Water Movement near the NTS*

Winograd was assigned the task of assembling and interpreting the hydrologic data from the two drilling programs. More than 6 years of reconnaissance and detailed geologic mapping, extensive geophysical studies, geochemical studies on ground water and rocks and minerals, and hydraulic tests on other drill holes in support of the nuclear-test program were available. Using these data, Winograd defined the subsurface distribution and hydraulic character of major aquifers and confining layers, identified and delineated the principal areas of recharge and discharge, and estimated the rate and direction of ground-water movement. Although the work by Winograd and Thordarson was not published until 1972 (PP 712–C), most of the study and interpretation of results was accomplished during 1957 to 1965.

#### *Geochemical Studies*

The tunnels of Rainier Mesa permitted collection of rock and water samples to define the initial distribution and concentration of radionuclides following the Logan and Blanca events. The GD and WRD chemists in Survey laboratories in Denver and Washington, D.C., supported the early investigations by analyzing water and rock samples for both stable and radioactive constituents. This analytical support continued and was expanded for all the projects conducted at the NTS. Barker, QWB, concurrently led studies on specific adsorption of radioactive species such as strontium and cesium with clays and rock materials. Barker, in 1958, summarized factors affecting the transport of radioactivity by water (Journal AWWA, v. 50, no. 5). This project included at times the services of John H. Baker, Barker, Beetem, Marvin J. Fishman, Victor J. Janzer, and James S. Wahlberg.

Studies of the geochemistry of ground water at the NTS and valleys surrounding the NTS were reported by Thomas E. Eakin, Schoff, and Philip Cohen in 1963 (TEI 833). Winograd continued geochemical studies on and off the NTS that he had begun in earlier reconnaissances. In the summer of 1960, Beetem replaced Barker as project chief for QWB studies related to the NTS. From 1960 to 1965, he coordinated the analytical support of WRD laboratories. The quality-of-water work at different times included Janzer, Clifford G. Angelo, Marvin C. Goldberg, David T. Nokaido, Robert L. Emerson, Edward Villasana, Charles T. Warren, and Leonard E. Wollitz.

Using rocks, minerals, soils, and ground water from the NTS, the project measured distribution coefficients for cesium, strontium, iodine, and mixed fission products. Geologists in the drilling program assisted by collecting and identifying rocks and obtaining water samples. Water samples were collected off the NTS to aid in deciphering the regional flow system and in supplying regional background data. Periodic sampling of NTS water-supply wells started by Winograd to document changes in water quality was continued. During 1963, water samples for geochemical analyses were collected from springs and wells in the Amargosa Desert, southwest of the NTS. Billy P. Robinson and Beetem compiled these data and, during the year when Pahute Mesa was being considered as a site for nuclear testing, they also compiled an inventory of wells and springs within 100 miles of Pahute Mesa from public records.

#### *Double-Ring Infiltrometer Tests*

William C. Rasmussen, a geologist with the GWB (see Part X, "Delaware"), measured 16 sites of unaffected alluvium in Yucca Valley at 18 sites in and around the Scooter event crater and at additional sites around the Sedan event crater to determine potential infiltration rates by using double-ring infiltrometers during the summer of 1962 (PNE 221–F, 1963). (A PNE report is one of the series published by the AEC under its Plowshare program for the development of peaceful nuclear explosives.) Tests on crater ejecta initially showed reduced infiltration rates.

#### Consolidation of Nuclear Test-Related Studies

Hale was transferred from the New Mexico District to Denver in the summer of 1962 to work with GD's Special Projects Branch in an analysis and planning unit devoted to the problems of water contamination from nuclear explosions. In October 1962, Schoff accepted a foreign assignment and Hale was designated coordinator of WRD studies for nuclear explosion sites. GWB and QWB projects and personnel in Denver and Las Vegas, funded by Nevada Operations Office, AEC, were placed under Hale's supervision for administrative and technical coordination.

#### Jackass Flats Investigations

John H. Abrahams, New Mexico GWB District, in cooperation with Los Alamos Scientific Laboratory, studied possible disposal of reactor wash-down wastes into a drain field on an alluvial fan in the vicinity of the Nuclear Rocket Development Station in Jackass Flats. The Denver Hydrologic Laboratory installed tensiometers in the drain field.

A water-supply investigation in 1963 was made by Young to delineate the welded-tuff aquifer, further characterize the chemical quality of water in the aquifer, estimate the quantity in storage, determine how long the supply would last under the expected rate of use, and to recommend sites for future well development (WSP 1938, 1972).

#### Aquifer Response

The Bilby event at Yucca Flat, on September 13, 1963, was the first nuclear test below the water table at NTS. Detonation was 2,339 feet below land surface with a reported yield of about 200 kilotons. Hale, Winograd, and Garber reported that water levels in wells surrounding the emplacement hole rose sharply after the detonation. Rapid transmission of hydraulic pressure occurred not only in the tuff in which the test occurred but also in the underlying Paleozoic carbonate rocks. The elevated water levels were similar to measurements made in 1962 by Garber in a well 1,000 feet from point of detonation a few weeks after an earlier explosion. The rapid transmission of hydraulic pressure and proximity of the detonation to the carbonate basement rocks suggested the possibility of nuclear contamination of the regional Paleozoic aquifer. Hale, Winograd, and Garber later found the water level depressed in the rubble chimney. Garber, in 1965, reported (USGS 474–105) measurements of the water-level rise in the Bilby rubble chimney. Beetem, Angelo, and Billy P. Robinson summarized chemical and radiochemical data from measurements made on both the sediment and water phases of samples pumped from the rubble chimney during field studies in July and December 1964.

#### Post-Bilby Event Study of Paleozoic Aquifer

A hydraulic test well was drilled, beginning in September 1965, within the collapsed chimney crater caused by the Bilby event to determine depth to Paleozoic rocks and occurrence of radioactivity in the Paleozoic rocks. Garber and Richard H. Johnston reported significant radiation levels in pre-existing joints of the ash-flow tuff. No radioactivity was detected in the 194 feet of Paleozoic rocks penetrated.

#### Hydrologic Investigations on Pahute Mesa, NTS

Further hydrologic studies on the eastern part of Pahute Mesa, NTS, were begun when the AEC considered deeper emplacements for larger yield nuclear explosions. Richard K. Blankennagel was hired to supervise the hydrologic testing in drill holes at Pahute Mesa. Exploratory drilling began in 1963 and continued until 1968. Nineteen holes, 4,500 to 13,686 feet deep, were drilled and tested to evaluate the subsurface geologic and hydrologic environment. Blankennagel was assisted by James E. Weir, Jr.; their work was reported in PP 712-B, 1973. Part-time field assistance was also provided from the New Mexico and Wyoming GWB Districts and from other NTS projects, including James B. Cooper, Robert L. Emerson, G.L. Meyer, William Thordarson, Harold A. Whitcomb, and Richard A. Young. Hydraulic testing to determine the water-yielding potential of volcanic rock strata in each exploratory hole involved geophysical logging, injection of known volumes of water into or withdrawal of known volumes of water from intervals isolated by straddle packers, and test pumping to allow predictions of water yields in various zones and to define the hydraulic properties of the rock strata. The interpretation of the deep-well testing was based on theoretical work of Hilton H. Cooper, Jr., John D. Bredehoeft, and S. Stavros Papadopulos, who published on the subject in 1967 (Water Resources Research, v. 3, no. 1).

### Tracer Studies

The nuclear explosions program provided both a need for and a unique opportunity to conduct tracer tests as a means of determining ground-water velocity.

At the NTS, dye was used by Lewis R. West and Winograd in 1961 in two wells at the southern end of

Yucca Flat to determine relative traveltimes between the wells under pumping conditions. Later, Beetem, Angelo, Noikado, and Villasana defined breakthrough curves for dye and tritiated water from the pumping well after the tracers had been introduced as a slug in the nonpumping well. The tests failed to give useful information on the relative ground-water velocity or porosity of the Paleozoic aquifer, so tracer tests on those wells were discontinued.

At the Project Gnome site near Carlsbad, N. Mex., the hydraulic response of the Culebra Dolomite aquifer as described by Thomas W. Robinson, (American Geophysical Union Trans., pt. 4, 1939) indicated that the aquifer was suitable for a successful tracer test. Under Hale's direction, a two-well tracer test in the Culebra Dolomite aquifer was conducted in which the discharge from a pumped well was reinjected into another well 185 feet away. It was hoped that the results would be transferable to the carbonate aquifers at the NTS.

The tracer test was planned, using as a basis the paper by Jose A. da Costa and Robert R. Bennett in 1960 (IASH publication no. 52) that described the pattern of flow in the vicinity of a recharging and discharging pair of wells as having parallel flow. A dilution factor for tritium injected in one hole and recovered by pumping from the other was determined February 9 to 15, 1963.

Using the same pumping well and recharging well arrangement, a similar test was conducted on February 21, 1963, until the two wells were in near hydraulic equilibrium. On February 22, tritium, iodine–131, strontium–90, and cesium–137 were infused into the water being injected into the aquifer. Beetem, assisted by Angelo, Robert L. Emerson, Everett A. Jenne, Smith, Thordarson, and Warren, conducted these tests. Because the test conditions drastically increased the hydraulic gradient, tritium took 40 hours, under the pumping conditions, to travel the 185 feet between the wells, compared to normal ground-water flow in the area of less than 0.5 ft per day. Strontium–90 moved less than one-twentieth as fast as the water.

The Gnome site demonstrated the utility of tracers in predicting retardation factors for radioisotopes, but the difficulty of monitoring and supporting studies at that distance from the NTS and the difficulty of transferring data from the Culebra Dolomite Member to the Paleozoic aquifer underlying the NTS led to the decision that further twin-well tests would be conducted on or near the NTS.

Based on several geophysical surveys and on available geologic and hydrologic data, three sites in the Amargosa Desert southwest of the NTS were selected by Winograd for exploratory drilling to locate a suitable site. The drilling and a series of tracer studies followed after 1965.

### Vela Uniform Program

The Vela Uniform Program of the AEC had the objective of determining if nuclear explosions could be decoupled in order to avoid seismic detection.

#### Project Dribble Site Studies

On October 22, 1964, the Salmon event, a 5-kiloton nuclear device, was detonated in the Tatum Salt Dome in southern Mississippi producing a 114-foot-diameter cavity 2,700 feet beneath the surface. In 1958, Joe W. Lang of the Mississippi GWB District and others had made a literature search and annotation of salt deposits. Lang also had reported on preliminary hydrologic studies in TL Dribble 9 (USGS–474–128). Edward J. Harvey and Robert V. Chafin reported on the geology and hydrology of the Tatum Salt Dome in TL Dribble 34 (USGS–474–131). John Skelton (SWB) summarized surface-water investigations in Lamar and Marion Counties, Mississippi, in TL Dribble 27 (1962) (USGS–474–286). Others reporting on surface-water investigations included Carney P. Humphreys, Jr., Michael W. Gaydos, Harold G. Golden, Donald E. Shattles, and Richard E. Taylor.

Mississippi GWB District personnel under the supervision of Edward J. Harvey participated in drilling through the five aquifers at the Project Dribble site and directed the hydrologic testing of those holes during 1961 to 1967. Other project personnel included Clarence A. Armstrong, Robert V. Chafin, Paul E. Grantham, Hobard V. Harris, Francis C. Koopman, Richard E. Taylor, Thad H. Shows, John F. Stanford, Jr., William T. Oakley, and Billie E. Wasson. The results of the test drilling and hydrologic testing were published in open-file reports or provided to AEC in technical letters. Beetem and Janzer (TL Dribble 31, 1963) (USGS–474–318) gave distribution coefficient data and Everett A. Jenne (TL Dribble 35, 1963) (USGS–474–291) reported his studies of the chemical character of selected core samples.

Taylor (TL Dribble 46, Suppl., 1967) (USGS–474–127), with Donald A. Morris and Oakley, assisted the AEC in investigating water-well complaints related to the Salmon event and the later Sterling event, a 350-ton nuclear device detonated in December 1966 in the cavity formed by the Salmon event. Hale, with Mississippi District and Denver personnel, documented the hydrologic effects of the nuclear test. Field personnel included Koopman, James A. Basler, Leonard E. Wollitz, John T. Evans, Humphreys, Oakley, and Taylor. If the compaction of the aquifer close to the detonation resulted in long-term elevated water levels, finding anomalously high water levels had been considered as a possible method to detect unannounced underground nuclear detonations. Tests included installing transducers in wells open to one aquifer and monitoring the pressure pulse at the time of the Salmon event and the decay of the pressure pulse over several days. The streamflow measurements before and after Salmon are the first known, documented changes in streamflow resulting from a nuclear detonation.

Taylor collected hydrologic data at the time water samples were collected by Isotopes, Inc., and transmitted splits of the samples from 10 test wells over or near the Tatum Salt Dome for analysis by WRD Denver analytical laboratories. Janzer, Robinson, Samuel J. Rucker, Beetem, and Grove (1965–66) summarized the radiochemical analyses of these groundwater samples in open-file reports (TL Dribble 42 and 44) (USGS 474–298 and USGS 474–115).

#### *Project Long Shot Site Studies*

On October 29, 1965, Long Shot, an 85-kiloton nuclear device, was detonated on Amchitka Island, Alaska. Leonard M. Gard, Jr., and Hale (TL Long Shot 1, 1964) and Hale (TL Long Shot 1A, 1965) reported on the geology and hydrology of the Long Shot site. Beetem and others summarized the distribution-coefficient data and analyses of water samples from Amchitka Island in TL Amchitka 26 (1965) (USGS–474–123) and TL Amchitka 29 (USGS 474–135).

### *Plowshare Program*

The Plowshare program of the AEC explored utilization of nuclear explosives for peaceful purposes. Most of the tests were aimed at creating underground space for storing fluids, but other tests, such as enhancing the permeability of tight gas sands, were conducted.

In addition to involvement in field studies, WRD personnel developed conceptual analyses. Arthur M. Piper (TEI–873, 1968), with contributions from other WRD authors, assessed different geologic terranes and their hydrologic environments that might be beneficially affected through the use of nuclear detonations. Piper and Stead (TEI–857, 1965) appraised potential applications of nuclear explosions in developing and managing water resources and delineated major steps needed to assess applicability to particular situations. Other WRD Plowshare work was reported in an AEC series designated PNE (Peaceful Nuclear Explosives).

#### *Project Gnome Studies*

Project Gnome, the first Plowshare experiment, was detonated in the Salado Formation near Carlsbad, N. Mex., on December 10, 1961. The 30-foot-thick Culebra Dolomite Member of the Rustler Formation is the most widespread aquifer in the project area at a depth of about 500 feet. Preliminary hydrologic studies, begun in October 1958 by New Mexico District GWB personnel, were reported by Hale and Clebsch in TEM–1045 (1958). Further studies in February to May, 1959 included locating wells, measuring water levels, and collecting water samples, well logs, and other subsurface data. Data from seven test holes, drilled for hydrologic information during July 1960 to June 1961, and water measurements made in the shaft and tunnel constructed for access to the future nuclear detonation point, were reported by James B. Cooper in TEI–767 (1960) and in TEI's 786 and 802 (1962). The final report was by Cooper and Virginia M. Glanzman in PP 712–A (1971).

Fifteen wells, including the hydrologic test holes, were examined by Koopman, Basler, Evans, and Walter A. Mourant in March and April 1959, before the detonation, and during July 1960 to June 1961, for possible damage. Leonard M. Gard, Jr., and Mourant logged and reported on rock distribution of the Project Gnome shaft. Distribution coefficients for rock and soil samples from the shaft, drift to shot point, samples of cores from test holes, and samples of water from the local aquifer were determined preshot by Janzer, Marvin C. Goldberg, Angelo, and Beetem and reported by Beetem and others in AEC's Project Gnome report PNE–130–F, (1962).

Observations of water levels during the Gnome event were made by Hale, Koopman, and James B. Cooper, and reported by Cooper in the PNE–130–F report. Elevated water levels were observed at shot time but were normal within 12 hours. This was the first observation by WRD personnel of the effects of a nuclear test on water levels.

#### *Project Sedan Studies*

Project Sedan was an experiment using multiple nuclear devices detonated in July 1961 in the alluvium of northern Yucca Flat, NTS, as part of a study of the feasibility of constructing a sea-level canal near the present Panama Canal. Piper and Beetem directed a study to determine the surface area per gram and the identity and distribution of several radionuclides as a function of surface area for the fallout samples from Sedan. Beetem, Janzer, Robert C. Scott, and Piper collected detonation fallout on sample trays placed in 1-mile, 3-mile, and 15-mile circles about the emplacement hole shortly after the detonation. Part of the fallout was separated into different particle-size fractions by Janzer, Beetem, and Roger W. Vernon to determine concentrations for different size fractions. Part of the fallout material was used at the Project Chariot site as described below.

***Project Chariot Studies***

The U.S. Army Corps of Engineers, in studies for the AEC, selected the Chariot site in the Cape Thompson region, north of the Arctic Circle in northeastern Alaska, as a location for a nuclear cratering experiment for harbor construction in an Arctic environment. Piper, in report TEI–810 (1961), analyzed the probable concentrations of radionuclides in local water supplies from fallout from Project Chariot. Values of possible radionuclide concentrations were calculated for an area of several thousand square miles using several rainfall, runoff, and streamflow models. The radionuclide concentrations projected for Project Chariot in this initial analysis did not consider the effect of suspended sediment and the distribution coefficients for the system.

Roger M. Waller of the Alaska GWB District studied the ground water of Ogatoruk Valley at the Chariot site during 1959 to 1961 and reported his work in AEC report PNE–481, (1966). In the same report, Elmer H. Likes reported the surface-water flow and other hydrologic analyses that he made at the Chariot site during 1958 to 1961. William L. Lamar, staff scientist with the Western Region, similarly reported in 1966 on the chemical and sedimentation characteristics observed from samples collected by Project Chariot project personnel during 1958 to 1961. Baker, Beetem, and Wahlberg also reported values of distribution coefficients measured for carrier-free cesium, strontium, and iodine on samples collected by Janzer in July 1961 (open-file report, 1964). Fallout from Sedan was spread over 10 test plots at the Chariot site in August 1962 by Janzer, Beetem, and Reuben Kachadorian (GD). The distribution coefficients and probable stream concentrations for radionuclides as measured in these tests were reported by Piper in PP 539 (1966).

The publication in 1966 of the report of the AEC Committee on Environmental Studies based on the hundreds of investigators' studies of Project Chariot was considered to be an epic environmental volume at the time. Their assessment discouraged conducting nuclear experiments above the Arctic Circle.

## Soil and Moisture Conservation Program

*By* Richard F. Hadley *and* reviewed *by* Norman J. King, Garald G. Parker, Sr., Charles T. Snyder, *and* Arvi O. Waananen

The work of the WRD in the Soil and Moisture Conservation (S&MC) program consisted primarily of collecting hydrologic data, investigating how to develop range-water supplies to facilitate management of the lands, and providing information for the design of conservation practices and land-treatment measures. Appraising the effectiveness of treatment practices in controlling erosion has been an important part of the activities, not only during the period 1957 to 1966, but since the Geological Survey first became involved in soil and moisture conservation activities in 1941.

In 1957, the S&MC program was headquartered in Denver, Colo., at the Federal Center following its transfer from Salt Lake City, Utah, in 1954. Field offices were located in Salt Lake City and Albuquerque, N. Mex. Harold V. Peterson, who had been in charge of the program since 1941, relinquished that position with the 1956 reorganization of WRD, at which time the S&MC program became a part of the new GHB. Peterson was appointed to the position of Branch Area Chief, GHB, RMA, in Denver, Colo., and Kenneth R. Melin was appointed project hydrologist for the S&MC program. All S&MC program projects, including work in the PCA, were supervised from the Denver office. In April 1959, the S&MC office in Salt Lake City was closed and Charles T. Snyder was transferred to Menlo Park, Calif., to continue S&MC program activities in the PCA under the supervision of the Denver office.

In early 1961, Peterson relinquished his position as Branch Area Chief and transferred to Menlo Park to devote full time to writing a history of the S&MC program. Melin was reassigned from his position as supervisor of the S&MC program to that of assistant to the Chief, GHB, with his headquarters remaining in Denver. Garald G. Parker, Sr., was transferred to Denver from Washington, D.C., to become Chief of the S&MC program. In July 1962, Melin again assumed direct supervision of the S&MC program, which consisted of several field projects, each headed by a project leader, and continued as Chief through the end of this period of WRD history. Parker continued his project work on arid-lands hydrology at the Warbonnet Creek site near Harrison, Nebr. But Parker's chief interests were in research, not administration, and in early 1962 he requested reassignment to full-time research on the hydrology of western drylands, with special emphasis on erosion and erosion processes. His request was granted and in September, 1962, he became Research Geologist (later, Research Hydrologist) to continue research of arid-lands hydrology and related elements of hydrogeology and geomorphology.

The part of the program dealing with investigations for ground-water supplies for livestock continued to expand and, beginning in FY 1964, the Bureau of

Land Management (BLM) transferred funds for this work.

As part of the 1961 reorganization, the ground-water supplies project and personnel of S&MC were transferred to the GWB and placed under the supervision of the Branch Area Chief, GWB, RMA. In December 1962, the project personnel were transferred back to the GHB, and those activities again became part of the S&MC program.

In 1963, with reorientation of the GHB program to research, the operational part of the S&MC program was set up as a separate unit (Soil and Moisture Conservation Unit) with Melin in charge. These activities included field investigations for water-resources development on public lands and research in arid-lands hydrology. This unit was transferred in July 1963 from the GHB to the Office of the Division Hydrologist, RMA (WRD Memorandum 64.9, O&M, para. 2; also Memorandum, Chief Hydrologist to Director, June 4, 1963, S&MC).

Research in the S&MC program to evaluate the effects of land-treatment practices were retained in the GHB program under the direction of the Branch Chief. In 1965 these projects and personnel were transferred to the Office of the Area Hydrologist, RMA, as part of restructuring WRD to a Division-line organization.

A long-term study of the effects of grazing on runoff, sediment yield, and plant cover at Badger Wash, near Grand Junction, Colo., begun in 1953, was continued through this period of history. Gregg C. Lusby was in charge of field operations, assisted by Farrel A. Branson, Lynn M. Shown, and others. In 1965, Lusby began a study on Bocco Mountain near Wolcott, Colo., to determine the effects of converting sagebrush cover to grass on the hydrology of small basins. This study was designed to continue until 1973. Another study of the effects of land treatment on the hydrology of small basins that began in 1951 was continued until 1961 at Cornfield Wash in northwestern New Mexico, with Frank W. Kennon and Durl E. Burkham in charge of field observations and data interpretation.

In cooperation with the BOR, Richard F. Hadley and Irel S. McQueen studied the effects of water-spreading on hydrology in Box Creek Basin, east-central Wyoming. This study was an outgrowth of the Cheyenne River Basin study (1950–54) of the effects of small reservoirs on river-basin hydrology.

Investigations of ground-water supplies for livestock continued and included individual sites and areal reconnaissance studies on grazing districts in the 11 Western States administered by the BLM and on Indian Reservations in New Mexico and Arizona. Norman J. King, Charles T. Snyder, Waite R. Osterkamp, Charles E. Sloan, Melvin Van Lewen, and Hadley were involved in these studies. Snyder completed studies on the public domain of western Utah and of the Ely grazing district in Nevada; Hadley completed a study in southeastern Idaho; Osterkamp completed a study of the Judith River formation in north-central Montana; King and Van Lewen completed a study on the Haxby area in north-central Montana; and Sloan completed a study of the Mescalero Apache Reservation in south-central New Mexico.

Farrel Branson, Reuben F. Miller, and Irel McQueen studied the relationship of plant communities and soil moisture in Colorado, Montana, and Wyoming.

The S&MC Program was funded primarily from the Geological Survey's S&MC appropriations from 1941 through this period (1957–66). In the late 1940's, program funding was supplemented by Missouri River Basin (MRB) funds. In the mid-1960's the BLM began to reimburse the Survey for ground-water investigations and for studies of the effects of land treatment. Annual funding amounts for the S&MC program are listed in the funding table for the GHB (see Part III, "General Hydrology Branch").

WRD personnel who worked in the S&MC program were R.S. Aro, 1960–63, 1966; F.A. Branson, 1957–66; W. Buller, 1962–66; D.E. Burkham, 1957–63; Scott Carson (summers), 1964–65; R.C. Culler, 1957–60; D. Dunagan, 1962–66; G.L. Fitzpatrick, 1964–65; M. Green, 1961–62; D.J. Hadju, 1962–64; R.F. Hadley, 1957–66; F.W. Kennon, 1957–64; N.J. King, 1957–61, 1963–66; R.W. Lichty, 1958–66; G.C. Lusby, 1957–66; I.S. McQueen, 1957–66; K.R. Melin, 1957–60, 1962–66; V.R. Meso, 1962–64; R.F. Miller, 1957–66; W.R. Osterkamp, 1963–66; G.G. Parker, Sr., 1960–64; H.V. Peterson, 1957; D.J. Proctor, 1957–62; K.W. Ratzlaff, 1959–66; B.N. Rolfe, 1957–66; S.A. Schumm, 1957–66; L.M. Shown, 1962–66; C.E. Sloan, 1959–64, 1963–64; R.E. Smith, 1964–66; C.T. Snyder, 1957–61, 1963–66; C.T. Sumsion, 1958–60; G.A. Tompkins, 1961–64; M.C. Van Lewen, 1957–61, 1963–66; D.A. Webster, 1966; and F. Zdenek, 1958–61, 1963–66.

In the 12 or 13 projects that made up the S&MC program during 1957–66, the topical material of the investigations can be grouped into six categories: (1) effects of land treatment and land use, (2) erosion and sedimentation, (3) general hydrology, (4) geomorphic processes, (5) ground-water supplies for livestock, and (6) soil-plant-water relationships. Of the 57 USGS and scientific journal publications resulting from these projects, key reports were by G.C. Lusby and others reporting on grazed and ungrazed watersheds in western Colorado (WSP 1532–B, 1963); R.F. Hadley on the history of sedimentation and erosion in Five Mile

Creek, Wyo. (PP 352–A, 1960); Hadley and I.S. McQueen on the effects of waterspreading on the hydrology of Box Creek Basin, Wyo. (WSP 1532–A, 1961); Hadley and S.A. Schumm on sources of sediment in the upper Cheyenne River Basin, Wyo. (WSP 1531–B, 1961). Also, N.J. King reported on hydrologic data of the Wind River and Fifteen Mile Creek Basins in Wyoming (WSP 1475–A, 1959) and H.V. Peterson on the hydrology of small watersheds in western States (WSP 1475–I, 1962). In addition, in 1960, B.N. Rolfe, R.F. Miller, and McQueen reported in PP 334-G on water dispersion characteristics of several clays and their control with phosphate dispersants. Regarding water supplies for stock, R.C. Culler reported on the hydrology of stock-water reservoirs in the upper Cheyenne River Basin (WSP 1531–A, 1961) and C.T. Snyder on the hydrology of stock-water development on the public domain of western Utah (WSP 1475–N, 1963). And, in PP 424–B, (1961), Miller, F.A. Branson, McQueen, and Culler compared soil moisture under juniper and pinyon with moisture under grassland.

### Water-Use Studies

*By* Kenneth A. MacKichan *and* John C. Kammerer with assistance *by* Edith B. Chase

The series of reports on national water-use estimates, begun in 1950 (Circ. 115, 1951 by Kenneth A. MacKichan) and prepared at 5-year intervals, was continued during 1957 to 1966. As in the past, WRD Districts provided a major part of the data in these reports. Other primary sources of information included the American Water Works Association, the PHS, the U.S. Bureau of the Census, and the FPC. The report for 1955 was compiled by MacKichan (Circ. 398, 1957); for 1960, by MacKichan and John Kammerer (Circ. 456, 1961), and for 1965 by C. Richard Murray (Circ. 556, 1968). The demand for this series of reports continued to be strong; the 1960 report was reprinted three times.

MacKichan and Kammerer also compiled a regional water-use report entitled "Preliminary estimate of water used in Southeast River Basins, 1960" (Circ. 449, 1961) for 11 water-use regions within and adjacent to the State of Georgia, a contribution to the U.S. Study Commission, Southeast River Basins. Lois E. Randall prepared an annotated bibliography of water-use data, 1960 (Circ. 455, 1961). Edith Becker Chase assisted the water-use staff on many reports and was coauthor of a water-quality-oriented report on public water supplies of the 100 largest cities in the United States, 1962 (Durfor and Becker, WSP 1812, 1964); the report included water-use data for each city. Others assisting MacKichan early in the 1957–66 period (as well as in previous years) were Orville D. Mussey and Louis E. Otts, Jr. In 1962, MacKichan was transferred to Ocala, Fla., as District Engineer, QWB. In 1966, C. Richard Murray transferred from WRD's Foreign Hydrology Section to become chief of water-use studies and was assisted by E. Bodette Reeves.

Beginning with the 1955 national water-use report, water data for each category of use were reported not only by States but also by major drainage regions, by water-use regions (1960 and 1965), or by Water Resources Council regions (1965). Also, beginning in 1960, separate totals were listed for Alaska, Hawaii, and Puerto Rico (and sometimes Puerto Rico and U.S. Virgin Islands). Further, in 1960, most of the categories of water use were expanded to include water consumed.

The subject of water resources, including water use, received increasing attention by Federal agencies during 1957–66 as a consequence of several legislative and executive actions, including (a) the establishment of the Select Committee on National Water Resources by Senate Resolution 48 of the 86th Congress, 1st session (1959); (b) the enactment of the Water Resources Planning Act in 1965 (PL 89–80) that formally established the U.S. Water Resources Council and directed it to prepare a periodic assessment of "the adequacy of supplies of water necessary to meet the water requirements in each water-resource region in the United States"; and (c) the implementation of BOB Circular A–67 (1964) that resulted in the creation of the Office of Water Data Coordination (OWDC) within the WRD. WRD personnel were active participants in many of the activities associated with these initiatives, and requests to USGS for water-use data were frequent. (See Part VIII, "Water Issues and Events.")

The Senate Select Committee, chaired by Senator Robert S. Kerr of Oklahoma, issued 32 Committee Prints (reports) prepared by various Federal agencies and others during 1959 to 1961 prior to publication of the final Committee report in 1961. Many of the prints contained substantial water-use information, in some instances provided by MacKichan and his staff or from their Circulars, especially Print No. 1, Water facts and problems (Luna Leopold, 1959); Print No. 3, National water resources and problems (USGS, 1960); and Print No. 32, Water supply and demand (Nathaniel Wollman, Resources for the Future, Inc., 1960).

Douglas R. Woodward of the Director's office, in a thesis for the Industrial College of the Armed Forces, discussed regional water supply and water use (much of the water-use data was from MacKichan's 1955 water-use circular) and evaluated the adequacy of the potential supply for meeting the anticipated needs of industry in 1980. Arthur M. Piper, using essentially the same 19 regional subdivisions of the conterminous United States as those in the Select Committee prints, prepared a report (WSP 1797, 1965), "Has the U.S. enough water?", examining the adequacy of water supply to meet water demands in 1960 and projected demands in the year 2000. [Note: In the January 1969 issue of the USGS Water Resources Review (p. 10), J.C. Kammerer presented a correlation chart of the water resources regional names described in reports noted above by Woodward (1957), Wollman (1960), and Piper (1965), and by the U.S. Water Resources Council (1968)].

### Delaware River Basin Project

*By* Garald G. Parker, Sr., *and* reviewed *by* Allen Hely

The purpose and objectives of this project, as explained to the author by Luna B. Leopold, Chief, WRD, George E. Ferguson, Division Hydrologist, ACA, and Charles C. McDonald, Chief, GHB, were to:

1. Demonstrate that an assessment of a large river basin's water resources and its geologic framework could be made quickly and inexpensively by a small, multidisciplinary staff of Division specialists using mostly existing data. If successful, the project would facilitate "selling" unification of effort within the WRD as an overall, integrated water-resources effort rather than as separate Branch efforts.

2. Make the Delaware River Basin project a model upon which future basinwide, comprehensive, and intensive studies could be based.

3. Provide published reports that would become comprehensive sources of water-resources and hydrogeologic information for water managers, water-specializing lawyers, legislators, administrators, and the interested general public. The Professional Paper was selected as the report mode because its larger page size would provide a better illustration medium, particularly for basin-size maps, diagrams, and charts. Additionally, a hydrologic atlas was designed for its uniquely favorable format for presenting hydrologic information.

4. Become a working partner with other Federal agencies, generally at that time under the auspices of the U.S. Army Corps of Engineers, in comprehensive river-basin planning.

5. Demonstrate that within the WRD itself, it is feasible, practicable, and highly desirable for unified, comprehensive, and integrated water-resources research to be conducted. This project was so manned and operated.

6. Demonstrate to the community of Federal and other agencies involved in water development, use, management, and regulation the capacity and competence of the Survey to provide regional and basin-scale water-resources evaluations for planning, developing, utilizing, conserving, and protecting the Nation's water resources.

The project, assigned to the GHB, was officially launched in September 1956, following much planning by Division officials and GHB staff throughout that summer, and the selection of Garald G. Parker, Sr., as project chief in early July. By the end of July, office space had been rented in Upper Darby, Pa., and by mid-October the project members had been selected and were on the job. The project team also included Walter B. Keighton, chemist, Allen G. Hely, hydraulic engineer, and Franklin H. Olmsted, geologist. Gertrude W. Moore was secretary and Martha E. Tabbutt, draftsperson. Others who contributed to the completion of the project are listed in PP 381. Working relationships and a teamwork plan were quickly established with the SWB, GWB, and QWB Districts operating in Pennsylvania, New Jersey, Delaware, New York, and Maryland.

Chosen as the basis for the project's water-resources evaluations was the water-budget approach developed so well by Walter C. Mendenhall in his analysis of four California coastal basins in which he, supported by other WRD members, integrated surface water, ground water, and quality of water data to obtain water-crop values in each basin. Published as WSP's 137, 138, 139, and 142 in 1905, these reports had almost been forgotten by later workers. His work, with modifications from that of Meinzer and Stearns, 1929, "A study of ground water in the Pomperaug Basin, Connecticut" (WSP 597–B) was adopted by the project chief as a guide for hydrologic assessment in the basin, with excellent support from all who were asked for help among the personnel of the field, Branch, and Washington offices.

The project team was able to assess the water resources and geology of the Pomperaug basin, and prepare an up-to-date geologic map (scale 1:500,000) of the basin that is currently recognized as the best available. In addition to the surface mapping, the geology, stratigraphy, structure, and fabric were described and graphically presented in cross-sectional and block diagrams. Two interim 300+ page reports, replete with hand-colored maps, diagrams, and graphs, were prepared for the U.S. Army Corps of Engineers (1957 and 1958), plus the Survey's final reports, PP 381 and HA–11. Work on the Basin assessment began in September 1956, and was completed by November 1958; a total of 26 months and well within the originally planned 3 years. More work was required to complete PP 381 and HA–11, which was a joint effort with the U.S. Weather Bureau (USWB).

HA–11 (1961) was the first to reach publication, having been submitted for processing for publication December 4, 1958. It was titled "Precipitation, water loss, and runoff in the Delaware River basin and New Jersey" and was authored by Hely, Nordenson (USWB), and others. It summarized climatic and hydrologic data for the basin, mostly in map format, for the period 1921–50. Five plates described mean annual and seasonal precipitation, mean annual water loss, mean annual and seasonal evaporation from free water surfaces, mean annual temperature, and mean annual and seasonal runoff.

As field work drew to a close, Parker moved back to Washington as Assistant Chief, GHB, in late November 1958, leaving Hely in charge with Olmsted and Keighton to assist occasionally in 1959 and 1960 making revisions needed to move the PP 381 manuscript toward printing. The Delaware River Basin project investigations were completed. Hely and Olmsted were assigned related research projects that resulted in PP 417–A, by Olmsted and Hely (1962), titled "Relations between ground water and surface water in Brandywine Creek basin, Pennsylvania" and PP 417–B, "Some relations between streamflow characteristics and the environment in the Delaware River Region," by Hely and Olmsted (1963).

Meanwhile Hely, Olmsted, and Keighton moved on to other projects leaving Parker, after January 1, 1961, engaged in field and office administration and research out of the Denver office, to make additional reviews and revisions to the manuscript. It was not until October 10, 1964, that the third round of proofsheets, corrections of maps, charts, diagrams, and text was mailed back to Washington for printing, and not until July 2, 1965, that PP 381 was printed and released, bearing a 1964 publication date.

PP 381, entitled "Water resources of the Delaware River Basin," was issued with a text of 200 pages in one volume and a second volume containing 12 large maps, diagrams, and charts. Authored by Parker, Hely, Keighton, Olmsted, and others, the report described the interrelations of ground water and surface water, their availability, variability, quality, development, uses, and, by water-budget analysis, quantified the water resources. Water problems were described, the foremost being: (1) saltwater encroachment; (2) industrial, agricultural, and municipal waste discharges, especially below Trenton into the estuary; (3) acid coal-mine wastes, especially into the Schuylkill River; and (4) suspended and bottom wastes as sediment. The report concluded, "Development of the water resources of the basin is limited more by economic and human factors, such as costs and water rights, than by the magnitude of the potential supply of water of good quality."

Total cost of the project could not be ascertained from records available. Division memoranda contain references to Federal program funding of $50,000 in FY 1957 and $75,000 in FY 1958. Undoubtedly some additional funds were expended in making the final reports ready for publication; however, the expenses of final typing and the reproduction of the 1957 and 1958 reports to the Corps of Engineers were borne by the Corps. The author estimates that total funding by the Corps of Engineers for the Survey's efforts did not exceed $100,000.

As a demonstration effort, the Delaware River Basin project fulfilled its multiple objectives as evidenced by the usefulness of the reports and by furthering the Division's goals to strengthen and diversify its programs of hydrologic information and research.

### Lower Colorado River Project

Based on material supplied *by* Charles C. McDonald *and* reviewed *by* Frank Olmsted

The Lower Colorado River project was rooted in ever-increasing demands on Colorado River water, recognition of the relationship between surface and ground water, increasing salinity of water in the lower basin, dissatisfaction by Mexico with the quality of water available for her use, and litigation among the American users, particularly the States, over equitable distribution of the river's water.

The issues were brought to the fore in the spring of 1959 in a letter from the Chief Engineer Matthews, Colorado River Board of California, to the Secretary of the Interior, stating that data being obtained are inadequate for proper analysis and utilization of the water supply in the Lower Colorado River particularly in the Yuma area. He pointed out that a more precise understanding of the hydrology of the lower river was needed and that Interior, either USGS or BOR, undertake the task. The Secretary's Technical Review Staff referred Matthew's letter to the Pacific Southwest Field Committee (PSFC) with instructions to draft a reply and develop an appropriate investigational program.

Arthur M. Piper was the USGS member of PSFC. He and Arthur Mitchell, BOR, were designated by the Chairman, PSFC, to draft a statement to the Secretary. By midsummer, and following a series of meetings, correspondence and conversations involving Piper, Mitchell, the Technical Review Staff, and S. Keith Jackson, a statement was drafted. Piper, however, felt that the proposed investigations were too severely limited and that a continual, comprehensive water-supply budget was needed for the entire basin downstream from Lees Ferry.

By the late summer, Leopold asked Piper and Jackson and the Branch Chiefs to develop a long-range plan for water-resources investigation in the Lower Colorado River Basin and assigned Thomas Maddock, Jr., to work with the group. After discussions with Director Nolan and before initiation of the studies, the proposed project would be discussed with other agencies to forestall adverse reaction and to obtain their support.

Hearings before the Senate Appropriations Committee on the Survey budget for FY 1961 were held in February 1960. Chairman Hayden asked Director Nolan for more details and to provide a statement for the record regarding the entire Survey plan. The statement included the following:

> SCOPE AND PURPOSE
>
> Intensive water resources investigations are needed along the main stem below Davis Dam and in the areas immediately adjoining the river channel. The principal objectives of the proposed investigation are as follows:
>
> 1. To determine the flow of ground water to Mexico and the effect of pumping, both in the United States and in Mexico on ground-water movement; to establish the relation between ground water and inflow to the Salton Sea; to establish the adequacy of aquifers in the vicinity of Yuma as a river-regulating reservoir; to establish the relation between ground-water pumping and riverflow in the reach of the river below Davis Dam; to determine the relation between regional ground-water conditions and drainage problems on irrigated areas.
>
> 2. To measure discharge of the Colorado River at critical locations below Davis Dam, the flow of major drains and tributaries entering the river, and the surface runoff to the Salton Sea; to review data on diversions from the river which had been collected by other agencies, and to measure more adequately the total diversion from the Colorado River.
>
> 3. To determine the evaporation from the Salton Sea and water lost from various kinds of vegetation and from open water surfaces.
>
> 4. To determine the requirements for a stable channel under different methods of river operation.
>
> METHODS OF STUDY
>
> The investigations would utilize techniques already developed for streamflow measurement and the determination of aquifer characteristics of pumping tests. Some drilling of new test wells would be required to determine water levels and for further information on subsurface conditions. Evaporation and transpiration would be measured, adapting methods now available which rely either on heat budget or energy budget measurements. Inventories would be made of unmeasured diversion and water pumped from the river. Some geologic mapping of a reconnaissance nature would be carried out. Evaporation from the Salton Sea would be measured by a combination of energy budget and water budget analyses.
>
> ESTIMATED COST
>
> The investigation would require between 8 and 10 years. The average expenditure per year would be in the order of $300,000, at least during the first part of the investigation. Of the total expenditure, estimated at $2,500,000, approximately $500,000 would be used for well drilling and for geophysical investigations. The bulk of the funds would be required for the measurement of evaporation, transpiration, streamflow, and investigation of the ground waters.

In a May 31, 1960, memo to Chief, GWB, Leopold announced his selection of Charles C. McDonald as project chief; that GWB was designated as the Branch to assume overall project leadership; that Yuma, Ariz., was to be project headquarters; and that $200,000 of Federal programs funds was being made available for FY 1961. For FY 1962, $325,000 was allotted to the project through GWB. Allocations for subsequent years are not available; however, Frank Olmsted recalled that about $1,000,000 was spent to drill 30 test wells (written commun., Olmsted to Hudson, November 30, 1989).

The project was concluded in 1970. PP 486–A (1976), "Water resources of lower Colorado River—Salton Sea area as of 1971; summary report," by C.C. McDonald and O.J. Loeltz, highlighted the course and content of the project as follows:

The ...project was started July 1, 1960, .... During the first year ground-water studies in the Yuma, Imperial and Coachella Valleys, and Parker-Blythe-Cibola areas were begun. Also begun were the studies pertaining to the surface-water supply of the project area and the studies for determining evaporation from the Salton Sea, consumptive use rates by phreatophytes, and chemical quality of both surface- and ground-water supplies.

Progress reports on these studies were presented at public meetings held in December 1961, March 1963, and May 1964 at Yuma, Ariz.

In 1962 fieldwork pertaining to the study of evaporation from the Salton Sea was completed, and ground-water studies in the Coachella Valley were suspended pending the completion of a report on the water supply of that area by the California Department of Water Resources.

By mid-1964 the first of two electric analog models of the Yuma area was being built in the Phoenix hydrologic laboratory.... Also, gravity, aerial magnetometer, Earth resistivity, and seismic surveys were being used to supplement the test drilling and other geologic investigations.

In 1966...because of newly acquired evidence regarding the hydrologic significance of the Algodones fault...additional investigations in the Yuma area were undertaken. The additional studies, which lasted more than a year, were needed to determine the location and extent of the fault and its effect on the movement and chemical quality of the ground water. Geophysical exploration and test drilling, in cooperation with the U.S. Bureau of Reclamation, disclosed that this northwest-trending fault was a significant barrier to the movement of ground water. Incorporating the barrier effect of the fault into a second, more sophisticated electric analog model of the Yuma area made possible the satisfactory simulation of historical changes in water level in the Yuma area. The project studies in the Yuma area were supplemented by studies made at the request of and for the U.S. Section of the International Boundary and Water Commission. These later studies were concerned with determining rates and directions of ground-water movement across segments of the international boundary under natural conditions and at various times during the development of ground-water and surface-water supplies both in Mexico and in the United States.

The U.S. Bureau of Reclamation, Yuma project office, furnished information from its files, did some exploratory drilling, financed a reflection seismic survey, contributed financially toward the construction of an electric analog model of the Yuma area, and, in addition, maintained a close working relationship with the Survey throughout the investigation. Both the U.S. Section and the Mexican Section of the International Boundary and Water Commission provided valuable data from their files. The U.S. Section also provided financial assistance toward construction of the analog model.

The cooperation of the Colorado River Indian Agency, the Upper Colorado River Commission, several private consultants, and the various irrigation districts in making available needed data from their files is gratefully acknowledged. Appreciation is also extended to the many well drillers who had drilled, or were drilling, wells in the project area for making available their logs of wells and the results of well-completion tests. Acknowledgment and appreciation are given to the many farmers and other landowners for generously permitting access to their lands and wells, for furnishing data on their wells and farming practices, and for their cooperation in the scheduling of aquifer tests.

The following summary of the results of the project studies is based mainly on project reports, published as PP 486, chapters B-K, the titles of which are:

B. "Precipitation, Runoff, and Water Loss in the Lower Colorado River-Salton Sea Area"

C. "Hydrologic Regimen of Salton Sea, California"

D. "Lower Colorado River Water Supply--Its Magnitude and Distribution"

E. "Salinity of Surface Water in the Lower Colorado River-Salton Sea Area"

F. "Consumptive Use of Water by Phreatophytes and Hydrophytes near Yuma, Arizona"

G. "Geohydrology of the Yuma Area, Arizona and California"

H. "Geohydrology of the Parker-Blythe-Cibola Area, Arizona and California"

I. "Analog Simulation of the Yuma, Arizona, ground-water system"

J. "Geohydrology of the Needles area, Arizona, California, and Nevada" and

K. "Geohydrologic reconnaissance of the Imperial Valley, California."

PP 486–A (1976) summarized the findings of the study, the principal elements of which were:

> ...The net supply of Colorado River water below Davis Dam for normal runoff conditions is estimated at 10.2 million acre-feet for 1975 and 8.4 million acre-feet for the year 2030. For dry conditions, the corresponding supplies are 8.2 million and 6.4 million acre-feet respectively. The present basic allotment to Arizona, California, and Mexico is 8.7 million acre-feet per year, to which is added conveyance and storage losses averaging 900,000 acre-feet per year, making the total 9.6 million acre-feet of water per year. The supply probably will be adequate during periods of near-normal runoff until about 1980.
>
> The river, either directly or indirectly, is the principal source of the ground-water supply. Large yields commonly are obtainable from wells that tap coarse Colorado River deposits. Evaporation from the river and from reservoirs consumes more than 1 million acre-feet of water per year. Riparian vegetation consumes more than 500,000 acre-feet of water per year. About 1.3 million acre-feet per year drains to the Salton Sea, where it evaporates. Normal annual evaporation from the sea is 69 inches.
>
> Dissolved-solids concentration of the river water increases with distance downstream and with time. For 1951–55 the dissolved-solids concentration below Hoover Dam averaged 658 milligrams per liter, and at Imperial Dam, 706 milligrams per liter. For 1961–65 the concentration was 714 and 824 milligrams per liter, respectively.
>
> Sulfate reduction appears to be a major process in the chemical alteration of river water to ground water that contains fewer dissolved solids than river water. Fresh water (less than 1,800 mg/L dissolved solids) extends to depth of more than 2,500 feet in the south-central and southwestern parts of the Yuma area. Beneath most areas in central Imperial Valley, ground water contains sufficient dissolved solids to make it unsatisfactory as a domestic or an irrigation supply.
>
> Westward movement of ground water to Mexico in 1960–63 was about 33,000 acre-feet per year; southward movement east of the river was about 35,000 acre-feet per year. A large part of the leakage from the All-American Canal in the 37-mile reach west of Pilot Knob, estimated at 150,000 acre-feet annually in 1961–63, moves southward across the international boundary to Mexicali Valley.
>
> Pumpage from drainage wells, sumps, and drains adjacent to Yuma Mesa increased from about 70,000 acre-feet in 1960 to 146,000 acre-feet in 1969. This increased drainage added to the problem of satisfactorily disposing of 200,000 acre-feet per year of moderately saline (4,000–6,000 mg/L) pumped return flow from the Wellton-Mohawk area.

Key members of the project during all or most of its duration in addition to McDonald included Allen G. Hely, Gerth E. Hendrickson, Burdge Irelan, Omar J. Loeltz, Donald G. Metzger, Franklin H. Olmsted, Eugene P. Patten, Jr., and James H. Robison. G. Earl Harbeck, Jr., assisted by Alex M. Sturrock, ran the evaporation studies and Gilbert H. Hughes, the transpiration studies.

### The Mississippi Embayment Project

*By* Ernest H. Boswell *and* reviewed *by* Elliott M. Cushing

The Mississippi Embayment, as defined for this project, comprises about 100,000 square miles in the Gulf Coastal Plain. From its apex in southern Illinois, the embayment fans out southward to about the 32d parallel and includes parts of Alabama, Arkansas, Illinois, Kentucky, Louisiana, Mississippi, Missouri, Tennessee, and Texas. (See fig. IV–1.)

In the early 1950's, about 90 percent of the water used in the embayment was drawn from wells and springs, and the use of ground water was increasing rapidly. Investigations of ground water in the past had been conducted within the cooperative program and typically were directed at segments of the formations in the embayment. By the mid-50's, the need was apparent for a study of the entire embayment, that within the limits of time, personnel, and data available, would:


Figure IV-1. Area of study, Mississippi Embayment.

1. Define the regional geologic structure and stratigraphy and determine their influence on the movement, availability, and quality of ground water.

2. Determine areas of ground-water recharge and discharge, the directions and rates of flow between these areas, the influence of these areas on the low-flow characteristics of the streams, and the influence of artificial withdrawals on the ground-water reservoirs.

3. Determine the relation between the geology and the low-flow characteristics of streams, the expected low flows of streams on a frequency basis, and the storage requirements for maintaining certain minimum flows.

4. Study the relation between streams and ground-water reservoirs.

5. Relate, by study of chemical analyses, the chemical quality of the water to its geographic and geologic environment.

6. Determine the downdip extent of freshwater in the formations and the presence of chloride, fluoride, nitrate, and other chemical constituents which, in excess concentrations, could possibly restrict the usefulness of the water.

The project began in August 1957 and was originally planned as a 5-year, $900,000 study. Funding was by allocation of Federal program funds. First-year funding was $75,000. At the end of the first year, project personnel were informed that funding for the study in subsequent years would not exceed $100,000 per year. The project was redesigned for completion in 9 years and was completed on schedule. Memphis, Tenn., was selected as the project headquarters because of being centrally located in the embayment. Memphis was also headquarters of the Tennessee GWB District.

Although A. Nelson Sayre, Chief of the GWB until 1959, advocated assigning staff to the project on a full-time basis and for the duration of the project, actual project staffing involved only four who were assigned full time to the project but many more who were assigned part time. Consideration was given to stationing the full-time personnel in Memphis; however, it was decided that it would be more efficient for personnel to have ready access to data in their Districts.

Elliott M. Cushing, District Engineer of the Tennessee GWB District, was chosen to head the project. Paul R. Speer of the SWB project office in Chattanooga, Tenn., directed the streamflow components of the project, and Merle E. Schroeder, District Chemist, succeeded by John H. Hubble, QWB, Fayetteville, Ark., directed the quality-of-water activities. Stephen M. Herrick, GWB, Atlanta, Ga., did the lithologic and micropaleontologic studies for the project. Besides Cushing, only Mildred S. Hankins, clerk-typist, was assigned to the project full-time from the Memphis GWB office. Ernest H. Boswell of the Jackson, Miss., GWB District was assigned full-time but remained in Jackson and Robert L. Hosman of the Little Rock, Ark., GWB District was also assigned full-time to the project and remained in Little Rock.

Other personnel who participated in the project by collecting and analyzing data and by preparing reports from their bases in other States were: Ernest T. Baker, GWB, Texas; Anthony Calandro, SWB, Louisiana; James H. Criner, GWB, Memphis, Tenn.; Robert W. Davis, GWB, Kentucky; Harold G. Golden, SWB, Mississippi; Curtis H. Hannum, SWB, Kentucky; C.E. Harris, GWB, Louisiana; Edward J. Harvey, GWB, Missouri; Leland D. Hauth, SWB, Arkansas; Vincent D. Herreid, SWB, Illinois; Marion S. Hines, SWB, Arkansas; Melvin E. Janson, SWB, and Horace G. Jeffery, QWB, Missouri; T. William Lambert, GWB, Kentucky; Oscar G. Lara, SWB, Illinois; Archie T. Long, GWB, Texas; Lawrence M. MacCary, GWB, Kentucky; John A. McCabe, SWB, Kentucky; Gerald K. Moore, GWB, Tennessee; John G. Newton, GWB, Alabama; William Ogilbee, GWB, Texas; James L. Patterson and Laurence B. Pierce, SWB, Alabama; Woodford J. Perry, SWB, Tennessee; Joe E. Reed, GWB, Arkansas; Ernest E. Russell (WAE), GWB, Mississippi; John Skelton, SWB, Mississippi; John Sullavan, SWB, Arkansas; William H. Walker, GWB, Louisiana; William J. Welborne, QWB, Arkansas; and George H. Wood, SWB, Tennessee.

Although the staff were widely dispersed, coordination of their activities was effectively accomplished. Meetings were held in Memphis or in other participating offices as needed for coordination and planning and were more frequent as the preparation of reports began.

To appraise the ground-water resources of the embayment region, it was apparent that the framework of the geohydrologic system should be delineated and that the relationship and continuity of aquifers be defined.

The plethora of geologic names that were in use in the several States were consolidated into a correlation chart that was submitted with suggested changes to the appropriate State geological surveys for review. The chart was eventually approved by all States and by the Geologic Names Committee of the USGS. Some field mapping was done to better define geologic units.

Surface-water studies emphasized the low flows of streams, the quality of water in streams, and relation of flow and quality to lithology of geologic units.

Project members from each State made studies of data needed to define and delineate the continuity and relation of geologic units and aquifers. Probably the most useful sources of data were the thousands of geophysical logs of oil tests that were available. Cutting samples from oil-company sample libraries and State geological surveys were available. Water-well driller's logs, water-use data, and water-quality analyses in each district were analyzed. Two deep stratigraphic test wells were drilled near the axis of the embayment trough in Arkansas and Tennessee. Drill cuttings from these test holes and from several sample repositories were described by Stephen Herrick.

The first publication was Circular 471, "Water Resources and the Mississippi Embayment Project," by Elliott M. Cushing, published in 1963. Also prepared by Cushing and published in 1966 was HA–221, a map showing the base of freshwater in the aquifers in the embayment. A paper, "Water Resources of the Mississippi Embayment East of the Mississippi River," by Boswell and Cushing, was published in American Institute of Mining Engineers Transactions in 1968 (v. 241).

Several District-level reports based on data developed during the embayment project were prepared by members of the project staff. MacCary and Lambert were the authors of "Reconnaissance of ground-water resources of the Jackson Purchase Region, Kentucky" (HA–13, 1962). "The Carrizo Sand, a potential aquifer in south-central Arkansas" (PP 501–D, 1965) was prepared by Hosman. Moore was the author of "Geology and hydrology of the Claiborne Group in western Tennessee" (WSP 1809–F, 1965). A report by Moore and Donald L. Brown, "Stratigraphy of the Fort Pillow Test Well, Lauderdale County, Tennessee," was published by the Tennessee Division of Geology in 1969.

The principal findings of the study were published in chapters A–I of PP 448, as follows: Chapter A (1970), "Availability of water in the Mississippi embayment," by Cushing, Boswell, Speer, Hosman, and others; Chapter B (1964), "General geology of the Mississippi embayment," by Cushing, Boswell, and Hosman; Chapter C (1965), "Cretaceous aquifers in the Mississippi embayment," by Boswell, Moore, MacCary, and others, with discussions of Quality of the water, by Jeffery; Chapter D (1968), "Tertiary aquifers in the Mississippi embayment," by Hosman, Long, Lambert, and others, with discussions of Quality of the water, by Jeffery; Chapter E (1968), "Quaternary aquifers in the Mississippi embayment," by Boswell, Cushing, and Hosman, with a discussion of Quality of the water, by Jeffery; Chapter F (1966), "Low-flow characteristics of streams in the Mississippi embayment in northern Arkansas and in Missouri," by Speer, Hines, Janson, and others, with a section on Quality of the water by Jeffery; Chapter G (1966), "Low-flow characteristics of streams in the Mississippi embayment in southern Arkansas, northern Louisiana, and northeastern Texas," by Speer, Hines, Calandro, and others, with a section on Quality of the water, by Jeffery; Chapter H (1965), "Low-flow characteristics of streams in the Mississippi embayment in Tennessee, Kentucky, and Illinois," by Speer, Perry, McCabe, Lara, and others, with a section on Quality of the water, by Jeffery; Chapter I (1964), "Low-flow characteristics of streams in the Mississippi embayment in Mississippi and Alabama," by Speer, Golden, Patterson, and others, with a section on Quality of the water, by Welborne.

## Missouri River Basin Program

[Note.—The Missouri River Basin [MRB] program is more fully described by Hugh H. Hudson in "The Missouri River basin development program and the Water Resources Division, U.S. Geological Survey, 1946–83," USGS Open-File Report No. 90–119 (1992).]

Planning the Missouri River Basin program began prior to World War II, Congressional authorization was granted in 1944, and funding began in 1946. The program, in its entirety, was a compromise between plans advanced by the DOI and the U.S. Army Corps of Engineers, each of which sought authorization to develop and manage the water resources of the basin. Interior, with the BOR as its lead agency, was assigned the responsibility by Congress for irrigation and associated development in the headwater areas of "the irrigation States." The Corps was authorized to construct flood control and navigation works along the main stem of the Missouri River. The Bureaus of Land Management and Indian Affairs and the Fish and Wildlife Service had relatively minor development roles in the plan.

The role of the WRD was to provide the water-resources information needed by the development agencies to plan and operate their parts of the program. The Corps' needs were for streamflow records, funds for which were provided by the Corps through normal OFA funding procedures. Such funds were comparatively minor and were not termed MRB funds. MRB funds for the support of the Interior program were contained in BOR's annual public works appropriations and were transferred to each Interior bureau, including USGS. The fact that MRB funds for water-resources investigations were initially in BOR's appropriations supported BOR's contention that it was entitled to set priorities of work. The GWB, and to a lesser extent the QWB, disagreed and maintained a broader, more thorough approach to investigating and reporting on the water resources of project areas. The issue was resolved, not by logic or mediation, but by a budget collapse that effectively removed GWB and much of the QWB staff from the program. The budget reduction began in 1952 and reached its severest level in 1955.

Management of the MRB program was a staff function under the direction of S. Keith Jackson, Division Hydrologist, RMA. The program continued to be developed each year on basis of meetings with the Bureaus of Reclamation, Land Management, Indian Affairs, and the U.S. Fish and Wildlife Service in Denver, Colo., and Billings, Mont. Each element of the program was given a priority ranking by the requesting bureau. Final decisions on program content were made at Regional headquarters on basis of hydrologic value, cost, logistics of operation, and possible application of data from alternative sites. Branch, later Division, representatives from the Colorado, Kansas, Montana, Nebraska, and North and South Dakota Districts participated in formulating each year's program.

During the early years of the period 1957–66, the program consisted almost entirely of supplying streamflow, ground-water level, sediment and chemical-quality data. Then, in the mid-1960's, a series of ground-water studies on Indian reservations was begun. Listed below is the MRB budget by year for the years of this history. Funds for 1951, the all-time maximum budget year, are also listed to illustrate the general extent of the budget range.

Missouri River Basin project allotments[1]

[est, estimated]

| Fiscal year | Surface Water Branch | Quality of Water Branch | Ground Water Branch | General Hydrology Branch | WRD Headquarters | Total |
|---|---|---|---|---|---|---|
| 1951 | $410,000 | $422,000 | $416,000 | $36,000 | $67,000 | $1,351,000 |
| 1957 | 239,180 | 194,310 | 166,685 | 3,165 | 33,860 | 637,200 |
| 1958 | 282,895 | 215,375 | 130,500 | 6,330 | 29,000 | 664,100 |
| 1959 | 190,725 | 136,645 | 93,930 | 4,220 | 22,980 | 448,500 |
| 1960 | 269,717 | 132,711 | 173,364 | 4,745 | 23,645 | 609,200 |
| 1961 | 285,249 | 183,577 | 172,237 | 9,405 | 20,296 | 651,100 |
| 1962 | 303,382 | 193,588 | 152,369 | 9,407 | 20,550 | 606,200 |
| 1963 | | | | | | 598,900 |
| 1964 | | | | | | 642,200 |
| 1965 | | | | | | 620,000 (est) |
| 1966 | | | | | | 834,200 (est) |

[1]Not available by Branch after 1962.

## Prairie Pothole Project

*By* Charles E. Sloan *and* reviewed *by* Jelmer B. Shjeflo

Prairie potholes are water-holding depressions of glacial origin that occur in the drift-covered prairies of North America, such as those that characterize the Coteau du Missouri where glacial stagnation has created a hummocky, knob-and-kettle topography.

Prairie potholes have been called the backbone of duck production in North America. Although the prairie pothole region makes up only 10 percent of the total waterfowl breeding area of this continent, it is said to produce 50 percent of the duck crop in an average year—more than that in bumper years. Potholes also furnish water and forage for livestock and, when drained, provide rich organic soils for the production of crops. Preservation of potholes for duck habitat as opposed to pothole drainage for crop production became a controversial issue between wildlife advocates and agricultural interests. It was to introduce a scientific understanding of the hydrology of the potholes that the WRD became involved in the issue.

Research into the hydrology of prairie potholes in North Dakota had three major objectives: (1) to define the hydrology of these distinctive water features, an important element in the water, agricultural, and recreational economy of a prevailing water-short region; (2) to enable estimating the net quantities of water discharged from potholes that could be eradicated in connection with the Garrison Diversion project, as a guide to the amount of water needed to create replacement wetlands elsewhere, and (3) to identify ecologic controls as a guide to selection of suitable potholes for lease or purchase in the waterfowl-preservation program.

Finding potholes suitable for the study was difficult. Many that looked promising on topographic maps and aerial photographs were dry in 1959. After spending a few days searching from the main highways and county roads, it became clear that this approach was impractical. Selection of potholes from an airplane flying at 1,500 feet was then tried, and six trips were made before suitable areas were found.

A group of potholes was found in Ward County in north-central North Dakota during the fall of 1959. The study area was enlarged in the fall of 1960 by including a group of potholes near Forbes in Dickey County, in south-central North Dakota. In 1963, a pothole near Buchanan in Stutsman County, about midway between the original study sites, was included in the study and provided a link between the two original study areas, which were about 200 miles apart.

The first part of the study was devoted almost exclusively to the determination of evaporation and transpiration losses at groups of potholes in Ward, Stutsman, and Dickey Counties. As a result of this study, it was found that seepage was a significant element in the water budget of the potholes. The second part of the study focused on ground water and its influence on the hydrology of prairie potholes.

The project began in 1959 in the GHB and was later transferred to the Division research program. The evapotranspiration research was done during the water years 1960 through 1964. With the termination of field work on the evapotranspiration phase in 1965, a full-scale ground-water investigation was begun. The study was part of the DOI program for the development of the Missouri River Basin (see "Missouri River Basin program"). Funding for the project was primarily from Missouri River Basin program funds which were supplemented starting in 1963 by WRD research funds.

The broad study of the hydrology of prairie potholes was under the technical supervision of G. Earl Harbeck, Jr., 1959–61, succeeded by William S. Eisenlohr, Jr., 1961–68. The evapotranspiration phase of the project was led by Jelmer B. Shjeflo, assisted by Roger A. Pewe, under the administrative direction of Harlan M. Erskine, who first proposed the study and was largely responsible for its implementation. Early ground-water investigations, including consultation in the selection of potholes and the supervision of drilling to explore the subsurface geology, was done by Edward Bradley. The later ground-water project was led by Charles E. Sloan, assisted by Franklin D. Holland, III.

Quentin F. Paulson and Hans M. Jensen consulted on the ground-water phases of the study. Special studies of the chemical quality of water were made by Hugh T. Mitten, Ben F. Leonard, Lester R. Petri, and James H. Ficken, and analyses of water samples were made in the Survey's Lincoln, Nebr., laboratory, under Don M. Culbertson, then Kenneth A. MacKichan. Richard S. Aro and Lyle F. Lautenschlager made field studies of the vegetation, and Farrel A. Branson, acting as consulting botanist, made many professional contributions. Beginning in 1962, there was close collaboration with the research program of the Bureau of Sport Fisheries and Wildlife through the Northern Prairie Wildlife Research Center at Jamestown, N. Dak., Harvey K. Nelson, Director. Robert E. Stewart and Harold Kantrud, of that Center, made botanic surveys for the study and furnished much useful data on aquatic vegetation. The staff of the Woodworth, N. Dak., research station, under the direction of Leo Kirsch provided much valuable assistance to the project.

The definitive, final report was published as PP 558, which was issued as separate chapters A-D as follows: (A) "Hydrologic investigations of prairie potholes in North Dakota," by W.S. Eisenlohr, Jr., and others, 1972; (B) "Evaporation and the water budget of prairie potholes in North Dakota," by Jelmer B. Shjeflo, 1968; (C) "Ground-water hydrology of prairie potholes in North Dakota," by Charles E. Sloan, 1972; and (D) "Vegetation of prairie potholes, North Dakota, in relation to quality of water and other environmental factors," by Robert E. Stewart and Harold A. Kantrud, 1972.

Other publications included: Circ. 472, "Current studies of the hydrology of prairie potholes," by Jelmer B. Shjeflo, 1962; Circ. 558, "Generalized hydrology of prairie potholes on the Coteau de Missouri, North Dakota," by William S. Eisenlohr, Jr., and Charles E. Sloan, 1968; in the Journal of Range Management, "Biotic and hydrologic variables in prairie potholes in North Dakota," by Charles E. Sloan, v. 23, n. 4, July 1970; and in the North Dakota Geological Survey, "Glacial geology of the Missouri Coteau, North Dakota—Ground-water movement as indicated by plants in the prairie pothole region," by Charles E. Sloan, 1967, Misc. Series 30.

### Saline Water Resources

*By* John H. Feth

Interest in saline water as a resource instead of a nuisance came to the fore in the 1940's but especially in the 1950's. Within the Department of the Interior, the Office of Saline Water (OSW) assumed leadership in exploring the resource and in developing technology for conversion into demineralized water. The OSW called upon the USGS to provide data on saline ground water for that effort.

Meanwhile, reverse osmosis and flash distillation emerged as the methods of choice for commercial demineralization. In 1959, Coalinga, Calif., became the first municipality to provide demineralized water for public use. Reverse osmosis was employed and was successful with the qualification that the feed water contained hydrocarbon residues, as Coalinga is near producing oil fields. The oily traces tended to clog the membranes used in the reverse osmosis procedure. As became fairly standard practice throughout the United States and indeed the world where demineralization has been used for public supply, the product water was blended with the mineralized feed stock to make a mixture that was acceptable in terms of concentration for domestic use.

Definitions of "saline" and "acceptable for use" have remained arbitrary. In general, "saline water" has been considered as water that is unsuited for human consumption or for irrigation because of its dissolved-solids concentration or because (then) Public Health Service standards for individual constituents were exceeded. A concentration of 1,000 mg/L (milligrams per liter) is a commonly used limit for acceptability, although that concentration has been exceeded in many public supplies—notably in the Plains States—where water of lesser concentration is not available.

The USGS had reported occurrences of saline ground water from early on. Coastal aquifers intruded by seawater were described from Connecticut by Brown (1925), and saline water in the arid West was mentioned by early workers such as in the Dakotas (Darton, 1896), Nevada (Meinzer, 1917), and Utah (Carpenter, 1913). But such descriptions were incidental to reconnaissance studies of ground water in such areas.

A series of publications in the 1950's that extended into the 1960's reflected the high interest of that time in saline ground water as a resource. The occurrences in Texas were reported by Winslow and Kister, WSP 1365 (1956), North Dakota by Robinove, Langford, and Brookhart, WSP 1428 (1958), New Mexico by Hood and Kister, WSP 1601 (1962), and California by Bader, open-file report (1963). Krieger, Hatchett, and Poole, WSP 1374 (1957) published a preliminary survey of saline ground water in the conterminous United States, and the Office of Saline Water, DOI report (1964) produced a survey of saline-water conversion studies and methods.

In 1963, the WRD undertook a more detailed survey of saline ground water in the lower 48 States. Thirty-seven WRD personnel contributed State or regional information that was compiled and illustrated by J.H. Feth in two maps, one showing occurrence by concentration groups and depth to first occurrence, the other an analysis of chemical types, of which water dominated by sodium and chloride was by far the most common. The work was published in 1965 as HA–199, by Feth and others, and twice reprinted.

The work was of sufficient interest at the time that when a group of Soviet scientists visited USGS Headquarters, a hand-colored copy of the maps was hand carried to Washington for display of work-in-progress. The report was intended to carry the title "Saline ground-water resources of the conterminous United States." However, a cooperator in one of the Midwestern States took exception to the idea that the USGS would report his State as being underlain by saline water. Arthur A. Baker, then Associate Director, retitled the report as "Preliminary map of the conterminous United States showing depth to and quality of shallowest ground water containing more than 1,000 parts per million dissolved solids," and so it remained through three printings. Feth, Circ. 499 (1965), also published a compendium of about 800 selected references on saline ground water in the United States.

With those publications, the major activity by the WRD in saline ground water ceased. Plans for additional State reports were abandoned. The research and development work of the OSW was assigned to the BOR when the OSW was terminated as an office of the DOI.

## Upper Colorado River Project

*By* Charles H. Hembree *and* Hal Langford *and* reviewed *by* Langford, Frank Ames, *and* Dave Phoenix

The Colorado River Compact of November 24, 1922, set into motion a continuing series of events and conflicts. The compact itself made no references to the quality of the water but dealt only with an "equitable" apportionment between the Upper and Lower Basins; the exclusive beneficial use by each of 7.5 million acre-feet annually. In addition, the Lower Basin was given the right to increase its use by 1 million acre-feet per annum until the 7.5 million acre-feet is reached. Mexico's recognized rights to use the water in the river system were to be supplied from surplus waters, and if these were insufficient the burden was to be borne equally by the two basins. In 1954 and 1955 the flow at "Lee Ferry" was less than half the apportioned amount. Of importance to Upper Basin water users is the stipulation in the Compact that the flow at "Lee Ferry" not be depleted by the States of the Upper Colorado River Basin below an aggregate of 75 million acre-feet in any consecutive 10-year period. The average annual flow at the Lees Ferry gaging station for the 23 years (water years 1965–87) after the close of the Glen Canyon Dam was 10,701,000 acre-feet.

The Mexican Water Treaty between the United States and Mexico was signed November 14, 1944. The 1.7 million acre-feet of water that Mexico was to receive of surplus Colorado River water was not being met in the mid-1950's and the water delivered to Mexico was unusable for irrigation.

Chief Hydraulic Engineer Carl Paulsen may have dealt the Survey into the issue at a meeting of the Colorado River Water Users Association on November 30 and December 1, 1955. In his speech to the Association members, he quoted from the introduction to the new Water-Supply Paper series, "Quality of surface waters for irrigation in the western United States," as follows,

> ...some of these allocations (of water) have been made without consideration of their effect on the quality of the downstream water or without adequate allowance for drainage purposes so that a proper salt balance can be made. As a result the productivity of many thousands of acres of agricultural land has been impaired due to the excessive amounts of mineral salts. It is becoming increasingly apparent that more judicious use must be made of available water for maintaining suitable quality and removing accumulations of salt.... These continuous long-term records will

assist in the determination of quality of water prior to irrigation development, the extent of impairment of water quality due to drainage return, requirements for maintaining proper salt balance, and the equitable division between projects, States, and adjoining nations.

Extensive hearings on the Colorado River Storage Project and participating projects finally culminated in the enactment of Public Law (PL) 84–485, which was signed by President Eisenhower on April 11, 1956. Section 15 of this law directed the Secretary of the Interior to continue studies of the quality of Colorado River water and to report to the Congress and to the States of the Colorado River Basin. The inclusion of Section 15 in PL 84-485 was a result of pressures from the California water users, especially the city of Los Angeles, who were concerned about further degradation of water quality by return irrigation flows.

On July 9, 1957, S. Keith Jackson, Division Hydrologist, RMA, accompanied by Francis M. Bell and Frank C. Ames of Jackson's office and Milton T. Wilson, Herbert A. Waite, and John G. Connor of the Salt Lake City SWB, GWB, and QWB, offices, met with BOR personnel in Salt Lake City, Utah, to discuss the Survey's plans for a Colorado River water-quality study as mandated by Section 15 of PL 84–485.

At this meeting, Jackson outlined the WRD plans and indicated that the Survey wished to integrate its studies with those of the BOR as much as possible and to exchange information on the plans and needs of the two agencies. He explained that the Survey's report would comprise a compilation and study of all existing data on the occurrence and distribution of surface-water and ground-water resources with emphasis on the quality of water.

Jackson emphasized that the study should estimate the effect on the quantity and quality of water of existing developments and not attempt to evaluate the effects of future developments, particularly future irrigation projects. However, the Survey's report would serve as a background for later evaluation of future developments. The meeting ended with agreement for close collaboration between the two agencies, which was maintained during the course of the project.

The QWB was assigned general responsibility for the project. Federal program funds were allotted to the QWB and final amounts were approved by the Division Hydrologist, RMA. Frank Ames, QWB Area Chief, RMA, was regional overseer for the project with assistance by other members of the RMA Committee and staff.

Because of the paucity of chemical-quality data in many areas that needed to be eliminated as soon as possible, Charles H. Hembree of the Lincoln, Nebr., office was assigned to the project and reported to Salt Lake City in early September 1957, to begin a series of reconnaissance studies in the Upper Colorado River Basin.

With the assistance of Connor, District Chemist, QWB, Salt Lake City, and his staff, Hembree made the final selection of a large number of reconnaissance sampling sites on streams where little or no quality-of-water data were available. These streams, as well as others, were sampled by District and project personnel in October of 1957 and again in the spring and summer of 1958. Flow measurements were made at these sites if there were no gaging stations nearby. Chemical analyses of the reconnaissance samples were made in the Salt Lake City District laboratory. Hembree met with personnel from the BOR and the State of Utah and arranged to obtain the published and unpublished chemical-quality and sediment data from those sources.

By early 1958, three additional professional members of the project staff, W. Vaughn Iorns, Project Chief, Godfrey L. Oakland, SWB, and David A. Phoenix, GWB, were at work on their phases of the study. James M. Knott and Daniel C. Hahl, engineering aids on the team, later became career, professional employees of WRD. Other project personnel were Afton Wright, Leah Steward, Mabel Young, Nellie Thornton, Gay Baxter, Patricia Davies, Thelma Pudlewski, Armand Beers, Donald Haney, and Betty Owens.

About $300,000 was allotted to the project. The reports were completed and field edited by July 1961. The project staff, except for Iorns and his secretary, moved on to other assignments. Iorns and Hembree completed final review of editorial suggestions and then manuscript proofs during the summer and fall of 1962.

Results of the study were reported in WSP 1535–E (1961) by C. H. Hembree and F.H. Rainwater; PP 442 (1964) by W.V. Iorns, Hembree, D.A. Phoenix, and G.L. Oakland; PP 441 (1965) by Iorns, Hembree, and Oakland; and PP 424-C (1961) by Phoenix. An unnumbered open-file report by Iorns, Hembree, Phoenix, and Oakland was released in 1959.

The principal findings of the study were that 92,739,000 acre-feet of water enters the basin as precipitation, 2,257,500 is consumed in or is diverted from the basin, 12,733,100 leaves the basin in the Colorado River (as of 1957), and 77,748,400 acre-feet is lost by evaporation and plant transpiration. If all the developments existing in 1957 had existed during the base period used for the study (water years 1914–57), the weighted-average concentration of dissolved solids of the Colorado River at Lee Ferry for water years

1914–57 adjusted to 1957 conditions of development would be 501 ppm. Of the 8,676,330 tons average annual dissolved-solid discharge at Lees Ferry more than 1/3 or 3,446,700 tons was probably contributed by irrigation return flows. Domestic and industrial uses contributed about 33,500 tons.

If there had been no activity by man to affect the flow of the river during water years 1914–57, exclusive of transmountain diversions, the long-term weighted-average concentration of dissolved solids at Lee Ferry would have been about 263 ppm. Thus, an increase of 238 ppm was caused mostly by irrigation return flows and is four times the increase that would have been caused by the transbasin diversion of an equivalent amount of water.

Ground-water inflow to the streams came from aquifers recharged by precipitation and from interchange between the streams and the alluvium during fluctuation in stream levels, from thermal springs, and from ground-water return flow from irrigated lands. Dissolved-solids discharge of ground water into the stream system of the Upper Colorado River Basin was found to be about 542,000 tons annually.

### *Subsequent Activities*

*By* Russell H. Langford

In addition to PL 84–485, legislation in 1962 authorizing the Navajo Indian Irrigation Project, the initial stage of the San Juan-Chama Reclamation Project (PL 87–483), and the Fryingpan-Arkansas Project (PL 87–590) reiterated, with minor differences in language, the requirement for the reports and further specified that DOI report to the Congress in January 1963 and every 2 years thereafter. The resulting reports were prepared biennially by the Survey and the BOR. The first DOI report of the series (1963) was in two parts: (1) a Geological Survey assessment of the water-quality situation in the Colorado River Basin upstream from Lee Ferry, Ariz., as of 1957, prepared by Arthur M. Piper using the draft reports by Iorns and others (later published as PP 441 and 442); and (2) a BOR projection of the water-quality effects to be expected from additional developments that involved storage and irrigation use of river water upstream from Lee Ferry.

The second DOI report (January 1965) appraised water-quality conditions in the entire basin. It was prepared by the BOR using data acquired largely by the WRD. The technical aspects of the report were reviewed by Langford and his staff (principally Daniel C. Hahl) of the Salt Lake City, Utah, QWB District and by Charles C. McDonald and his staff (principally Burdge Irelan) of the Yuma, Ariz., Lower Colorado River project.

The third DOI report in the series (January 1967) also appraised water-quality conditions in the entire Colorado River Basin. It, too, was prepared principally by the BOR using WRD data. Members of the WRD Salt Lake City and Yuma offices reviewed technical aspects of the BOR's report and prepared specific sections of the reports, as follows: "Salinity variation in the Colorado River below Lee Ferry" (Burdge Irelan, pages 27-32); "Chemical quality of ground water in the Lower Colorado River basin" (Burdge Irelan, pages 32–34); "Flaming Gorge Reservoir" (D.C. Hahl, pages 34–41); and "Contribution of salts to the river system by major springs" (R.H. Langford, pages 42–49).

All of the DOI biennial reports released in 1963, 1965, and 1967 were titled "...Progress Report, Quality of Water, Upper Colorado River Basin."

Relations between personnel of the WRD and the BOR involved in preparing the first report in the series were somewhat strained. Piper was detailed to Salt Lake City in 1962 to work with BOR personnel to prepare the Department's response to the legislative requirements. Piper wanted to use the results of the study by Iorns and others which had been completed but was not yet published. The BOR had developed its set of base-line conditions for appraising the water-quality situation in the Upper Colorado River Basin. Thus, two different sets of conditions—the Survey's estimates for water years 1914-57 adjusted to 1957 conditions and the BOR's estimates for 1941–58 adjusted for new developments during the 18-year period—were utilized in preparing the Department's report. Piper and the BOR personnel also did not agree on the contribution from irrigated lands of dissolved solids to the rivers downstream from those lands. Piper, using the findings of Iorns' team, believed (and so reported in his part of the report) that some irrigated lands in the Upper Colorado River Basin yielded as much as 5.6 tons per irrigated acre, yearly, of dissolved solids to the stream system receiving the return flows from those lands. Based on estimates for 21 valley or lowland areas in the Upper Basin, he estimated the irrigation-caused yields of dissolved solids ranged from 0.1 to 5.6 tons per irrigated acre, yearly, with a weighted mean of 2.4 tons per acre per year. The BOR authors used two assumptions for contributions of dissolved salts from irrigated lands to the river system: "Zero pickup" and "two tons per acre pickup" for each irrigated acre in each of the proposed projects for which they made projections.

These differences of opinion and approaches resulted in the Department's 1963 report consisting of the two agencies' contributions bound together with a brief lead-in section on legislative directives and response. In the 1965 and 1967 reports, the BOR's base-line conditions and its projections were accepted by the Survey in its technical review of the report.

Another significant use of the results of the Upper Colorado River Basin project was in shaping the program for collecting basic water-quality data in the Upper Basin. Russell H. Langford and his staff in Utah and Colorado used the correlations developed by Iorns and Hembree in their study to develop strategies for reducing costs of data collection while maintaining the accuracy and utility of the records obtained. As a result, data vital to the continuing appraisal of water-quality conditions in the Colorado River Basin were obtained in the Upper Basin despite increasingly tight annual budgets for such data-collection activities.

## Water Resources of States

*By* Arvi O. Waananen

Two series of reports on to the water resources of States were prepared during the 1957–66 period. In one series, reports were prepared in response to requests from members of the U.S. Senate, particularly the Senate Committee on Interior and Insular Affairs, for information on mineral and water resources. These were entitled "Mineral and water resources of (State)," and the resource descriptions and summaries were presented generally in scientific and technical terms and were published as Senate documents or Committee prints.

In the second series, reports were prepared for the informed lay reader, written in nontechnical terms, and were directed to an audience with a wide range of interests and knowledge and a need to understand water resources and associated problems. These reports were published as Water-Supply Papers.

### *Mineral and Water Resources of States—For the U.S. Senate*

A strong upsurge and growth in interest in local and national water resources developed in the years following World War II, notably in the late 1950's. Congressional interest in water was further enhanced following passage of Senate Resolution 48, 86th Congress, 1st session, in 1959, which established the Senate Select Committee on National Water Resources. (See Part VIII, "Senate Select Committee on National Water Resources.")

A brief report on the mineral and water resources of Wyoming, prepared in 1959 in response to a request from Senator Gale W. McGee, Wyoming, was the first in this series. Senator McGee, a member of the Senate Select Committee, had requested the information in preparing for a public hearing by the Committee in Laramie, Wyo., in early October. Senator McGee's request was dated August 3, 1959, and the report, prepared by the headquarters staff, was sent to the Senator on September 24, 1959, and published in 1960.

On August 23, 1962, Senator Lee Metcalf, Montana, requested a similar report. WRD staff in Montana and Wyoming prepared the water-resources part.

After the report for Montana was published in 1963, other requests were received from members of the Senate, mostly members of the Senate Committee on Interior and Insular Affairs, for preparation of similar reports for their States. Thor H. Kiilsgard, Chief, Mineral Resources Research Branch, Geologic Division, was assigned overall responsibility for interdivision coordination in Washington. Medford T. Thomson, Chief, Special Reports Section, WRD, coordinated the water-resources sections. Authorship and coordination in the field was arranged through the Division Hydrologists.

Ten additional reports followed in which the water-resources sections were prepared generally by WRD district staff and by cooperating or collaborating Federal, State, and local agencies. Typically, these sections provided appraisals and summaries of the water resources, their extent, distribution and quality, development and utilization, special regional and areal problems, and long-range plans for future development. In several reports, separate sections on water-resources development and use, problems, and plans were contributed by Federal and State agencies.

The mineral and water resources reports are listed below chronologically, by title, authorship of the water-resources sections, dates of publications, cooperating/collaborating agencies, and requesters.

Water Resources, *in* Mineral and Water Resources of:

Wyoming, by USGS staff, 1960. U.S. 86th Cong., 2d sess., Senate Doc. No. 76, p. 30–40, requested by Senator Gale W. McGee.

Montana, by Frank Stermitz, T.F. Hanly, and C.W. Lane, 1963. U.S. 88th Cong., 1st sess., Senate Comm. on Interior and Insular Affairs, Comm. Print, p. 137–166, requested by Senator Lee Metcalf.

Utah, by M.T. Wilson, R.H. Langford, and Ted Arnow, 1964. U.S. 88th Cong., 2d sess., Senate Comm. on Interior and Insular Affairs, Comm. Print, p. 239–275. Prepared in cooperation with Utah Water and Power Board, requested by Senator Frank E. Moss.

Alaska, by, Giles, G.C., and Waananen, A.O., 1964. U.S. 88th Cong., 2d sess., Senate Comm. on

Interior and Insular Affairs, Comm. Print, p. 149-179, requested by Senator Ernest Gruening.

South Dakota, by J.E. Powell, J.E. Wagar, and L.R. Petri, 1964. U.S. 88th Cong., 2d sess., Senate Comm. on Interior and Insular Affairs, Comm. Print, p. 161–212, requested by Senator George McGovern.

Colorado, by J.W. Odell, D.L. Coffin, and R.H. Langford, 1964. U.S. 88th Cong., 2d sess., Senate Comm. on Interior and Insular Affairs, Comm. Print, p. 233–283, requested by Senator Gordon Allott.

Nevada, by H.E. Thomas, 1964. U.S. 88th Cong., 2d sess., Senate Doc. No. 87, p. 273–314, requested by Senator Howard W. Cannon.

Idaho, by W.I. Travis, H.A. Waite, and J.F. Santos, 1964. U.S. 88th Cong., 2d sess., Senate Comm. on Interior and Insular Affairs, Comm. Print, p. 255–335. Prepared in collaboration with Idaho Bureau of Mines and Geology, Idaho Department of Reclamation, and others, requested by Senator Frank Church.

New Mexico, by S.W. West, R.L. Cushman, and W.L. Heckler, 1965. U.S. 89th Cong., 1st sess., Senate Comm. on Interior and Insular Affairs, Comm. Print, p. 387–437. Prepared in collaboration with New Mexico Bureau of Mines and Mineral Resources and State Engineer Office, requested by Senator Clinton P. Anderson.

Washington, by F.T. Hidaka, 1966. U.S. 89th Cong., 2d sess., Senate Comm. on Interior and Insular Affairs, Comm. Print, p. 311-355, requested by Senator Henry M. Jackson.

California, by A.O. Waananen and others, 1966. U.S. 89th Cong., 2d sess., Senate Comm. on Interior and Insular Affairs, Comm. Print, Part II, p. 451–650. Prepared in collaboration with BOR and California Department of Water Resources, requested by Senator Thomas H. Kuchel.

Missouri, by A. Homyk, E.J. Harvey, H.G. Jeffery, and others, 1967. U.S. 90th Cong., 1st sess., Senate Doc. No. 19, p. 253-347. Prepared in collaboration with U.S. Bureau of Mines, U.S. Soil Conservation Service, Missouri State Park Board, Water Resources Board, Water Pollution Board, and University of Missouri, requested by Senators Stuart Symington and Edward V. Long.

#### ***Water Resources of States—For the Informed Layman***

In 1958, the WRD began a series of reports on the water resources of States. The objective was to meet needs described by Raymond L. Nace, Associate Chief, WRD, in his January 20, 1958, memorandum to Division Hydrologists and Water Resources Councils entitled, "PROGRAMS AND PLANS: Reports on water resources of entire States," as follows:

> A principal deficiency in published water-resources information is the lack of broad geographic coverage, Not much of our project information and basic data are tied together in appraisals of the water resources of entire States or basins. Also, most of our reports are aimed at specialized audiences and are scarcely usable or understandable by many people who are directly concerned with the use of water and with developing plans for its use. The audience for the proposed series of reports would be everyone concerned with water. The reports will be technically sound but popularized to make them meaningful to the informed layman.
>
> Another need is that of military and civilian defense agencies for overall summaries of information about water resources as an aid to national-emergency planning, including plans for emergency water supplies. The reports should be made useful for such purposes. Also, they should place special emphasis on water in industrial areas and population centers. The present sources of water for such areas should be described and sources available to meet expanding or future needs should be identified.

Initially, reports were proposed for the States of Arizona, Oklahoma, Oregon, and Georgia, and preparation of these reports by local groups was soon underway. Alabama and Delaware were evidently enlisted in the program soon after the selection of the first four States and a report for Idaho was scheduled (Nace memorandum of Dec. 8, 1958, same subject). Records available, however, do not show that an Idaho report was completed.

Subsequent planning contemplated production of a report for each State at a yearly rate that would give nationwide coverage in 5 or 6 years. The reports were to be based on information available at the time of writing. Authorship was to be by several of the best informed and most facile writers in the District offices, nominated by their WRD Councils, including designation of the senior authors. Time tables of less than a year were proposed for preparing each report.

Nace's memorandum provided pertinent guidance relating to report handling, overall responsibilities, planning and programming, as well as funding, scope, and scheduling. State Councils and Area Councils were requested to give prompt attention to early programming and scheduling of subsequent reports in this series.

Reports were prepared for Alabama, Georgia, Oregon, Arizona, Delaware, and Oklahoma and were published as Water-Supply Papers. Each contained descriptions of the occurrence, extent, and utilization of the water resources of the State, and problems related to their availability and development. The reports, illustrated with photographs, charts, and graphs, were written in nontechnical terms and based mainly on information previously collected cooperatively with Federal, State, and local agencies. Quantitative information was generalized and not in the detail usually required for engineering and legal purposes. Specialists and other readers were referred to USGS publications and other sources for technical data and other information.

Published reports for the informed layman were as follows:

Callahan, J.T., Newcomb, L.E., and Geurin, J.W., 1965, Water in Georgia: WSP 1762.

Dover, T.B., Leonard, A.R., and Laine, L.L., 1968, Water for Oklahoma: WSP 1890.

Harshbarger, J.W., Lewis, D.D., Skibitzke, H.E., Heckler, W.L., and Kister, L.R., 1966, Arizona Water: WSP 1648.

Phillips, K.N., Newcomb, R.C., Swenson, H.A., and Laird, L.B., 1965, Water for Oregon: WSP 1649.

Rasmussen, W.C., Odell, J.W., and Beamer, N.H., 1966, Delaware water: WSP 1767.

Swindel, G.W., Jr., Williams, M.R., and Geurin, J.W., 1963, Water for Alabama: WSP 1765.

Preparation of these reports was funded from the Federal program in amounts ranging from $8,000 to $15,000 per State. The program was discontinued, after the first six reports were completed, for reasons not apparent from information available. It appears likely, however, that the effort and funds yielded to higher priority activities.

### Clinch River Study

*By* P.H. Carrigan, Jr., *and* R.J. Pickering

Since the early days of operation of Oak Ridge National Laboratory (ORNL), low-level radioactive wastes from a variety of sources in the White Oak Creek watershed, which drains the laboratory area, have been released through White Oak Creek to the Clinch River and thence to the Tennessee River. On the basis of their relative abundance, their radioactive half-lives, and their significance to human health, the principal radionuclides of concern since the start of releases in 1944 have been strontium-90, cesium-137, ruthenium-106, and cobalt-60.

In 1959, the AEC requested that the Department of Public Health, the Game and Fish Commission, and the Stream Pollution Control Board (all of the State of Tennessee), TVA, USGS, PHS, and ORNL determine the fate of these radioactive materials as they moved down the Clinch River and into the Tennessee River near Kingston, Tenn. They were also asked to develop an understanding of the dispersion processes affecting the radioactive materials, assess direct and indirect hazards, determine the usefulness of the riverine environment for disposal of these radioactive materials, and recommend long-term monitoring procedures for release of these radionuclides. The involved agencies formed the Clinch River Study Steering Committee, which provided oversight of the study and coordinated participation of the agencies. Joseph S. Cragwall, Jr., represented the Survey on the Steering Committee.

P.H. Carrigan, Jr. (project chief) and R.J. Pickering were stationed at Oak Ridge to provide day-by-day leadership for the physico-chemical parts of the study. Carrigan had been reassigned from the SWB Research Section, Atlanta, to the Chattanooga SWB District, Oak Ridge subdistrict office, where Raymond M. Richardson (previously in the GWB) was subdistrict chief. Pickering joined the project in December 1961. In 1962 the study became part of the newly formed Tennessee WRD District. Bernard J. Frederick of the SWB Research Section, also stationed at Oak Ridge since 1960 (see Part IV, "Tracers in Hydrology"), led the dispersion studies for the project. The Knoxville, Tenn., Subdistrict, under the leadership of Elmer P. Mathews and, subsequently, John P. Monis provided streamflow information and aided in manpower-intensive activities such as the dispersion measurements.

All of the funding for the Survey's work came from the AEC (see Part X, "Tennessee") and totaled about $430,000 for the fiscal years 1961–64.

The physico-chemical parts of the Clinch River study involved (1) establishing a network of automatic water-sampling stations to measure mass transport of stable and radioactive chemical constituents, (2) conducting dispersion studies, and (3) determining the radionuclide content of the bottom sediments in the Clinch River.

Three automatic water-sampling stations were operated on the Clinch River, one at mile 41.4, upstream from the location of the discharge of radionuclides into the river, another near the mouth of White Oak Creek, the stream discharging the radioactive wastes into the river, and a third in the Clinch River 5.5 miles upstream from the mouth of the river. A fourth station was operated for a short period of time at mile 14.4 on the Clinch River. The station on White Oak Creek was developed and operated by ORNL. The two primary stations on the Clinch River collected once-daily, equal-volume samples, which were then composited into discharge-weighted weekly samples.

Stable chemical and radiochemical analyses of samples from White Oak Creek were performed at ORNL. Stable chemical analyses of samples from the Clinch River stations were performed by the Tennessee Stream Pollution Control Board in Nashville; radionuclide analyses were done at the Robert Taft Laboratories of the PHS in Cincinnati, Ohio.

Three sampling stations were operated on the Tennessee River by the TVA. One was upstream from the mouth of the Clinch River as a background station at Tennessee River Mile (TRM) 591.8 and the other two were downstream at Watts Bar Dam (TRM 529.9) and at Chickamauga Dam (TRM 471.0). Radionuclides were determined on weekly composite samples, except at the background station where sampling was monthly, and stable chemical analyses were performed on monthly composite samples from each site.

Five dispersion studies were conducted, the two most important being a simulation of the effects of winter and summer power-release operations at the newly constructed (1962) Melton Hill Dam on the Clinch River (2.3 miles upstream from White Oak Creek). Twice-daily power releases were to be made from the dam on weekdays and none on the weekend, allowing radioactive materials to accumulate in the tailwater pool of the dam. Personnel from ORNL and WRD injected a fluorescent dye into White Oak Creek to simulate the buildup of radionuclides in the river at the end of a power release on Friday afternoon and continued this injection until the start of a power release on Monday morning. The movement of the dye down the Clinch River due to flushing from power releases on Monday and subsequent work days was then measured throughout the length of the study reach.

Detection of gamma ray emissions and sampling of the surface layer of sediments in the bed of the Clinch River had indicated radionuclides in these sediments. In the summer of 1962, 135 undisturbed, full-length core samples of the bottom sediments were taken at 10 cross sections. This work was headed by Pickering and employed a commercially patented Swedish Foil Sampler. The samples were analyzed for vertical distribution of gamma radiation in the cores and for radionuclide content. The equipment used to determine the gamma radiation distribution in the intact cores was designed by Carrigan and fabricated at the ORNL. Near the end of the project, Carrigan also developed water-sampling equipment that would take samples proportional to flow in the Clinch River.

Because sedimentation in the lower Clinch River, Watts Bar Lake, and Chickamauga Lake had been more or less continuous since the release of radionuclides from ORNL began, many of the longer cores showed a pattern of radionuclides (particularly cesium-137) with depth that matched the pattern of radionuclide release from ORNL with time.

Through the Clinch River study, essentially completed in 1965, the following findings important to water management were: (1) strontium-90, ruthenium-106, and to a lesser extent, cobalt-60 were found to move with the water in a calcium bicarbonate system without significant depletion, (2) bottom sediments with a significant clay mineral content formed an important repository for radionuclides in the Clinch and Tennessee Rivers. In the Clinch River, at least 20 percent of the cesium-137 and rare earths and 9 percent of the cobalt-60 released to the river were associated with the bottom sediments, (3) the Swedish Foil Sampler was extremely useful in obtaining undisturbed cores of soft, watery bottom sediments, and (4) water-sampling stations can be developed to automatically collect samples composited in proportion to the flow throughout a day.

The Clinch River study, in many ways a pioneering field investigation in radiohydrology, was extensively reported, principal citations being:

Carrigan, P.H., Jr., Pickering, R.J., Tamura, T., and Forbes, R., 1967, Radioactive materials in bottom sediment of Clinch River: Part A. Investigations of radionuclides in upper portion of sediment: ORNL–3721, Supplement 2A.

Carrigan, P.H., Jr., and Pickering, R.J., 1967, Radioactive materials in bottom sediment of Clinch River: Part B. Inventory and vertical distribution of radionuclides in undisturbed cores: ORNL–3721, Supplement 2B.

Carrigan, P.H., Jr., 1968, Radioactive waste dilution in the Clinch River, eastern Tennessee: PP 433–G.

Carrigan, P.H., Jr., 1969, Inventory of radionuclides in bottom sediment of the Clinch River, eastern Tennessee: PP 433-I.

Churchill, M.A., Cragwall, J.S., Jr., Andrew, R.W., Jr., and Jones, S.L., 1965, Concentrations, total stream load, and mass transport of radionuclides in Clinch and Tennessee Rivers: ORNL–3721, Supplement 1.

Parker, F.L., Churchill, M.A., Andrew, R.W., Jr., Frederick, B.J., Carrigan, P.H., Jr., Cragwall, J.S., Jr., Jones, S.L., Struxness, E.G., and Morton, R.J., 1966, Dilution, dispersion, and mass transport of radionuclides in the Clinch and Tennessee Rivers, *in* Disposal of radioactive wastes into seas, oceans, and surface waters, International Atomic Energy Agency, Vienna.

Pickering, R.J., Carrigan, P.H., Jr., and Parker, F.L., 1965, The Clinch River Study—An investigation of the fate of radionuclides released to a surface stream: Circ. 497.

Pickering, R.J., Carrigan, P.H., Jr., Tamura, T., Abee, H.H., Beverage, J.P., and Andrew, R.W., Jr., 1966, Radioactivity in bottom sediment of the Clinch and Tennessee Rivers, *in* Disposal of radioactive wastes into seas, oceans, and surface waters, International Atomic Energy Agency, Vienna.

Struxness, E.G., Carrigan, P.H., Jr., Churchill, M.A., Cowser, K.E., Morton, R.J., Nelson, D.J., and Parker, F.L., 1967, Comprehensive report of the Clinch River Study: ORNL-4035.

In addition to the reports cited above, Morton of the ORNL compiled annual status reports for the years 1961–66. Carrigan, Pickering, and other project investigators reported extensively on specific topics and techniques in other publications of the USGS and other organizations.

### Columbia River Radionuclide Studies

*By* David W. Hubbell *and* reviewed *by* Leslie B. Laird *and* Herbert H. Stevens

In 1961, the AEC solicited proposals from local universities and government agencies for studies of the disposition and ecological effects of radioactivity discharged into the Columbia River from the Hanford Atomic Works just upstream from the tri-cities area (Kennewick, Pasco, and Richland) in southeastern Washington. The need for studies resulted from findings that several species of fish were contaminated with unusually high levels of radioactivity. Because of the complexity of the problem and the wide distribution of Columbia River effluent, studies were required in the riverine, estuarine, and adjacent marine environs. In response, Leslie B. Laird, District Chemist, QWB, Portland, Oreg., submitted proposals to utilize the capabilities of the WRD to study the movement and disposition of radionuclides in the Columbia River and its estuary.

William L. Haushild transferred from the QWB field unit at Colorado State University, Fort Collins, to the QWB District in Portland, Oreg., as project leader of the initial phases of the study under the general supervision of Laird. Other professionals assigned to study were Herbert H. Stevens, Jr., George R. Dempster, and Edmund A. Prych. In September 1962, active study of the movement of radionuclides in the Columbia River in the reach between the tri-cities area in southeast Washington and Vancouver, Wash., was started. Data collection began at stations along the Columbia River at Pasco, Wash.; Hood River, Oreg.; and Vancouver, Wash. At each of these locations, water discharge was measured and water samples were collected to determine suspended-sediment and radionuclide concentrations and discharges. In addition, stations were established on the Snake River at Pasco and the Willamette River at Portland to document flow and suspended-sediment concentrations and discharges.

The two streamflow-measuring stations farthest downstream, namely, the Columbia River at Vancouver and the Willamette River at Portland, were affected by tides from the Pacific Ocean. Therefore, stage-discharge relations, normally used to compute river discharge, could not be established. A one-dimensional transient-flow model, newly derived by Robert A. Baltzer and John Shen, of the SWB Research Section, Arlington, Va., was used to compute the continually varying discharges.

To facilitate field measurements, Stevens and Dempster used a P–61 suspended-sediment sampler as the sounding weight for a Price current meter. Water-sediment samples were collected and flow velocity was measured concurrently. Samples collected for radionuclide concentrations were analyzed by the contractor-operated Hanford Atomic Works. Initially the contractor was the General Electric Corporation; later, Battelle Northwest.

In the early fall of 1963, the investigation was expanded to include the part of the Columbia River from Vancouver downstream through the estuary to the mouth. David W. Hubbell transferred from the QWB field unit at Colorado State University to Portland as project leader of the estuarine phase of the study. Soon thereafter, Edmund A. Prych, Jerry L. Glenn, and V. Chinta Lai joined the estuary project staff.

The estuarine phase of the investigation was designed to define the levels and distribution of radioactivity throughout the estuary and to better understand the factors and phenomena that affected the disposition of radioactivity in the estuary. To accomplish these goals, levels of gamma radiation were measured in-situ and surficial and core samples of bottom material were collected throughout the estuary to define the areal and vertical distribution of specific radionuclides and sediment characteristics. In addition, water discharges, suspended-sediment concentrations, and particulate and solute radionuclide concentrations were measured at cross sections of the estuary located 14 and 54 river miles upstream from the mouth. The in-situ radiation measurements and samplings of the bottom material permitted direct determination of the spatial distribution and amounts of chromium–51, zinc–65, manganese–54, cobalt–60, scendium–46, and naturally occurring and fallout radionuclides throughout the bed of the entire estuary. Comprehensive estuary-wide surveys of radioactivity levels were made in June 1965 and October 1967.

The early phase of the estuarine investigation involved developing and testing radically new equipment systems and measurement procedures. Prych and Hubbell designed a sled-mounted radiation-detection unit for monitoring radiation emanating from the bottom material, a vibro-core sampler for obtaining 6-foot-long vertical cores from the streambed, a suspended-sediment sampler for rapidly collecting large-volume uncontaminated samples of water-sediment mixture, a high-volume filter system for rapidly separating water-sediment samples into particulate and solute phases, and a flow-measurement system for rapidly defining, from a continuously moving boat, the magnitude and direction of the horizontal velocities in stream verticals. Later, Stevens, Gale A. Lutz, and Hubbell developed a collapsible-bag sampler that permitted depth-integrated suspended-sediment samples to be collected without the depth limitation inherent in the operation of conventional depth-integrating samplers. Stevens and Hubbell also developed systems for continuously monitoring temperature and conductivity at different levels in the flow at a fixed location and for continuously monitoring the position of the survey vessel during topographic and seismic surveys of the estuary bottom.

In 1966, Haushild's group conducted a time-of-travel study using rhodamine-B dye to define travel-times from the confluence of the Snake and Columbia Rivers at Richland, Wash., downstream to McNary Dam. Also, by utilizing the radiation-monitoring equipment and bottom-sediment sampling systems developed by the estuary project group, Haushild's group defined the levels and areal distribution of radionuclides in the Columbia River from Richland downstream to Vancouver.

As an adjunct to measurements of the discharges of water, sediment, and radionuclides, Glenn collected bottom material from cross sections between Richland and Vancouver and from many locations in depositional areas throughout the estuary and analyzed the material by conventional sizing techniques and x-ray diffraction in order to define relations between physical properties of the sediments and radionuclide content. This work served as a foundation for interpreting results of the in-situ radiation monitoring and the rate-measurement data.

At the end of fiscal year 1967, funding for the river phase of the project was discontinued and its personnel were reassigned elsewhere within the Division. At that time, Stevens joined the estuary project group. In 1966, the estuary group began regular measurements of the total water discharge throughout 12- to 14-hour segments of tidal cycles at river mile 54, where the flow direction reversed twice daily except at times during the spring freshet, and at Astoria (river mile 14), where the estuary is approximately 4.5 miles wide and the intrusion of saltwater creates highly complex vertical and horizontal velocity distributions that continually vary with time throughout the tidal cycle. Concurrent, continuous measurements of water-surface elevations over 5- to 10-mile reaches encompassing the flow-measuring sections provided the necessary data to apply the "Method Characteristics" transient-flow model developed by Lai. After completing his model in 1966, Lai rejoined the research group in Washington, D.C. At about the same time, Prych began graduate studies at the California Institute of Technology and Lutz joined the estuary project.

Comparisons of discharges computed throughout the tidal cycle with Lai's model, a one-dimensional flow model, with actual discharges measured over partial tidal cycles showed that in the freshwater parts of the estuary, the roughness parameter in the model varied only with major changes in the mean discharge; whereas, at river mile 14, where the flow was nonhomogeneous and velocity components were not unidirectional, the roughness parameter varied between tidal cycles and within each phase of the tidal cycle. Based on numerous flow measurements throughout a wide variety of partial tidal cycles, Lutz and Hubbell developed a technique that utilized the daily mean freshwater discharge at rivermile 54 and stage information at Astoria to determine appropriate values of the roughness parameter by a trial-and-error analysis. The results were shown to be reliable and, in turn, served as an essential component in sediment and radionuclide discharge determinations.

One of the most significant studies undertaken in the part of the estuary affected by salinity gradients was the documentation of the existence of a so-called "turbidity maximum" wherein the longitudinal profile of the concentration of suspended particulate matter corresponds to a bell-shaped distribution that: (1) during each phase of the tidal cycle, translates upstream or downstream along the channel with the flow and progressively grows in magnitude and peakedness as flow velocities increase—then diminishes to near zero during each slack water; and (2) occupies different parts of the estuary depending on the magnitude of the freshwater flow.

The position of the turbidity maximum relative to the cross section at river mile 14, where routine water-sediment sampling was conducted, uniquely determined the temporal pattern of particulate and radionuclide concentrations throughout each tidal cycle. By using continuously measured salinities, Stevens and Hubbell developed models, founded on index sampling at critical times during the tidal cycle, to determine, continuously, estimates of sediment and radionuclide concentrations. These concentrations, combined with modeled-flow discharges, permitted the continuous determination of sediment and radionuclide discharges from June 1968 to July 1970 at river mile 14. Similar discharges computed from daily sampling and modeled discharges at river mile 54 and at Vancouver (river mile 103) provided required inflow-outflow data for computing a continuous accounting (mass-balance inventory) of the change of sediment and radionuclide storage within the river reaches between river miles 103 and 54 and river miles 54 and 14. The inventory data complemented similar data computed by Haushild's group for the reach between Pasco and Vancouver during the period from 1964 to 1966. The estuary inventory results demonstrated a gradual reduction in levels of radioactivity in response to the elimination of radionuclide-waste discharge from the Hanford reactors, and an annual flushing of fine sediment from the estuary during the spring freshet, but a net accumulation of most of the sand and approximately 30 percent of the fine sediment delivered to the estuary by the river.

Sub-bottom profiling and side-scan sonar measurements showed that large dunes exist in some parts of the tide-affected parts of the river, 3- to 5-foot-high dunes exist throughout the estuary, and sediment transport along the bottom is landward in the lower part of the estuary.

Following the preparation of reports on various aspects of the estuarine investigation in the fall of 1971, the estuary project was terminated and its personnel reassigned within the Division.

Representative of the more than 18 published reports and papers prepared from the Columbia River studies were the following:

Glenn, J.L., Hubbell, D.W., and Stevens, H.H., Jr., 1973, Sedimentation in the lower Columbia River and estuary (abs.), /inù Symposium International Relations Sedimentaires Entre Estuaires et Plateaux Continentaux, July 1973: Institute de Geologie du Bassin d'Aquitaine, Bordeaux.

Haushild, W.L., Stevens, H.H., Jr., Nelson, J.L., and Dempster, G.R., Jr., 1973, Radionuclides in transport in the Columbia River from Pasco to Vancouver, Washington: PP 433–N.

Haushild, W.L., Dempster, G.R., and Stevens, H.H., Jr., 1975, Distribution of radionuclides in the Columbia River streambed, Hanford Reservation to Longview, Washington: PP 433–O.

Hubbell, D.W., Glenn, J.L., and Stevens, H.H., Jr., 1971, Studies of sediment transport in the Columbia River estuary, in Proceedings, 1971, Technical Conference on Estuaries of the Pacific Northwest: Oregon State University Engineering Experiment Station, Circular 42, Corvallis.

Hubbell, D.W., and Glenn, J.L., 1973, Distributions of radionuclides in bottom sediments of the Columbia River estuary: PP 433–L.

Lutz, G.A., Hubbell, D.W., and Stevens, H.H., Jr., 1975, Discharge and flow distribution Columbia River estuary: PP 433–P.

Prych, E.A., Hubbell, D.W., and Glenn, J.L., 1966, Measurement equipment and techniques used in studying radionuclide movement in the Columbia River estuary, *in* Coastal Engineering, Santa Barbara Specialty Conference, October 1965: ASCE.

### Compilation of Surface-Water Records to 1950

*By* Francis J. Flynn

The nationwide compilation project, summarizing all streamflow records that had been published in hundreds of Water-Supply Papers from the beginning of records through 1950, began with an appropriation for FY 1952. Although much of the compilation work in the district offices had been completed by mid-1957, the work of the project engineers in reviewing and preparing the data for publication was far from over. In fact only 7 of the ultimately 21 volumes in the WSP series of 1950 compilation reports had been published by 1957. The last volume of that series of reports was published in 1961.

The 1950 compilation project turned out to be a more sizable task than first contemplated, but one that was well worth the effort. Not only were the records for a station that may have been published previously in as many as 50 annual reports now available in one report, those records were reviewed and corrected as necessary. Review and analyses were made on the basis of all available information. Records were tested whenever possible by comparison with records of discharge at other stations. For some stations, additional data obtained subsequently permitted reinterpretation and recomputation for more accurate discharge records. Records that were found to need substantial revision were recomputed or omitted if revision was not feasible. Estimates of discharge were made wherever practicable to fill short gaps to complete the continuity of the record. The total cost of the project for the fiscal years 1952 to 1961 was almost $3.0 million, peaking in FY 1954 at $395,000.

The compilation project was under the technical surveillance of the Annual Reports Section, headed by Barney J. Peterson through 1957 and by Francis J. Flynn thereafter. The actual work of reviewing and compiling the records was done in the District offices under the direction of the district engineers. Project engineers for various areas or drainage basins, designated to represent the Annual Reports Section, guided the planning and the execution of the work from the district office in which they were headquartered (see table IV–4). Not only did the project engineers review the final product of the District offices, but they were also responsible for the typing of the offset copy of the report for transmittal to the printer.

Table IV–4. Summary of compilation of surface-water records to 1950

| River basin parts | WSP numbers | Project engineers |
|---|---|---|
| 1–A, 1–B | 1301, 1302 | Charles E. Knox |
| 2–A | 1303 | Knox succeeded by Albert B. Goodwin |
| 2–B | 1304 | Paul R. Speer |
| 3–A | 1305 | Albert B. Goodwin |
| 3–B | 1306 | Paul R. Speer |
| 4 | 1307 | Charles E. Knox |
| 5, 6–A, 6–B | 1308–1310 | Roy E. Oltman succeeded by Howard F. Matthai |
| 7 | 1311 | James K. Searcy succeeded by Speer |
| 8 | 1312 | Joseph S. Gatewood succeeded by Speer |
| 9 | 1313 | Joseph S. Gatewood |
| 10,11–A,11–B | 1314–1315–B | Gatewood succeeded by Alfonso Wilson |
| 12, 13, 14 | 1316–1318 | Earl G. Bailey |
| Hawaii | 1319 | Earl G. Bailey |
| Alaska | 1372 | Earl G. Bailey |

## Flood-Frequency Studies

*By* William P. Somers *and* reviewed *by* Tate Dalrymple

Flood data have been documented in a multitude of observations, reports, and publications by the USGS during its existence and by numerous Federal, State, and private organizations. Interpretation of the scattered data base for purposes of estimating flood risk at a particular site was largely piecemeal and subject to biases of assumptions and judgments. A comprehensive, systematic approach to analysis of flood data was greatly needed.

Tate Dalrymple, prior to the 1950's, was a vigorous proponent of developing a flood-frequency program by the Survey. His efforts led to a national program, federally funded, by the mid-1950's. Later, in WSP 1543–A (1960), he described the method used by the Survey to determine the magnitude and frequency of momentary peak discharges at any place on any stream, whether gaging-station records were available or not.

After study of methods and theories of the many contributors to the body of flood-frequency methods, of special studies by Langbein (AGU Trans., v. 30, 1949), and of Benson (WSP 1543–A, 1960), and of the knowledge gained in preparation of 24 statewide and regional flood-frequency reports, a coherent, specific method of analysis evolved.

This method used two primary relationships. The first expressed a flood discharge-time relation showing variation of annual peak discharge expressed as a dimensionless ratio to the mean annual flood. The second related the mean annual flood, in cubic feet per second, to the size of the drainage area and possibly other significant basin characteristics such as altitude, slope, or shape. The curves were developed for as large a region as could be included so long as the region was homogeneous in character.

The nationwide flood-frequency program started with Federal program funding in FY 1956 of $30,000 and increased to about $55,000 per year thereafter. The project was estimated to cost $500,000 over a 6-year period. It was essentially completed by the end of FY 1965 at a total cost very close to the estimated amount.

The nationwide studies were laid out by the river-basin parts used in surface-water data reports. Data for the studies were tabulated mostly in the districts with analytical work done under the supervision of the Technical Standards Section, Tate Dalrymple, Chief, assisted by the field staff of Area Staff Engineers who oversaw individual studies.

In the 1957 reorganization of the SWB, "Floods Section" superseded "Technical Standards Section" and "Flood Specialist" superseded "Area Staff Engineer" (See Part III, "Surface Water Branch"). Dalrymple, Chief of the Floods Section, assigned studies and managed their completion and technical review. Following dissolution of the Floods Section in 1963 the completed studies were prepared for publication under the direction of Francis J. Flynn, Chief, Basic Records Section. A. Rice Green provided technical guidance and coordination during all phases of the program.

The area engineer program set up in 1949 provided a continuum of expertise that was focused on flood-frequency studies as well as a wide variety of flood-related activities. Tate Dalrymple fathered the program and energized it throughout its development until his retirement in 1964. Area engineers (flood specialists) and other members of the Section and Branch who were involved with flood-frequency methods, training, and studies were James F. Bailey, Harry H.

Barnes, Jr., Manuel A. Benson, G. Lawrence Bodhaine, Dean B. Bogart, Seth D. Breeding, Rolland W. Carter, Joseph S. Cragwall, Jr., Walter Hofmann, Harry Hulsing, Howard F. Matthai, Roy E. Oltman, James L. Patterson, Mervin S. Petersen, William P. Somers, and Richard H. Tice.

Credit for contributing to and producing the reports went beyond Section staff and authors. District personnel provided data listing, discussed and criticized analyses in progress, and reviewed the final reports.

Manuel A. Benson, other Research Section members, and district staff explored statistical approaches to analyses of the relation of annual peak discharges to many hydrologic factors in New England (Benson, WSP 1580, 1962). The final nationwide reports used such factors in estimating flood frequencies as follows:

| Factor | Parts 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drainage area | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Elevation | | | | | | x | x | x | x | x | x | | | |
| Precipitation | | | | | | | | | | | x | x | x | |
| Runoff | | | | | | | | | | | | x | | x |
| Area of lakes and swamps | | | | | | | | | | | | x | | x |
| Geographic factor | | | | | | | | | | | | x | x | x |

The Water-Supply Papers on magnitude and frequency of floods by number, drainage-basin part, date of publication, and author were: 1671, 1–A, 1964, by A. Rice Green; 1672, 1–B, 1968, by Richard H. Tice; 1673, 2–A, 1964, by Paul R. Speer and Charles R. Gamble; 1674, 2–B, 1966, by Harry H. Barnes, Jr., and Harold G. Golden; 1675, 2–B, 1965, by Paul R. Speer and Charles R. Gamble; 1676, 3–B, 1964, by Paul R. Speer and Charles R. Gamble; 1677, 4, 1965, by Sulo W. Wiitala; 1678, 5, 1968, by James L. Patterson and Charles R. Gamble; 1679, 6–A, 1966, by James L. Patterson; 1680, 6–B, 1968, by Howard F. Matthai; 1681, 7, 1964, by James L. Patterson; 1682, 8, 1965, by James L. Patterson; 1683, 9, 1966, by James L. Patterson and William P. Somers; 1684, 10, 1966, by Elmer B. Butler, J. Kenneth Reid, and Vernon K. Berwick; 1685, 11, Volume 1, 1967, by Loren E. Young and Russell W. Cruff; 1686, 11, Volume 2, 1967, by Loren E. Young and Russell W. Cruff; 1687, 12, 1964, by G. Lawrence Bodhaine and Donald W. Thomas; 1688, 13, 1963, by Cecil A. Thomas, Henry C. Broom, and John E. Cummans; and 1689, 14, 1964, by Harry Hulsing and Nicholas A. Kallio.

Manuel A. Benson (chairman) and Nicholas C. Matalas represented the Survey on an interagency work group on flow-frequency analysis that advised the Hydrology Committee of the Water Resources Council on the uniform technique for use in all Federal planning involving water and related land resources. Their recommendations were adopted in December 1967. At that time the door was left open to submit comments, criticism, and proposals toward improving determination of flood frequencies.

Meanwhile, engineers in Federal, State, and local government as well as private enterprise were using Survey reports and methods and the orderly history of flood data to estimate flood frequencies for flood-plain management, river crossings, highway design, flood-damage potential, flood mapping, and any activity involving flood discharges or elevations.

### Flood Inundation Mapping

*By* George W. Edelen, Jr. *and* reviewed *by* Donald M. Thomas

The Flood Act of 1936, which recognized flood control as a Federal obligation, accelerated the demand for flood data, particularly for information about the most damaging floods—a demand that continued to increase for the next three decades.

The average annual flood damage in the United States, in dollars, had increased from less than $100 million at the beginning of the century to almost $300 million by 1960. By 1945, Gilbert F. White, University of Chicago, Walter B. Langbein, USGS, and others recognized that the increasing annual flood damages apparently were not due to greater floods but to increased encroachment on flood plains. It was evident that, in addition to structural measures, flood-plain management was needed to mitigate the ever-increasing average annual flood damages.

The July 1951 floods in Kansas and Missouri resulted in damages exceeding $870 million. As a result of these losses, the Federal Government initiated a study to determine the feasibility of a flood-insurance program. Several meetings were held at which various agencies, including the USGS, represented by Walter B. Langbein and Tate Dalrymple, took part. A study financed by the insurance industry generally did not favor flood insurance, and in a short time interest in the subject diminished.

The floods of August 1955 in the Northeastern United States and of December 1955 and January 1956 in the far Western States resulted in damages exceeding $500 million. Those events revived interest in flood insurance, and the Federal Flood Insurance Act of

1956, Public Law (PL) 84–1016, 84th Congress, 2d Session, was enacted. This Act was the formal beginning of the present National Flood Insurance Program, now (1991) administered by the Federal Insurance Administration in the Federal Emergency Management Agency.

The method of determining rates was the key item in the success or failure of the flood-insurance program. It was early evident that the insurance industry and the government hydrologists had different views on the subject. The approach advocated by government hydrologists was that (1) rates should reflect the highly variable exposure to risks, and (2) the rates and other policy criteria should be such as to deter improvident development of flood plains.

An important part of PL 84–1016 was a provision which encouraged the management of development on flood plains. A technical manual for the guidance of those engaged in flood-plain management in Pennsylvania was prepared through a cooperative arrangement between the USGS and the Commonwealth of Pennsylvania, Department of Forests and Waters. The manual, published as WSP 1526 (1961), and titled "Hydraulic and hydrologic aspects of flood-plain planning," was authored by S.W. Wiitala and K.J. Jetter of WRD and A.J. Sommerville of the Pennsylvania State Department of Forests and Waters.

A project was initiated through a cooperative agreement between the Survey and the Department of Housing and Urban Development to determine the feasibility of a flood-insurance program based on the flood-zone or risk concept. The project was conducted by the Floods Section, under Tate Dalrymple. Manuel A. Benson was project chief, assisted by Donald M. Thomas. Administrative reports, completed in 1966 for six pilot studies, and the authors of each were: Alexandria, Va., by D.M. Thomas; Asheville, N.C., by J.F. Bailey; Hattiesburg, Miss., by H.H. Barnes, Jr.: Joliet, Ill., by W.D. Mitchell; Nashville, Tenn., by L.G. Conn; and Ventnor City, N.J., by D.M. Thomas.

The emphasis on the reduction of flood damage by flood-plain management resulted in an important addition to the WRD program of collecting flood data. The conservative position of reporting only elevations and discharges of floods gave way to publishing more interpretive information—areas covered by floods of selected frequencies. Publication of flood-inundation maps delineating boundaries of inundated areas, water-surface profiles, and flood-frequency relations became a standard means of reporting specific floods.

In 1954, Langbein designed a report format consisting of a map as the essential product with the pertinent text shown in the margins. This report, issued in fancy library folio form with covers, became Hydrologic Investigations Atlas No. 1 (HA–1). The change in form to letter-size folio followed in 1959 with HA–14, "Floods at Topeka, Kansas," prepared by G.W. Edelen, L.W. Goodman, W.B. Langbein, and W.P. Somers, the first of a series of flood atlases for that area. A second flood atlas, HA–39, "Floods near Chicago Heights, Illinois," prepared by J.M. Carns, O.G. Lara, H.E. Allen, W.D. Mitchell, and G.W. Edelen, was published in 1960.

In reporting the data on the floods of January 1959 in Ohio, WRD adopted, for the first time, publication of flood-inundation maps as another means of depicting flood information, in addition to the traditional reporting of flood peaks and flood hydrographs.

The Ohio Legislature was in session during the January 1959 flood. It recognized the urgent need for modern topographic maps and appropriated sufficient funds to finance a cooperative agreement with the Topographic Division to complete topographic mapping of the entire State. At the same time, Lawrence C. Crawford, District Engineer, SWB, Ohio, negotiated an agreement with the Ohio Department of Natural Resources to finance the preparation of flood atlases in urban areas where flooding had been most severe. Flood atlases for the 1959 flood in Ohio were published during 1961–63, for each of 12 cities. The atlases were prepared by Frederick H. Ruggles, Jr., George W. Edelen, Jr., William P. Cross, and William P. Somers.

In addition to the routine reporting of rare floods through the use of inundation maps, a special project was conducted by Clifford T. Jenkins, in which the areas inundated by floods of several frequencies were constructed synthetically from past records and physical surveys of the flood plain of Boulder Creek at Boulder, Colo. The results of this study were summarized in the third flood atlas, HA–41, "Floods at Boulder, Colorado," 1961. Soon after HA–41 was published, Secretary of the Interior Udall received a protest from the Consulting Engineers Council, who viewed the type of flood information contained in HA–41 as an infringement on the role of engineers in private practice. The response from the Secretary pointed out that HA–41 was simply a new way of presenting flood data that provided more and better design data for the practicing engineer. His reply appeared to quiet their concern. Interest in the work of the Survey in flood mapping of metropolitan areas rapidly increased, and by the end of 1960 several cooperatively financed projects were underway.

An increase in available Federal cooperative funds in FY 1961 and 1962 permitted the addition of several other flood-inundation projects. Districts were encouraged to negotiate cooperative flood-mapping programs because of their value to communities. By the end of 1966, 69 flood atlases at sites in 17 States had been published. The Floods Section, under Tate Dalrymple, was given the responsibility for the program. George W. Edelen, Jr., became the project chief. The program was successful because it permitted another practical and useful application of streamflow records.

Following the publication of HA–39, the Northeastern Illinois Metropolitan Area Planning Commission proposed to cooperatively finance a flood-inundation mapping project in six counties in northeastern Illinois. The final agreement, negotiated in 1961 by William D. Mitchell, District Engineer, SWB for Illinois, provided for preparing flood atlases for 43, 7.5-minute quadrangles (scale 1:24,000) in 5 years for $300,000 (about $7,000 each). The project was assigned to the Oak Park, Ill., subdistrict office under the direction of Davis W. Ellis, Engineer-in-Charge. WRD, in an unusual move, assigned in advance a block of consecutive HA numbers to the project. By 1966, 38 atlases had been published. The atlases were prepared by the following authors: Howard E. Allen, Davis W. Ellis, Dean E. Long, V. Jeff May, Roman T. Mycyk, Allen W. Noehre, and Robert J. Schafish. Later, the project was expanded and by 1973, 31 additional atlases had been completed.

The need for good, large-scale topographic maps for flood-plain management was recognized early, but the maps were not generally available. In 1960, Rolland W. Carter, Chief, Research Section, was instrumental in initiating a cooperatively financed, large-scale flood-mapping project in Fairfax County and the city of Alexandria, Va., to study the effects of basin development on floods. He developed procedures for defining changes in flood heights at sites subject to various degrees of future development. The project was under the direction of Daniel G. Anderson of the Fairfax Subdistrict office of SWB, assisted by Lewis G. Conn and James F. Bailey.

The project offered assistance to the county in obtaining flood information needed for flood-plain use planning and in developing techniques for synthesizing flood heights and profiles. In addition, the program included an opportunity to collect a large amount of flood data on small drainage areas in various stages of urbanization using 150 partial-record gaging stations established for that purpose. Large-scale (1 inch = 100 feet) maps were prepared from low-altitude photography procured by the Topographic Division.

The first "flood hazard" maps from the northern Virginia project, submitted for approval (1964), received an unfavorable response from the Director, who at that time was hesitant to endorse WRD's flood-mapping activities. The maps delineated boundaries for 25-, 50-, and 100-year floods which would occur under conditions of ultimate watershed development as projected by Fairfax County authorities. The Director was concerned because the profiles were based on derived data rather than observed data and because the position of flood-boundary lines shown on large-scale maps could affect land and property values.

The assurance of Hendricks, Associate Chief Hydrologist, that the project was essentially a research effort and that there were no plans to enter into further cooperative projects that would result in the routine production of flood-plain maps in such detail and scale as those submitted, resulted in the Director's approval.

The first flood-hazard maps were approved January 11, 1966, by the Director as administrative reports, for release to only the cooperators—Fairfax County and the city of Alexandria, Va. However, the maps soon were in the hands of the public and approval for release to the open file was quickly arranged.

The experimental project evolved into a long-time one. By 1975, when it was completed, 525 maps had been prepared and WSP 2001in 1961, C, titled "Effects of urban development on floods in northern Virginia," by D.G. Anderson, had been published.

In 1964, the Tennessee District, under Joseph S. Cragwall, District Chief, undertook a cooperative program for mapping the potential extent of flooding in Browns Creek Basin in Nashville and Davidson County. The project was modeled after the Fairfax County project except that the flood information was recorded on large-scale maps supplied by the cooperator. Lewis G. Conn became the chief of the project that produced 88 large-scale flood maps.

In due time, similar research projects were undertaken in St. Louis, Mo., and Charlotte, N.C. Large-scale topographic maps were provided by the cooperators for those projects. In the ensuing years, flood-prone areas were delineated on more than 13,000 quadrangle maps (scale 1:24,000) and shown in descriptive pamphlets for 1,000 selected communities at a cost of about $7 million. The maps were used extensively for local planning and to meet objectives of Federal legislation and Executive Orders subsequent to this period of history.

### Hydrologic Data Networks

*By* H.C. Riggs *and* reviewed *by* Clayton H. Hardison

By the 1950's the Division was collecting hydrologic data at many sites, but it became apparent that some modification of the data-collection program was needed to provide information at additional sites without an appreciable increase in total cost. In 1953, a

SWB committee chaired by Walter B. Langbein examined the national stream-gaging program and proposed (SWB memo dated April 17, 1956) a means of getting a well-balanced and desirable stream-gaging program for the available funds. The committee suggested two main categories of gaging stations—hydrologic stations to provide general information and water-management stations to provide information for specific needs. Two classes of hydrologic stations were proposed: primary stations which were to be operated indefinitely and secondary stations to be operated for 5 or 10 years. The short records obtained at the secondary stations were to be extended in time by correlation with the primary stations. Over a period of years this program was expected to provide flow information at a great many sites, thus approaching the objective of regional coverage.

The proposals of the 1953 committee were used to prepare a report, "Nationwide Review of Streamgaging Program" which was completed in 1957 by Glennon N. Mesnier and John E. McCall. Their report (SWB Memorandum June 30, 1958) classified all existing and most discontinued stations as primary, secondary, or water-management; it proposed a network of primary stations, most of which were existing stations; it listed all existing or discontinued stations for which an adequate secondary record was available, and it recommended increasing areal coverage in the period 1959–68 by establishing new complete-record stations at specific sites. Their report also included the recommendation that the discontinued secondary stations be operated as high-flow or low-flow partial-record stations for several additional years. The network and station classification concepts were espoused by Langbein and Hoyt (1959) in their book "Water facts for the Nation's future" and by McCall (1961) in his paper "Streamgaging Network in the United States" (ASCE Proc., v. 87, HY–2).

A part of this program was the development of methods for correlating concurrent monthly means of a secondary station with those for a primary station for assessing the feasibility of the secondary station concept. These studies, by Clayton H. Hardison, indicated that uniform areal reliability could not be expected throughout the conterminous United States.

A network of water-quality stations patterned after that for streamflow stations was planned and announced in 1957 but was abandoned when it was found that water quality at a site is so influenced by man's activities that most records had no transfer value.

In the years following 1957, the District offices were directed to make their streamflow data-collection programs conform to the recommendations of the nationwide review to the extent that funds permitted. But few of the secondary stations were discontinued after 5 or more years of operation because the correlations were not made (or the results were not adequate), or because the stations were supported financially for other purposes.

Neither of the previous studies suggested how the secondary station record might be adjusted to represent the period of record of the primary station. Nor were there any subsequent directives as to how or whether this should be done. However, at the request of the Upper Colorado River Commission in the late 1960's, the monthly means at secondary stations in the Upper Colorado River Basin were extended to the period of record of the primary stations by L.E. Carroon (WSP 1875, 1970).

In 1957, a nationwide system for numbering gaging stations was developed. Each station number was composed only of digits so that it could be used in programs for processing streamflow data. The first two digits showed the drainage Part number, the following four digits the downstream order within the Part, and the last two digits allowed for expansion in the system. Numbers were assigned in 1957 to all the gaging stations and partial-record stations listed in the 1955 indexes.

In 1958, Luna B. Leopold proposed a nationwide hydrologic benchmark program, and in 1961, the criteria for the program were established and responsibility for its implementation assigned to the SWB. Its purpose was to acquire and preserve the data to evaluate long-term hydrologic changes with time. A hydrologic benchmark was defined as a site at the outflow point of a basin in which hydrologic conditions were not now nor likely to be affected by man and at which hydrologic records would be collected indefinitely. Selection of benchmarks began in 1963 with the designation of six basins. As of December 1965, 36 benchmark stations were installed or authorized. By 1970, the network had grown to 57 basins encompassing a wide variety of natural environments. Data collected at most of these include continuous streamflow and water quality. On some basins, precipitation, ground-water levels, and various other hydrologic data are obtained. This program was financed by Federal funds and was described in 1971 by Cobb and Biesecker in Circ. 460–D.

At the 1961 UNESCO/WMO meeting in Rome, Leopold proposed an international (vigil) network of landscape observations on small basins. At the first session of the Coordinating Council for the International Hydrological Decade (IHD), held in 1965 in Paris, vigil basins were recognized as one of the IHD projects for collection of basic data. A principal objective of the Vigil Network was to preserve the results of field measurements for future generations of scientists. The program was begun in the United States in 1963 with the establishment of several watersheds as a nucleus for a vigil network along the 41st parallel between the Appalachians and the Rockies. Minimum data to be collected annually, or less frequently, included a crest-stage record, channel cross sections, rainfall from a storage gage, and maps of geology, soil, topography, and vegetation. Richard F. Hadley reported that 56 Vigil Network stations had been established in the United States by 1965. He and W.W. Emmett (1968) reported on the preservation of and access to the Vigil Network data in Circ. 460–C. Permanent repository for the data on the United States sites is in the USGS Library.

BOB Circular A–67, issued in 1964, vested responsibility for the design and operation of a national network in the DOI. Responsibility for the execution of the functions of A–67 were assigned to the Survey, which established the Office of Water Data Coordination (OWDC) in WRD to carry out those functions. By the end of this period, OWDC in consultation with its advisory committees, had adopted a system of network identification that was more conceptual than rigorous and was based on three levels of information perceived as being needed for (1) broad national planning, (2) water-resources planning within a basin, and (3) water-resources management. (See Part VIII, "Water Data Coordination," BOB Circular A–67.)

### Regional Low-Flow Analyses

*By* H.C. Riggs *and* reviewed *by* Clayton H. Hardison

Prior to the severe drought of 1954 in the Southeastern States, low-flow characteristics of streams had been defined only in a few regions where the objective was to define the lower limit of the aquatic habitat or the amount of waste that the stream could receive without exceeding water-quality limits.

In 1955, the SWB responded to the new widespread interest in probable minimum flows with a memorandum on regional low-flow analysis which recommended that all records in a region be analyzed and that discharge measurements of small ungaged streams be obtained and used to estimate low flows at small recurrence intervals. Specific methods for doing this had not been developed at this time. But by 1958, computer processing of daily streamflow data made annual low flows readily available for study.

Within the next few years, Clayton H. Hardison advised field offices on methods for defining low-flow characteristics at gaging stations, and he personally participated in the preparation of such studies with R.O.R. Martin at 85 long-term gaging stations in the Eastern United States and for 95 stations in the Delaware River Basin (WSP 1669–G, 1963). Frequency curves for stations with records shorter than the standard period used were adjusted to the longer period.

A major hydrologic study of the Mississippi Embayment (see "Mississippi Embayment Project") included low-flow frequency curves and investigations of the reasons for the variability among sites (Speer and others, 1960, PP 448–F).

In 1961, Riggs published a short paper on regional low-flow frequency analysis (PP 424–B). Hardison explored methods of estimating the low-flow characteristics of small ungaged streams from a few discharge measurements and encouraged personnel in District offices to do the same. Robert E. Fish and Grover C. Goddard, in North Carolina, estimated low-flow characteristics of many streams on the basis of discharge measurements and published the results in WSP 1761 (1963). Some work on this problem was also done in the SWB Research Section.

In 1962, the SWB evaluated the various methods that had been used and recommended ones that conformed to statistical principles. In 1965, H.C. Riggs published a procedure for estimating probability distributions of drought flows from base-flow measurements (Water and Sewage Works, v. 112, n. 5) that was later evaluated theoretically and empirically and is still being used.

Concurrent with the development of methods for defining low-flow characteristics from a few discharge measurements was the identification of the principal basin characteristics that affect low flows and the development of methods for using them to define low-flow characteristics at ungaged sites. The data bases provided by the frequency curves at many gaging stations were indispensable to this effort. The character of the geological formation appeared to be the principal factor affecting low flows but, unfortunately, it is not possible to describe the effect of a formation quantitatively even from detailed geologic maps. Riggs used the slope of the base-flow recession curve of streamflow as an index of the effect of geology on low flows. He found a good relation between the 20-year low flow and the 2-year low flow, drainage area, and the recession slope using data from streams in New England, Georgia, and Kansas. But neither the 2-year low flow nor the recession slope can be readily obtained at an ungaged stream. Consequently, it appeared that broad geographic coverage of low flows would have to depend on obtaining discharge measurements at many ungaged sites.

Low-flow frequency curves were considered as a basis for defining the potential yield from storage, but studies by Walter B. Langbein, Luna B. Leopold, Hardison, Riggs, and others led to methods which use daily and monthly mean flows for defining draft-storage-frequency relations. Separate relations were developed for within-year and for multiyear periods. Hardison later combined these into a single relation which was adjusted for reservoir evaporation (Riggs and Hardison, TWRI book 4, chap. B–2, 1973).

### Artificial Recharge Through Wells, Grand Prairie Region, Arkansas

*By* Richard T. Sniegocki *and* reviewed *by* Fred H. Bayley, III, U.S. Army Corps of Engineers, Vicksburg District

The Grand Prairie region of Arkansas was selected by WRD in 1953 as the site for research on recharging ground-water reservoirs through wells. An apparently continuous aquifer underlying the Grand Prairie provides water for the irrigation of rice that had been grown in the region since 1904. Continual pumping of water from Quaternary deposits to irrigate up to 135,000 acres of rice caused a serious overdraft on the ground-water supply. The average water-level decline from 1910 to 1958 was approximately 1 foot per year. Thus, the region was a large natural laboratory for studies of artificial recharge; those studies continued well into the Leopold years of WRD history.

Two wells, constructed differently, were used to make recharge tests. More than 23 million gallons of water was recharged during the series of tests. An analysis of the cost of recharge through wells based on results of the study showed that water that had been recharged and recovered cost more than $30 per acre-foot (1961). The major item contributing to the cost was the treatment of an injection supply to obtain low-turbidity water with few micro-organisms.

The results of the recharge study (1953–61), conducted in cooperation with the U.S. Army Corps of Engineers (Vicksburg District) and the University of Arkansas are reported in WSP 1615–A through H (1963–66). The principal investigators for the WRD, the Corps and the University, respectively, were Richard T. Sniegocki, Fred H. Bayley, III, and Kyle Engler. A. Ivan Johnson and William J. Drescher of WRD offices in Denver, Colo., and Madison, Wisc., respectively, gave generously of their time to assure a technically sound project.

Although figures are no longer available to accurately reconstruct project costs, it is estimated that the 8-year project cost approximately $450,000. The WRD provided about $250,000 from its Federal program funds. The Corps contributed roughly $185,000, largely in manpower and in the expense of drilling one recharge well and eight or so observation wells. The University of Arkansas, through its Rice Branch Experiment Station near Stuttgart, Ark., was an enthusiastic and active participant in the study. The University's costs are estimated at about $50,000 and included the cost of assistance such as equipment housing, occasional manpower, and the use of power equipment.

## Research and Development

Virtually all of the special programs and projects previously described involved some elements of research, innovation, and development of techniques. With the Division's emphasis on increased research, however, there emerged during the period a growing formal program component having research and development its primary objective. It became recognized as "the research program," and with increased Federal funding for research, "the core research program."

The major components of the program during the period 1957 to 1966 are described in the next series of articles, each authored by Division scientists and engineers personally involved in the activity being recounted.

### Ground-Water Research

*By* Russell H. Brown *and* reviewed *by* O. Milton Hackett *and* Roger G. Wolff

Important ground work for a federally funded program of research in ground-water hydraulics and hydrology was laid by Robert R. Bennett in April 1956. He described, in considerable detail, the areas of inadequate knowledge in the field of "mechanics of ground-water movement" and suggested the following four principal research areas under which individual projects might be organized and funded: (1) flow of water through unsaturated media, (2) flow of water through saturated media, (3) mechanics of aquifers and associated confining rock material, and (4) sedimentational and structural features of rock units with respect to ground-water flow.

In FY 1957, Federal funds became available for the first time earmarked specifically for research. The amount allocated to the ground-water discipline was distributed among several senior or specially trained men who had designed research projects compatible with the above-cited areas of needed knowledge. The beginning principal researchers and their projects were: R.R. Bennett in hydrodynamics of Tensleep sandstone; H.H. Cooper in saltwater/freshwater diffusion; J.F. Poland in mechanics of aquifers, principles of

Table IV–5. Project leaders in the Research and Development programs in ground-water hydraulics hydrology

| | Fiscal Years | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Project Leaders** | **1957** | **1958** | **1959** | **1960** | **1961** | **1962** | **1963** | **1964** | **1965** | **1966** |
| | | | | | **Unsaturated Flow** | | | | | |
| Remson, I. | NJ | NJ | NJ | NJ | | | | | | |
| Smith, W.O. | | | DC | DC | DC | DC | DC | DC | DC | DC |
| Skibitzke, H.E. | | | | | AZ | AZ | AZ | | | |
| Stallman, R.W. | | | | | CO | CO | CO | CO | CO | CO |
| | | | | | **Saturated Flow** | | | | | |
| Bennett, R.R. | DC | DC | DC | DC/VA | | | | | | |
| Cooper, H.H. | FL | FL | FL | FL | FL | FL | FL | FL/VA | VA | VA |
| Smith, W.O. | DC | DC | DC | DC | DC | DC | DC | DC | DC | DC |
| Stallman, R.W. | VA | VA | VA | VA | | | | | | |
| Ogata, A. | | | AZ | AZ | HI | HI | HI | HI | HI | HI |
| Skibitzke, H.E. | | | AZ | AZ | AZ | AZ | AZ | | | |
| Olsen, H.W. | | | | | DC | DC | DC | DC | DC | DC |
| Papadopulos, S. | | | | | | | | VA | VA | VA |
| | | | | | **Mechanics of Aquifers** | | | | | |
| Poland, J.F. | CA | CA | CA | CA | CA | CA | CA | CA | CA | CA |
| Bennett, R.R. | | | DC | DC/VA | VA | VA | VA | VA | VA | VA |
| da Costa, J.A. | | | DC | DC/VA | VA | VA/AZ | AZ | AZ | | |
| Upson, J.E. | | | | NY | NY | NY | NY | | | |
| Upson, J.E. | | | | | NY | NY | NY | | | |
| Payne, J.N. | | | | | LA | LA | LA | LA | LA | LA |
| Bredehoeft, J.D. | | | | | | | VA | VA | VA | VA |
| Brown, P.M. | | | | | | | | NC | NC | NC |

compaction, and deformation; Irwin Remson in unsaturated flow in porous media; W.O. Smith in transient flow in saturated porous media; and R.W. Stallman in analog model development, steady-state flow.

As this period of WRD history progressed, additional personnel were recruited or assigned to undertake new projects, and there were some project completions or terminations. An overall view of the time sequence of such events is given in table IV–5, which shows, by fiscal year, the active research project leaders and their headquarters locations. The groupings are in accordance with only the first three cited principal research areas, the fourth area having been included in the third. Within a group the names are generally in chronological order of project activation. Some feel for the overall Federal fund allocations to this research effort may be gleaned from the following rough estimates:

| Research area | Range in total estimated allocations |
|---|---|
| Unsaturated flow | $30,000 - $80,000 |
| Saturated flow | 70,000 - 200,000 |
| Mechanics of aquifers | 70,000 - 240,000 |

The project leaders, some of their principal associates and assistants, and the main objectives of their projects are summarized in the order of the project leaders' appearances in table IV–5.

### *Research in Unsaturated Flow*

Remson, Irwin.—Joined the GWB District in Trenton, N.J., in June 1949, as a P–2 geologist with a newly minted Master's degree in geology from

Columbia University. In December 1950, he transferred to Seabrook, N.J., to head a new cooperative study of moisture relationships in the zone of aeration in and around Seabrook Farms. Concurrently with his full-time workload, over the next several years Remson was in graduate school at Columbia and earned his Ph.D. in 1954. When Federal money for research became available in 1957, the Seabrook, N.J., area was recognized as an unparalleled field laboratory offering wide-ranging opportunities for research into instrumentation and techniques for measuring moisture content and movement in the zone of aeration. A research project led by Remson was a logical step, and as the work progressed, wide experience was gained in field use of resistance elements and nuclear meters for measuring soil-moisture content and in use of tensiometers for measuring liquid-head values at points in the unsaturated zone.

For the duration of the project, Remson's principal assistant was James R. Randolph, geologist. Remson terminated his project leadership in 1961 to return to the Trenton office on a part-time basis, so that he could accept a teaching assignment at Drexel University.

Smith, William O.—Physicist, recruited from the Department of Agriculture in December 1945 for the specific purpose of running the GWB laboratory in Washington, D.C. Smith continued the laboratory's dedication to measuring the physical properties of porous media and to describing how these properties could be related to the movement of ground water. With the new Federal research money in FY 1959, Smith undertook to develop some indirect methods for measuring the moisture content of unsaturated porous media. He designed and conducted studies seeking to relate porosity, moisture content, grain size, and sorting to the dielectric properties of selected types of water-bearing sands. He also examined the effects of structure, ion exchange, and water content on the dielectric properties of a set of standard clay types.

Skibitzke, Herbert E.—Joined the GWB in Phoenix, Ariz., in September 1949 as a mathematician, P–1, and worked several years in the District program. Then his mathematical prowess became known to C.V. Theis, who enlisted his help in analyzing ground-water problems relating to the waste-disposal programs of the AEC. In response to those needs, he devised an analog model that featured both electrical and artificial-sandstone modeling techniques. In fiscal year 1961, Federal research money was allocated to support this work, particularly to simulate some of the mathematical functions that describe the unsaturated flow system. Radiotracer and dye experiments in the artificial sandstone models identified and measured the factors controlling rates of fluid and vapor movement. During the 3 fiscal years of this project, Skibitzke was assisted primarily by Albert E. Robinson, engineer, and Howard T. Chapman and James M. Cahill, engineering technicians.

Stallman, Robert W.—Joined the GWB District in Indianapolis, Ind., in March 1945, as a junior hydraulic engineer, P-1, with a B.S degree in civil engineering from Rose Polytechnic Institute. In March 1949, he was transferred to the GWB headquarters office in Washington, D.C., to augment the staff of the Hydraulics Section, which became the Research Section in 1957. He worked on research in saturated flow until May 1960 when he and his activities were transferred to the Office of the GWB Area Chief in Denver, Colo.

At the time of his transfer, Stallman had just completed a manuscript on unsaturated flow—an incisive summary of the current state of knowledge. This served as a springboard to launch him on a full-fledged research project in unsaturated flow. During the next 6 years, his work encompassed investigations into the design of electrical analogs to represent unsaturated flow in nonhomogeneous porous earth materials; the use of pressure cells and electric tensiometers to measure head distribution in the unsaturated zone; and the use of highly sensitive thermistors to measure minute temperature changes in that zone.

### *Research in Saturated Flow*

Bennett, Robert R.—After several years of outstanding leadership as District Geologist for the Maryland GWB District, Bennett was transferred in September 1953 to the office of the Branch Chief at Headquarters. He quickly filled a key role in designing a research program for the Branch and in November 1956 was selected to head the newly established Research Section. With the availability of the 1957 research funds, Bennett chose to apply this Federal support to a research project he had started several years earlier on the hydrodynamics of regional ground-water flow in the Tensleep sandstone, Big Horn Basin, Wyo. During the several years of the project, his work defined the regional three-dimensional ground-water flow patterns and related these to the distribution of petroleum and to chemical constituents in the water. Ingenious methods of data analysis were used to define the regional flow systems, including a rubber membrane analog model to simulate the head distribution near the outcrop areas of the Tensleep sandstone and a microplotter to read data from drill-stem test curves collected as deep as 15,000 feet in oil test wells.

Bennett's principal assistant on this project was Jose A. da Costa, hydraulic engineer.

Cooper, Hilton H.—With the advent of new Federal funds for research in FY 1957, Cooper (headquartered in Tallahassee, Fla.) was selected to head a research project that involved field and mathematical investigations into the occurrence and movement of seawater in coastal aquifers. He had been preparing himself for just such a role by completing, in the early to mid-50's, 15 credit hours in graduate mathematics at Florida State University. He continued his formal training into the 1960's by attending Columbia University, where in 2 academic years (1959–60 and 1962–63), he completed 36 credit hours in advanced mathematics, hydrodynamics, and related engineering subjects, and audited 16 hours of other courses. In June 1963, he received an M.S. degree in engineering.

During the first few years of the project, Cooper made a mathematical analysis of the flow system for a fluid of variable density in the zone of diffusion of a coastal aquifer and compared it with actual field data. Some laboratory tests were run on Ottawa sand in the Hydrologic Laboratory in Denver to evaluate dispersion coefficients associated with reciprocative tidal motion. In the later project years the work was broadened to embrace a host of flow problems under the general title "Mechanics of ground-water flow." During his research, Cooper collaborated with Robert R. Bennett, John D. Bredehoeft, Robert E. Glover (BOR, Denver), Harold R. Henry, Francis A. Kohout, Stavros Papadopulos, and Matthew I. Rorabaugh.

Smith, William O.—From his laboratory program of basic research (see discussion on Smith in segment on "Research in Unsaturated Flow"), Smith chose for support with some of the new Federal research money in FY 1957 a research project on transient flow in saturated porous media. Under tightly controlled and measured laboratory conditions, he studied transient-flow interrelationships between fluid head, velocity, and discharge rate for selected uniform sands and in capillary tubes ranging in diameter from 0.1 to 5 mm. In some of the larger tubes, he extended the flow conditions through the transition zone from laminar to turbulent states, continuing into the upper regions of turbulency. Part of the justification for these experiments lay in the fact that the validity of Darcy's law, on which so many ground-water flow equations were based, had never been demonstrated for transient conditions. Also hanging in the balance were the precise meaning and significance of the coefficient of storage.

Stallman, Robert W.—By the time Federal money for research became available in FY 1957, Stallman had turned to the use of electronic analog devices as the most economical and versatile means for solving the mathematical equations that described complex ground-water flow problems. For several years he was supported in the development of such models for analyzing steady-state flow problems. An end result was the design and assembly of a variable-resistor grid, containing 480 nodal points, complete with appropriate electrical power supplies, to simulate or model an aquifer system. A highly sensitive and accurate digital voltmeter served to read voltages at the nodal points in the grid. Stallman used this model most effectively in analyzing flow problems in anisotropic and nonhomogeneous aquifers at the GWB short courses.

Although project support ended in FY 1960, Stallman continued to turn out by-products in the realm of saturated flow. Notable in this regard was PP 514 (1966), coauthored with Stavros Papadopulos, on "Measurement of hydraulic diffusivity of wedge-shaped aquifers drained by streams." It contained four pages of text, 46 pages of tables, and 120 type-curve plates. With this publication, Stallman laid claim—with Papadopulos—to "the American type-curve manufacturing championship!"

Ogata, Akio.—Discovered by C.V. Theis while in graduate school and working on an AEC contract at Northwestern University, Ogata was awarded a Ph.D. in fluid mechanics by Northwestern in August 1958 and joined the GWB research field unit in Phoenix, Ariz., in November 1958 as a hydraulic engineer. Ogata proposed a research project that involved laboratory and theoretical studies of the mechanics of transverse and longitudinal dispersion in porous media. In the beginning, it entailed constructing artificial sandstone models to simulate situations, such as heterogeneities, in aquifers and using dyes or radio tracers to detail dispersion effects. As the work progressed, it was expanded to include mathematical as well as laboratory-model studies and comparisons of the diffusion process, the role of adsorption in underground waste disposal, and the criteria for relating model results to the actual field situations where the flow systems are complex. As the project was located in Phoenix, Ogata collaborated with Herbert E. Skibitzke and some of his assistants.

Skibitzke, Herbert E.—Initially, the research group that Skibitzke marshalled in Phoenix, Ariz., was supported by AEC funds, and the problem solving was aimed at that agency's program (see discussion on Skibitzke in segment on "Research in Unsaturated Flow"). In FY 1959, however, additional support was given to the ongoing development of electric-analog models to permit the analysis of three-dimensional unsteady-state flow problems. Over a period of several years, support was increased and the work broadened to include saturated-flow experiments with artificial sandstone models—to investigate effects of heterogeneity—and mathematical studies of specified ground-water flow systems. Over part or all of the 5 fiscal years in which the foregoing work was supported by Federal research funds, Skibitzke was assisted by Geraldine M. Robinson and Boris J. Bermes, hydraulic engineers, and Garth E. Ghering, Sr., and Chester J. Kordylas, electronic technicians. After FY 1963, Skibitzke's research interest and funding support shifted to hydrologic remote sensing. (See Part IV, "Hydrologic Remote Sensing.")

Olsen, Harold W.—Discovered at MIT by W.O. Smith as Olsen was completing his Ph.D. in soils mechanics and fluid movement through clays, he joined the GWB headquarters in Washington, D.C., in January 1961 as a hydraulic engineer. Olsen's research project was to build the equipment needed to study the phenomena of liquid movement in clays. These phenomena were known to depend on such factors as hydraulic gradients, porosity, liquid viscosity, induced and applied electric potential gradients, ionic concentration, temperature, and mineralogical composition of the clay and pore liquid. During the 6 years of the project, the work was aimed at identifying separately the effects of each of these factors, as well as the manner in which they might be interrelated.

Papadopulos, Stavros.—Papadopulos worked part time for USGS for several years while completing his Ph.D. in engineering at Princeton, then joined the WRD research group headquartered at Arlington, Va., in February 1964 as a hydraulic engineer. Papadopulos' graduate training was strong in advanced mathematics and fluid dynamics. He therefore designed a research project that over the next several years developed the fundamental and rigorous mathematical solutions for specific kinds of ground-water flow problems commonly encountered in field investigations. Some of his colleagues in much of this work were Robert R. Bennett, John D. Bredehoeft, and Hilton H. Cooper.

### *Research in Mechanics of Aquifers*

Poland, Joseph F.—After a number of years of outstanding leadership as District Geologist for the California GWB District at Sacramento, Poland—as one of the Branch's cadre of senior experienced men—was asked to lead a research project to investigate the principles and factors controlling the deformation (compaction or expansion) of water-bearing and associated earth materials resulting from changes in internal fluid pressure. Ongoing cooperative studies in areas of major land subsidence in California offered ideal field environments for pursuing this research. The work was concentrated in the Tulare-Wasco and Los Banos-Kettleman City areas and in the Santa Clara Valley, where much of the geology and hydrology were known. The work included drilling many core holes to obtain samples for laboratory analysis of physical, hydrologic, and consolidation properties; installing subsidence recorders in specially constructed observation wells; and periodic remapping of subsidence areas. Information was also collected on other areas of major land subsidence in California, Nevada, Texas, and Arizona. During the course of the project, Poland had as many as eight professional associates working with him including George H. Davis, Jack H. Green, and Francis S. Riley, geologists, and Ben E. Lofgren, engineer.

Bennett, Robert R.—In FY 1959, Bennett began a new project to define the directional and spatial distribution of permeability in fine-grained sediments and to relate such characteristics to grain orientation (petrofabrics) and to sedimentational features and processes. His work continued through the remaining 7 years of this period of WRD history. Laboratory petrographic analyses were an important aspect of this work. Jose A. daCosta assisted Bennett during part of this period in developing mathematical relationships.

da Costa, Jose A.—Joined the GWB at headquarters in January 1954 as a geologist. da Costa worked first in the Technical Reports Section under Charles L. McGuinness and then in the Foreign Hydrology Section under Thomas E. Eakin. In October 1956, he was reassigned to a research hydraulic engineer position which formalized the working relationship already underway with Robert R. Bennett on his research project. In fiscal year 1959, daCosta proposed a new research project in which seismic waves in porous media would be examined in minute detail to see whether the response characteristics could be related to the geologic and hydrologic conditions. Over the 6 years of the project, some extremely sensitive recording equipment was designed and built, capable of documenting earthquake-induced water-level (or pressure) fluctuations in a well. The equipment was installed on a flowing artesian well in Safford Valley, Ariz., and records were obtained of the amplitude and wave length of such pressure fluctuations. From these data, aquifer elasticity and compressibility characteristics were computed.

Upson, II, Joseph E.—After spending a year in the Netherlands as a Rockefeller Public Service Awardee studying the occurrence of saltwater in coastal aquifers, Upson returned in July 1959 to conduct a research project he had proposed a year earlier. This entailed investigating, over the 4-year project life, the relation of Pleistocene sea stages to historical positions of freshwater/saltwater interfaces in coastal aquifers as revealed in 12 major buried valleys of coastal streams along the New England shore. The work included selectively collecting data on depth to bedrock to determine buried-valley topography; collecting well logs to define the nature of the sediments in each valley; and mapping some of the geology to define late-glacial substages in New England.

As a followup to the year he spent in the Netherlands, Upson, in 1961, began preparing a report on his observations there. His report, prepared over a 3-year period, illustrated the role of geologic events in the occurrence of seawater, as observed in coastal aquifers of the Netherlands.

Payne, J. Norman.—With a Ph.D. in geology from the University of Chicago (1936) and experience in petroleum reservoir research and stratigraphy, Payne joined the Baton Rouge, La., GWB District in August 1960 as a geologist. He headed a research project on the Sparta Sand, one of the principal Gulf Coast aquifers, beginning in 1961 and continuing through this period of history. He applied oil company reservoir-delineation techniques to the vast body of raw data concerning this aquifer. Well logs, drill-stem tests, and core analyses, collected from oil companies, State agencies, and commercial firms, were processed and evaluated to produce isopach, facies, isolith, and isoporosity maps. These were then interpreted with respect to depositional environments and related to aquifer hydraulic characteristics.

Bredehoeft, John D.—Awarded the Ph.D. in geology by the University of Illinois in 1962, Bredehoeft joined the WRD research group headquartered at Arlington, Va., in October 1962 as a geologist. During the remainder of this period of WRD history, he worked on developing mathematical solutions to selected ground-water flow problems. He stressed the design of digital computer-analysis techniques and collaborated with Robert R. Bennett, Hilton H. Cooper, and Stavros Papadopulos.

Brown, Philip M.—Brown, in 1964, began a research project to investigate the distribution of permeability and its control of ground-water occurrence in the Atlantic Coastal Plain. In the remaining 3 years of this period of history, the work entailed analyzing voluminous subsurface data to delineate the structural framework that controlled the landward transgressions and seaward regressions of Cretaceous and Tertiary seas. This in turn led to definition of the systematic distribution of permeable deposits beneath the Coastal Plain, such deposits being literally the "plumbing system" which controls the movement and chemistry of the ground water.

In much of this work Brown was assisted by James A. Miller, Marjorie S. Reid, and Frederick M. Swain, geologists.

#### *Publications*

A steady stream of papers emerged from this new program of federally supported research reporting the significant accomplishments. The principal outlets favored by the researchers included Water-Supply Papers, Professional Papers, the USGS annual reports titled "Geological Survey Research 19__," and the American Geophysical Union technical journals titled "Water Resources Research," and the "Journal of Geophysical Research."

### Geochemical Processes in Ground Water

*By* William Back *and* John D. Hem

It was a most propitious time in the history of "chemical hydrogeology" for Luna B. Leopold to become Chief and to implement a formal Federal research program. Many of the required elements such as methodology, instrumentation, and rationale were in a place that permitted rapid development of an effective research program involving topics of geochemistry of ground water. As clearly documented in the earlier five volumes of this series, the WRD and its organizational predecessors have a long history of making contributions in understanding the geochemical character of ground water.

Among the early USGS activities in water chemistry was the development of analytical techniques for characterizing chemical attributes of water. One of the early uses of chemical analysis of water, in the late 1800's, was to correlate the chemical constituents with the perceived therapeutic value of water. An indication of the interest in this topic was the publication of USGS Bulletin 32, by A.C. Peale in 1886, a compilation of data on mineral springs of the United States. With increased use of steam engines, it became critical to supply the proper chemical type of water that would minimize the formation of boiler scale. For Western United States irrigation, the chemical character of water available in those regions became crucial in determining its compatibility with soils and agricultural crops. Specific treatment techniques also were developed for various industrial uses of water, and the type of treatment required for industrial and municipal supplies depended on the chemical type and variability with time in the composition of the natural water.

Historically, USGS scientists have pioneered research in the controlling factors and the characterization of dissolved solutes in natural waters. In the United States, extensive studies of river-water chemistry were conducted at the beginning of the 20th century by the Survey in cooperation with the Reclamation Service (WSP–236, Dole, 1909; Stabler, 1911). The first edition of "The data of geochemistry," by F.W. Clarke was published as Bulletin 330 in 1908 and was revised and enlarged through five editions by 1924. Some of the ways in which we mathematically and graphically interpret and depict water-quality relations were first developed by USGS scientists (Palmer, Bulletin 479, 1911; Rogers, Bulletin 653, 1917; Collins, WSP–496, 1923; Piper, WSP–889–B, 1944).

Scientists in the WRD were leaders in understanding problems associated with developing water supplies in coastal regions where ground water might be affected adversely by saltwater encroachment. Studies of this problem in the 1920's, 1930's, and 1940's brought together chemists, geologists, and engineers. Many concepts and principles of the physical controls on saltwater encroachment were developed by studies along the east coast of the United States, particularly in Connecticut, New Jersey, and Florida. Chemical aspects were investigated primarily in southern California during the 1940's and 1950's (Poland, Garrett, and Sinnott, 1959, WSP–1461). Another topic in ground-water geochemistry that received attention at an early time was the natural softening effect brought about by cation exchange at the surfaces of silicate minerals (B.C. Renick, WSP 520–D, 1925). One of the papers that was published in the first issue of the new research journal "Geochimica et Cosmochimica Acta" in 1950 was written by WRD chemist Margaret Foster. She explored geochemical factors in the origin of sodium bicarbonate-type ground water in the Atlantic Coastal Plain. A paper by Hem in Economic Geology (1950) summarized the state of knowledge in ground-water geochemistry and suggested some research topics for future work.

Although much research in ground-water geochemistry had been done prior to 1950, the results were mostly expressed in a rather qualitative fashion. The potential value of chemical thermodynamic concepts and techniques for more mathematically exact interpretations was not developed until the 1950's. Some interdisciplinary linkage between academic scientists and USGS geochemists began to occur after 1950, and the concepts and techniques that were developed as a result had a powerful impact on the WRD geochemical research program during the 1957–66 period. Thermodynamic equilibrium data and methodologies for their use that were published in books such as the second edition (1952) of "Oxidation potentials," by W.F. Latimer (University of California, Berkeley), and "Thermodynamics of dilute aqueous solutions," by the Belgian corrosion specialist M.J.N. Pourbaix (English translation published in 1949) provided a framework for the application of redox chemistry to ground-water systems. Hem and W.H. Cropper used the Nernst equation and pH-Eh diagrams and calculations to develop a theoretical framework that could be used in evaluating the geochemistry of iron in ground water in WSP 1459–A (1959).

Many important contributions were made by Robert M. Garrels, who was employed in the USGS uranium-exploration program in the Colorado Plateau region in the early 1950's. Garrels developed redox geochemical methods for explaining the processes of uranium and vanadium transport and deposition in many published papers (American Mineralogist, v. 38, p. 1251–66, 1953, and v. 40 p. 1004–1021, 1955). Garrels spent most of his professional career in professorships at Northwestern, Harvard, Hawaii, and South Florida Universities. He was deeply interested in the application of chemical thermodynamics to geochemistry of water and rocks. His widely used textbook, "Mineral Equilibria" that described this approach was published in 1960, and a second enlarged edition came out in 1965. Among Garrels' graduate students who were recruited by WRD during the 1957–66 period were Ivan K. Barnes and Bruce B. Hanshaw, who made many contributions to the Division's research program. (See author's note following this topic). Barnes' early interests included calcium carbonate equilibria, and redox chemistry of iron, as related to field studies of corrosion and encrustation in well screens and casing, the chemistry of iron-bearing acidic drainage associated with coal mining, and the occurrence of high ferrous iron concentrations in parts of the Atlantic Coastal Plain aquifer system. Publications that were produced included Barnes and Back's 1964 paper "Geochemistry of iron-rich water of southern Maryland" (PP 473–A); Barnes and Frank E. Clarke's "Chemical properties of ground water and their corrosion and encrustation effects on wells" (PP 498–D, 1969); and Barnes' "Field measurement of alkalinity and pH" (WSP 1535–H, 1964). It is of interest to note that the Barnes and Clarke paper contains a computer program developed by Frederick B. Sower (mathematician, Administrative Division) for chemical equilibrium calculations called "IONIC ACTIVITY." This program is the first version of what later evolved into the SOLMNEQ and WATEQ series of computer programs.

With improved measuring instruments that became available in the 1950's, better values for unstable properties of natural water such as pH and alkalinity could be obtained through measurement in the field at the sample-collection site. As noted by Barnes in

WSP 1535–H, accurate field measurements are necessary before meaningful calculations of equilibrium states can be made for most dissolution and precipitation reactions. The first publications of methods for making equilibrium calculations for natural waters were by Hem in WSP 1525–C, and by Back in WSP 1535–D, published in 1961. Results of research on the chemistries of iron and manganese in water by Hem and his project associates at WRD's Research Laboratory in Denver were described in WSP 1459, A–I, and in WSP 1667, A–D, issued between 1959 and 1965. Among topics considered were the preparation and use of pH-Eh diagrams, effects of organic and inorganic complexing agents, effects of plant metabolism, carbonate equilibria, and reaction kinetics as affected by solution properties and nature of solid phases present. Barnes and Back (1964, PP 473–A) demonstrated that Eh measurements helped interpret the chemistry of iron in ground water in Maryland.

Additional geochemical research related to other dissolved constituents of ground water was conducted at Menlo Park under the direction of John H. Feth and his project staff. The approaches used in Feth's studies were strongly field oriented, and a major product was a summarizing report "Sources of mineral constituents in water from granitic rocks, Sierra Nevada, California" (WSP 1535–I, 1964). In this work a considerable amount of data was obtained on the chemical composition of rain and snow water. Evolution of chemical characteristics of the ground water from ephemeral and permanent springs in granitic rock was shown to follow reaction pathways in which igneous rock minerals such as orthoclase, albite, and mica were altered to clay minerals and finally to gibbsite by the action of rainwater and snowmelt containing carbon dioxide, releasing solute cations. Stability diagrams showing equilibrium relationships in such systems that were included in WSP 1535–I were widely utilized by other geochemists. Garrels was an active advisor to this research project.

Wilfred L. Polzer conducted equilibrium solubility studies of kaolinite and with Hem published a free-energy value for this mineral in 1965, in the Journal of Geophysical Research (v. 70, p. 6233–6240).

The first edition of WSP 1473, "Study and interpretation of the chemical characteristics of natural water," was written by Hem during the mid-1950's, and was published in 1959. The book was intended to serve as a handbook for introducing aqueous geochemistry to geologists and hydrologists who had a limited background in chemistry. Because of the increasing public interest in water quality, the book was well received, and by 1966 plans for a second edition were being made.

There was a considerable emphasis in the first edition on the relation of general rock types and mineralogy of aquifers to the chemical character of the associated ground water. Another treatment of this topic was given in a 1963 interdivision publication by D.E. White, J.D. Hem, and G.A. Waring, PP 440–F (1963), one of the chapters in the 6th edition of "Data of Geochemistry." The second edition of WSP 1473 (finally published in 1970) included a much more extensive treatment of chemical thermodynamics and mathematical calculation methods for evaluating solubilities of gases and minerals, stabilities of complex ions, reaction kinetics, and related topics. The lack of emphasis on these topics in the first edition reflects the fact that very little research on the application of chemical thermodynamics to natural water had been published prior to 1959. A great amount of progress in that sector of aqueous geochemistry occurred during 1957–66. The expanded discussion in the 2d edition was an indication of the general change in emphasis in ground-water geochemistry toward a more quantitative application of chemical thermodynamics that occurred in that period.

Other ground-water geochemical research during this period included studies of radioactive solute in the ground water of the United States summarized by Robert C. Scott and Franklin B. Barker in PP 426 (1962). Pioneering research relating to a specific organic pollutant, alkylbenzene sulfonate (ABS) in ground water was done by Cooper H. Wayman, John B. Robertson, and Harry G. Page beginning in the early 1960's (PP 450–C, D, and E, 1962–63). ABS was a synthetic detergent that was resistant to bacterial attack. A less stable form of this material was developed by detergent manufacturers, and this particular form of ground-water pollution eventually declined in importance. Methods for isolation and analysis of organic solutes using ion chromatography were developed by William L. Lamar and Donald F. Goerlitz in Menlo Park (WSP 1817–A, 1966). Research in organic geochemistry also was conducted in Denver beginning in the mid-1960's by Ronald L. Malcolm, Jerry A. Leenheer, and their associates, with more emphasis on naturally occurring organics such as humic and fulvic acids.

A benchmark paper by Francis A. Kohout was published in 1960 on the cyclic flow of saltwater in coastal aquifers. Fred Berry (University of California, Berkeley) and Hanshaw stimulated interest and investigations on clays acting as geologic membranes and resulting development of anomalous head values and the origin of brines. Other work on the origin of brines was being carried out by Blair F. Jones, whose significant PP 502–A was published in 1965. Other non-Survey publications that appeared during the 1957–66 period included landmark books and papers on mineral equilibria, redox potential, and isotopes. Therefore, with the recognition of the importance of ground-water geochemistry, the great amount of chemical data available, the principles and concepts of chemical thermodynamics, and development of mass spectroscopy, all combined to provide a most opportune time for vigorous research activities during Leopold's tenure.

Up until Leopold's time, most of the significant contributions to chemical studies had been made by those trained in the disciplines of chemistry and engineering with few notable exceptions, such as Piper and Poland. In the early phase of the Research Program, Robert R. Bennett provided the stimulation and guidance to demonstrate that the study of ground-water chemistry need not be the exclusive responsibility of chemists, but that ground-water geologists could make contributions by relating chemical data to ground water in much the same manner as other geologic and hydrogeologic data. The concept of hydrochemical facies was developed by Back (1960, 21st Int. Geol. Congress) to emphasize that chemical composition of water was not an unrelated entity but an integral part of hydrogeology. This chemical work, combined with the experience gained from study of the hydrogeology and flow systems of regional aquifers, was to lead nearly two decades later to the formal program of the Regional Aquifer Systems Analysis (RASA) studies.

This regional approach was well within the established philosophy of the USGS with its great strength in having the institutional responsibility and privilege of comparing and contrasting geologic features and processes in various regions of the United States. The philosophy underlying the regional interpretation of geology was no less effective for physical and chemical hydrogeology. It has been well documented that many of the basic principles of physical hydrogeology were recognized through studies of the regional aquifer systems of the United States. We can see similar contributions of regional analysis in the early development of chemical hydrogeology. It was a description of the distribution of the chemical character of water in aquifers in various stratigraphic units, along with identification of controlling chemical reactions that permitted the talents of geologists and hydrogeologists to bear on scientific topics that had originally been almost entirely within the purview of chemists. The combination of scientific talents of chemists, geologists, and engineers within one organization makes the USGS unique among the various institutions within the United States and permits fundamental contributions in developing the interdisciplinary sciences of ground-water geochemistry.

Many of the early regional and areal studies of ground-water resources contain chapters on the quality of water and its relation to the lithology of the aquifers in ground-water flow path. For example, Jones clearly demonstrated (WSP 1651, Jordan and others, 1964) that the salinity of the Saline River, Kansas, was the result of highly mineralized ground water discharging into the river. These studies gradually evolved into regional studies wherein geochemistry was the dominant theme and demonstrated that the chemical character of ground water provided an additional dimension of understanding the physical functioning of the ground-water system. The evaluation for the contributions of chemistry that began during the Leopold years is continuing at the present time through the chemical modeling that identifies reactions that produce the observed chemical character of water, determines extent and rates of reactions and physical effects that such reactions have on behavior of aquifer material.

Because much of the principles of the physics of ground-water flow were developed for porous media, it was some period of time before the application to carbonate systems was understood. Problems of recharge, lateral flow, and discharge were complicated by flow through fractures and solution channels. Early contributions from WRD scientists considered the relationship of potentiometric head to direction of flow in carbonate aquifers (Stringfield, WSP 773–C, 1936, Floridan aquifer; Sayre and Bennett, AGU Transactions, Pt. 1, p. 19-27, 1942, Edwards Limestone Aquifer, Texas). Survey investigations of carbonate aquifers have been quite extensive since these early beginnings. Because of the diversity of textural and lithologic characteristics of carbonate aquifers in the United States, it has been possible to compare and contrast not only the physical characteristics, but also the role of chemical reactions in controlling the movement of ground water.

The often monomineralogic lithology of carbonate aquifers made them ideal field laboratories for the early regional geochemical studies. WRD scientists were the first to use principles of chemical thermodynamics to determine carbonate mineral saturation in ground water (Back, WSP 1535, 1961). Among the early modeling studies to determine chemical reactions was that based on the data from the Floridan and Yucatan aquifers (Back and Hanshaw, 1970), which later extended to more sophisticated modeling in the Madison Limestone around the Black Hills. Accompanying the field investigations in carbonate aquifers, WRD scientists have been leaders in contributing theoretical and laboratory studies of the kinetics and thermodynamics of carbonate rock-water systems. Laboratory studies were undertaken to determine the solubility and rates of dissolution and precipitation of carbonate minerals as a basis for evaluation and verification of the application of theoretical models to field sites. For example, WRD scientists were the first to quantify predictions of mineral dissolution and precipitation along mixing boundaries between carbonate waters of differing salinities. An important study today is focusing on predicting changes in porosity and ground-water flow in freshwater-saltwater mixing zones through coupled hydrochemical simulations of seawater encroachment.

During the past century, hydrologists have sought chemical tools that would enable them to trace water movement and to determine the age of water masses. Examples of applications of stable and radioactive isotope data to hydrologic processes include determination of ground-water flow rates and ages of ground water, quantification of recharge processes to the unsaturated zone and ground-water systems, identification of leakage between aquifers, determination of ground-water discharge into lakes, characterization of flow paths in geothermal reservoirs, and measurement of temperatures in geothermal systems. The most significant advances have been made using the radioactive isotopes tritium and carbon-14 and the stable isotope ratios of oxygen, hydrogen, and carbon. By the 1950's research in isotope hydrology was being done by WRD (see "Radiohydrology" and "Tracers in Hydrology"). Recognizing that vast amounts of tritium were produced in atmospheric atomic weapons testing, early WRD scientists Leland L. Thatcher, Gordon L. Stewart, and Charles W. Carlston established greatly needed precipitation and surface-water networks, set up a major low-level tritium laboratory, and began field investigations of water movement. Hanshaw, Back, and Meyer Rubin (Geologic Division) demonstrated in Florida (1965) the use of carbon-14 for ground-water age dating. During the following two decades, this dating technique has been refined by Survey scientists through the use of geochemical models. The benefit to society of the development of isotope hydrology is evident by the daily use of this technique by the USGS and university hydrologists to provide an understanding of ground-water problems nationwide.

Several of the chemical studies that began in the Research Program were seminal investigations for resolution of environmental problems that were to develop much later. For instance, the techniques and principles for study of acid rain had its beginning in the Research Program, with studies on the chemical composition of snow and rain in the northern Sierra Nevada and other areas (Feth, Rogers, and Roberson, WSP 1535–J, 1964); on the dissolution of granitic rocks in the Sierra Nevada (Feth, Roberson, and Polzer, WSP 1535–I, 1964); and the studies showing annual variations in the chemical composition of rainfall in North Carolina and Virginia (Gambell and Fisher, WSP 1535–K, 1966). Other studies demonstrated the role of rainwater as a chemical agent for geologic processes (Dorothy Carroll, WSP 1535–G and K, 1962).

Problems of ground-water contamination were foreseen very early by scientists in the Water Resources Division, who during Leopold's time were developing techniques for identification and measurement of chlorinated organic pesticides and the use of gas chromatography. Another concern was the concentration of metals and other trace elements in ground water. The analytical techniques and methods of interpretation of these elements also had their beginning in the research program with a series of Water-Supply Papers (1459, 1667, 1827) on chemistry of iron, manganese, and aluminum. Scientific investigation of management of radioactive wastes and the occurrences of radon gases, which are currently national concerns, began with studies of the origin, analytical techniques, and reactions involving radioactivity (Barker and Robinson, WSP 1696–A, 1963) on the determination of beta activity in water (Barker and others, WSP 1696–C, 1965) on determination of uranium in natural waters (Johnson, WSP 1696–G, 1971) on determination of radium 268 in natural waters, and similar studies.

The research scientists of WRD also were among the early developers of the use of isotopes in ground-water systems, particularly tritium and carbon-14 for tracing water, identifying the source of water, and determining the hydrologic parameters of the aquifers. This work has continued and expanded to the use of other isotopes to decipher chemical reactions and flow systems of aquifers.

### *Author's Note on Geochemical Research*

*By* William Back

I think it is worth recording how the principles of chemical thermodynamics became incorporated into the geochemical research project of the Water Resources Division. Originally there were three independent sources that later merged most cohesively. While serving as Vic Stringfield's administrative assistant beginning August 1953, I was selected to be the WRD's Ford Foundation Fellow for 1954-55 to study the conservation of renewable natural resources at the Littauer Center of Public Administration (now the John F. Kennedy School of Government) at Harvard University. This was Bob Garrels' first year at Harvard having just resigned from the USGS. After completing the Master's degree in public administration in 1954, I requested permission from the WRD to remain at Harvard for 1 year to study with Garrels. This was before the Government Employees Training Act was passed, and I was required to work half-time for the GWB while taking courses from Garrels and John Miller, who was a close associate of Luna Leopold. After completing the year with Garrels and the others, I was assigned to the Research Program then housed in Arlington Towers, where I continued working on the Atlantic Coastal Plain project that led to the publication in 1966 of PP 498–B on hydrochemical facies. One of the term papers for Garrels' class was a paper using the chemical thermodynamic data to determine the degree of saturation of carbonate minerals in ground water. Although this term paper was completed in the spring of 1956, for various reasons it was not published until 1961. The graduate-level course that Garrels taught during my year with him was to develop and apply the concept of Eh-pH to natural environments. He had done earlier work on this topic in connection with the uranium exploration of the Colorado Plateau. In this work he relied quite heavily on Pourbaix's work, a metallurgist from Belgium. Ivan Barnes was in the same class. Garrels' personal interest was in the chemistry of iron, and, by this time John Hem had already started his research on this topic, of which Garrels was unaware until I told him of Hem's work. So Hem and Garrels had both started independently to apply the Nernst equation to the concept of Eh-pH to natural-water systems. During the preparation of this present article, John wrote in a letter dated November 28, 1990,

> At the time I was launching the Chemistry of Hydrosolic Metals research project I had never heard of Bob Garrels, or his work in the Geologic Division, and he had left Denver some years before. I did however, take on as a temporary appointee, Bill Cropper, a freshly minted Ph.D. chemist from University of California, Berkeley, who had studied under Latimer and was well versed in redox chemistry. Frank Barker had also been exposed to some of these concepts that seemed to be especially relevant to the chemistry of iron in ground water. We got copies of the books by Latimer and Pourbaix and proceeded to draw the Eh-pH diagram based on calculations of Eh from the Nernst equation, measured Eh's in the lab and field, and wrote what later became WSP 1459–A on redox chemistry of iron.
>
> As I recall, Luna paid us a visit while we were working on the above mentioned manuscript and our presentation of these concepts did not get an enthusiastic response. He could not see any relevance to what we were doing, but was broad minded enough to send a copy of the manuscript to Bob Garrels, asking his advice. I learned later that Bob gave us high marks, and I had no trouble with Luna after that. This also opened my direct communication with Garrels which was very useful later.

The above agrees with my recollection, but there is one additional contact of which John Hem is unaware until now. One of Luna's leadership techniques was to frequently test his staff, particularly the researchers, by asking very pointed questions and expecting explicit answers. On one occasion, I was in Luna's office with Ray Nace, who was Associate Chief at that time. I do not remember the purpose of the visit, but the question pertinent to this narrative was from Luna, "Bill, what is John Hem doing?" I am not sure that Luna really cared what John Hem was doing, but he wanted to be most certain that I knew what John Hem was doing because our projects had certain mutuality about them. I explained briefly John's work on iron and that he was starting to work on aluminum also. Ray Nace interrupted rather belligerently to comment, "I don't see the purpose of this, does he intend to go through the entire periodic table?" I responded by explaining the need for understanding the mineralogic controls on the chemical constituents in water, and that with proper understanding we could delineate areas of potential iron problems and this would be a valuable approach to planning. Apparently, planning was the magic work and Ray Nace picked up on it and asked several more questions. Apparently my responses alleviated some of his concerns and he became almost friendly during the rest of the discussion. This may have contributed to Luna's later appreciation of the geochemical research; also, I am sure that Luna's close colleague, John Miller, played a bridging role between Garrels, Luna, and John Hem.

During the early part of Luna's administration we were urged to recruit outstanding students who were completing their Ph.D.'s at major universities. At the GSA meeting in St. Louis, 1958, I had a long discussion with Ivan Barnes about the desirability of coming to work with WRD, which he later did. One of our first projects was to extend John Hem's laboratory work on chemistry of iron into the field by making pH and Eh measurements in the ground water of the coastal-plain sediments near Annapolis. Ivan continued research on this topic for several years and was joined by Frank E. Clarke, chemical engineer, who had recently transferred from the U.S. Navy to the Survey. He was an expert on corrosion of metals associated with Navy equipment and, therefore, was also quite familiar with the work of Pourbaix. Clarke and Barnes carried out several research investigations on the corrosion of metal in wells in various parts of the world including Pakistan, Nigeria, and Egypt. Blair Jones also joined Frank Clarke to study the mineralogical encrustation associated with corrosion of wells in Algeria and Tunisia (WSP 1757–M, 1972).

At the annual meeting of the Geological Society of America in Denver, 1960, I mentioned to Blair Hostettler our desire to hire additional low-temperature geochemists. Blair had been with Ivan and me at Harvard and was then with the Geologic Division in Menlo Park, where he and John Hem had close association. Blair told me that Bruce Hanshaw was finishing his Ph.D. at Harvard and that I should convince him to come work with us. This I did and Bruce continued his work on the osmotic properties of clays and began work on the use of isotopes in ground-water studies, and we started our long association of research on the geochemistry of the carbonate aquifers in Florida and other parts of the United States and Mexico.

Bill Back

## Analog Modeling of Hydrologic Systems

### *Research and Development*

*By* Mary Lou Brown *and* reviewed *by* Herbert E. Skibitzke

By 1957, the feasibility of using digital methods at the existing state of the art had been ruled out, the electrical analog concept had been accepted, the mathematical theory had been formulated, and early models were under construction.

In 1948, Herbert E. Skibitzke, a mathematician newly employed by the WRD, was assigned to assist Theis in a cooperative study with the AEC relating to the disposal of nuclear wastes in the vicinity of ground-water aquifers and major surface-water sources. Theis urged Skibitzke to find techniques for computing the effects of the interactions of wells and streams at aquifer magnitude.

In 1953, Bennett and Skibitzke, both proteges of Theis, began to plan the project for developing the analog computer. The two spent many hours discussing the mathematical concepts of the analog model as well as the physical aspects of design and construction. When Skibitzke produced a series of drawdown curves that demonstrated the similar flow characteristics of heat, electrical current, and water, A. Nelson Sayre, Chief of the GWB, evinced interest in the project by allocating $300, the first funding toward the development of the analog computer. In that year, Skibitzke moved from the offices of the Phoenix GWB Subdistrict to a separate office that could meet AEC security requirements. The new unit became known as the Phoenix Research Office. According to Skibitzke, it was Bennett's quiet, but brilliant, leadership of the research effort and his insight into the problems involved that paved the way for the development of the analog model, and later, the digital methods for solving the finite-difference equations. Bennett was the effective and articulate scientist-administrator who could explain the complex scientific processes to those who allocated funding, and he was exceptionally adept at utilizing the talents of emerging scientists who could contribute to the research efforts. His diplomacy tended to moderate conflicts between the scientists in the field and administrators at headquarters.

After considerable experimentation, Skibitzke formulated a finite-difference approach and introduced variations in time. In his approach, the area of study is broken into small cells, each representing a single set of parameters. Each cell is calculated separately, and each succeeding calculation is based on the results of the preceding calculation with a variation in time. Skibitzke's method was inspired to a degree by earlier work of R.V. Southwell, in England. Southwell, however, did not consider variations in time.

For a while, it was difficult to convince the mathematicians that the finite-difference approach was feasible. When verbal descriptions failed to satisfy Skibitzke's detractors, he successfully demonstrated the finite-element technique, that is, the time-dependency of the relationship of one element and all its parameters to another, by constructing models with Tinker Toys. (The author was employed as a "temporary" clerical assistant to Skibitzke just in time to try to explain to irate supervisors that the purchase of Tinker Toys was vital to the scientific effort!)

The need for a method to compute the thousands of simultaneous equations for water-resources studies was known, but research scientists were faced with the problem of finding that method. The digital computers at the time could solve no more than a hundred simultaneous equations, and their solutions were unstable and unreliable. Large, multistoried buildings with rigorously controlled air-conditioning were required to house the digital computers of that time. Although skeptical of the capabilities of digital methods of the era to handle the complex ground-water equations, Skibitzke and Albert E. Robinson, electronic engineer, experimented with them briefly. However, they soon turned their efforts to analog methods. Applying the analogy of the storage and flow of electrical current

(Maxwell's equation) to the storage and flow of ground water (Theis' nonequilibrium equation) they constructed a computer capable of solving thousands of simultaneous equations with accuracy and stability. Robinson was the ideal research technician, ever enthusiastic and tireless in the trial-and-error process.

Once the finite-difference concept was accepted, other analogous relationships were added: function generators furnished difficult bar graphs; diodes represented streamflow, evapotranspiration, and other discontinuous parameters; capacitors represented ground-water storage; and resistors simulated ground-water flow. When electrical current was applied to a gridwork of electrical components superimposed on a map of the area under study, the output was fed to an oscilloscope. The resulting oscillograph produced essentially the same results as the mathematical computations of the equations.

In addition to his mentors, Theis and Bennett, Skibitzke attributes much of the success of the analog model development to the theoretical input of Boris J. Bermes, mathematician; the electrical knowledge and electronic experimentation of Albert E. Robinson; the mechanical talents of Howard T. Chapman; the mathematical calculations and drafting capabilities of Geraldine M. Robinson, hydrologist.

Once the theories were developed and the equations written, the next stage involved practical application, that is, the construction of models for specific areas. The Phoenix Research Office became a beehive of activity. Because of budgetary constraints, a relatively small amount of metering and monitoring equipment was purchased. In addition, literally tons of military surplus electronic components were acquired through a process known as Transfer Without Exchange of Funds (TWOF). The author, by then an administrative assistant, became the liaison between the Geological Survey and the General Services Administration, as well as the military services, to obtain the materials needed for the project, while Geneva M. Magness, engineering assistant, sorted and coded thousands of resistors, capacitors, and diodes. As in the case of the Remote Sensing Unit and the ground-based radar project, the utilization of sophisticated surplus electronic equipment was vital to the development of the analog computer. The agency may be justifiably proud of its record in adapting and using sophisticated surplus military equipment for scientific purposes. The equipment, already paid for by tax dollars, would otherwise have been destroyed; and the scientific purposes for which it was used could not have been pursued for lack of funding.

Papers that Skibitzke presented at the closing session of the International Geophysical Year, in Helsinki, Finland (1959), discussed the application of computer techniques to solving nonequilibrium equations. Those discussions triggered considerable interest in applying analog methods to actual problems, such as those in or near Wichita, Kans.; Houston, Tex.; and Miami, Fla. For the first time, vast amounts of geologic and hydrologic information could be manipulated in a computer to produce a true picture of the ground-water basin and analyze its potential response under actual and hypothetical scenarios.

It was recognized that spatial variables were important to ground-water analysis, but little spatial data were available because of the difficulty of collection. By 1958, all the known methods of measuring spatial data in the laboratory had been considered, and it was decided that the quantity of data needed could probably be obtained only through aerial photography and the newly developed infared imagery. Thus, as an adjunct to the analog computer development, the WRD Remote Sensing Project was established in 1959. (See "Hydrologic Remote Sensing.")

Measurement of the spatial characteristics of rainfall and other hydrologic parameters by ground-based radar for computer input was another spin-off from the analog model development. Several military surplus M–33 radar vans were used to track the movement and precipitation patterns of localized thunderstorms at various locations in the Southwestern desert. Although the ground-radar method of tracking provided valuable data that were not available elsewhere, funds were not sufficient to support the effort.

Until 1961, computer models were built in the basement of the old Ellis Building in downtown Phoenix, where a workbench and a few square feet of space were shared with the janitorial staff and supply storage for all the occupants of the building, as well as with the Skibitzke's radiotracer experiments and a photo laboratory. The models varied in size according to the size of the area of interest; most were large enough to present a problem of construction within the available space and of removal when completed.

In 1961, the Federal Building in Phoenix was completed, providing new and larger quarters for the Phoenix Research Office. By that time, the unit was involved in several major research efforts: specifically, the analog computer, radiohydrology and remote sensing. Increased calls for analog model studies required additional staff and space. William Bruns, an electronic technician, became a sustaining figure in the analog computer operations, assisted by Chester J. Kordylas, Michael L. Field, and Garth E. Ghering, Sr. "The Analog Model Unit" was moved to rented space at Roosevelt and Second Streets in Phoenix in 1962. Models were built to simulate ground-water basins and aquifers in many areas of the United States, at the request of State cooperators; in Central Africa, for UNESCO; and in Pakistan, for the office of President John F. Kennedy. In the early 1960's, the developmental phase of the analog computer for ground-water analysis was considered closed, and the Analog Model Unit was operational. By 1964, the research staff in Phoenix had grown to more than 30 employees. At Skibitzke's request, Eugene P. Patten, geologist, returned from an assignment in Pakistan to assume responsibility for the computer laboratory, and Skibitzke focused his attention on the development of remote sensing techniques to provide synoptic data for computer input.

In retrospect, it was the analog computer development that highlighted the need for vast amounts of accurate historical records and synoptical data on water resources and provided the impetus for modernization of techniques for data collection, storage and retrieval. In the 1990's, the analog model is still used in some Third World countries where labor is inexpensive but funds for equipment are not available.

The concept of hydrologic analysis by analog computing techniques was disseminated widely as Skibitzke was called upon for frequent attendance at scientific meetings within the United States and overseas, to lecture at major universities, to provide on-the-job training for hydrologists from developing nations, and to participate in founding the first degree program in hydrology in the United States at the University of Arizona, in Tucson. (See Part VI, "Establishing Degree Programs in Hydrology at Universities.")

### *Analog Model Unit*

*By* Eugene P. Patten, Jr.

The application of electric analog techniques to the study and solution of ground-water problems was almost wholly a product of the 1960's. The first operational studies started in the early 1960's, and diminished with the increasingly dominant role of digital computer techniques that emerged in the mid-1970's.

After the initial phase of development of techniques by Skibitzke and Robinson in 1954, a number of demonstration (unpublished report) projects were started, among them Bodie Island, N.C., with Joel O. Kimrey, and San Simon Valley, Ariz., with Natalie D. White, William F. Hardt and Edward S. Davidson. By 1959, sufficient interest in modeling had developed in the Division to warrant a full-time contact and coordinator for the construction and analysis of models. With additional funding provided by the GWB, Boris J. Bermes was transferred to the Phoenix Research Section in 1959 to take charge of the modeling activity.

Among Bermes' highest priorities was the thorough evaluation of the design characteristics and scaling considerations that would promote optimum model design, and with strong support from the GWB, the Phoenix Research Section obtained funds to purchase commercial electronic equipment to replace the slow and obsolete military equipment that had been used. The results of these labors were detailed by Bermes in a 1960 report "An electric analog method for use in quantitative hydrologic studies." This report, like Skibitzke's earlier report, was never published, but it did receive wide distribution among those interested in developing analog capabilities. A 1963 report in the Journal of the Hydraulics Division of the ASCE by non-Survey authors cited Bermes and gave a condensed but complete description of his scaling factors and equipment utilization. (Also, in 1973, when this writer was in Spain helping establish a modeling capability in the Spanish Geological Survey, he found a copy of the report in Spanish, typeset and printed in Chile!)

In 1960, the Analog Model Unit was established as an operational service unit of the GWB. It was charged with modeling all operational studies submitted to it by District and project offices throughout the Nation. In addition, the Unit was responsible for concurrent research into problems of analog application and for anticipating the types of problems for which solutions would be required in the future.

Two studies were initiated in 1960: one a ground-water/surface-water evaluation in Beaver Valley, Colo., and the other a study of pumping-induced water-level changes in Estancia Valley, N. Mex. In 1961, the first of a continuing series of models was developed in support of the Arkansas District's evaluation (for the Corps of Engineers) of the effects of locks and dams on land adjacent to the Arkansas River from Little Rock to Tulsa. (See Part X, "Arkansas.")

Bermes transferred from the model unit to St. Augustine, Fla., in 1961, and day-to-day operations were left in the capable hands of William F. Bruns, an electronic technician who had previously been in charge of constructing and operating the models. Subsequently, Eugene P. Patten was transferred from an assignment in West Pakistan to the Phoenix Research Section in July 1962, and given responsibility for the continuing operation and future development of the Analog Model Unit. In addition to Patten and Bruns, the Model Unit personnel included Michael L. Field, hydrologic technician, and Thomas W. Anderson, a part-time aid. Patten's first assignment at the Model Unit was to assist Skibitzke and Geraldine Robinson in performing a model analysis of an area of about 29,000 square miles in West Pakistan.

Skibitzke was one of three WRD members on the White House-Department of Interior [sic] Panel on Waterlogging and Salinity in Pakistan and was in heated disagreement with certain other panel members concerning the feasibility of large-scale ground-water development in the Indus Basin. The results of the model studies designed by Skibitzke were published in the Panel's "Report on land and water development in the Indus Plain," and proved to be a powerful argument in support of the feasibility of developing ground water in the area. (The Panel chair was Roger Revelle, and the two other WRD members were Walter B. Langbein and Thomas Maddock, Jr.). The highly favorable Department response to the WRD's contributions to that report may have, in turn, prompted a new $40,000 line item in the FY 1964 Phoenix Research budget for the Analog Model Unit.

Other models that were operational in 1962 included the Wichita, Kans., area (Equus Beds), John Winslow, project chief, and the Houston, Tex., area, Leonard A. Wood, project chief, with Robert K. Gabrysch. To a considerable extent the evolution of the Houston study set the tone for the conduct and execution of all subsequent modeling activities. It quickly became evident that a considerable amount of give and take would be necessary between the project chief, with knowledge of the hydrologic system, and the Model Unit personnel with expertise in simulation methods. The ultimate goal of this dialogue would be the design of an experimental framework that would lead to the satisfaction of an explicitly stated set of objectives. Often, the experimental design would be modified as new capabilities were developed, or as insight into functioning of the ground-water system required modification of the original conceptual model of the hydrologic system.

By 1964, Stanley M. Longwill had transferred to the Unit from Harrisburg, Pa., bringing with him a keen interest in electronics and a strong background in quantitative hydrology. At that time five model studies had been completed and nine were underway. Among the major new active studies were the Big Blue River Basin, Nebr., Philip A. Emery, Project Chief; Miami River Valley, Ohio, Andrew M. Spieker, Project Chief; the Arkansas River project, Colo., John E. Moore and Clifford T. Jenkins, Project Chiefs; and the Lower Colorado River, Charles C. McDonald, Project Chief. In 1965, an additional 12 projects were started, including two demonstration projects funded by the GWB (Long Island, N.Y., and the Texas-Louisiana Gulf), and one major request by the Chief Hydrologist.

In occasional conversations with Bennett, the Chief Hydrologist would question Bennett on "why can't you model streamflow in the same manner as ground-water flow?" and although Bennett's answer isn't on record, it probably was something like "surface water is measured in feet per second, and ground water in feet per year ...." Whatever Bennett's reply, it was clear that Leopold wanted some demonstration of an integrated surface-water/ground-water simulation capability, and wanted it quickly—as it turned out, within a month! Bennett quickly selected the Little River Basin in North Carolina for the study and flew over it to gain some quick insight into its hydrologic character. His notes were written directly on topographic maps of the area. He then went to Phoenix for discussions with Skibitzke and Patten. It was decided that the objective of the simulation would be to demonstrate a computing system that could (potentially) predict the effects of changes in the drainage basins—such as deforestation or urbanization—on the flow characteristics at the downstream gaging station.

The model developed from that concept was organized so that the rainfall-runoff surface-water system computed storm runoff and recharge to the ground-water system, and the ground-water system computed baseflow. The two components were then electronically added at the gaging station to yield a hydrograph of flow in relation to time. By changing the value of components of the system representing variables such as roughness or mean slope of a subbasin, the effects of activities such as deforestation could be simulated.

By working 10 people two shifts a day, the model was designed, constructed, and tested in 3 weeks and was then shipped by air (1,500 pounds) for display in the Chief Hydrologist's conference room. The display was very well received and was seen (or tolerated) by most WRD personnel in the area. The Chief Hydrologist was quite enthusiastic about the demonstration and indicated that he wanted the development of the system continued, but with real, not hypothetical, data.

By about the beginning of 1966, a suitable candidate drainage basin was selected in the North Santiam Basin of Washington, and Charles H. Swift was designated as District liaison to the Model Unit for the purpose of compiling the necessary data. It was also at this time that the Commissioner of the U.S. Section of the International Boundary and Water Commission (IBWC) personally contacted the Chief Hydrologist to request that the Survey develop a model analysis of the Yuma, Ariz., ground-water system to support U.S. positions in negotiations with Mexico. Two models had been constructed earlier (1965) for the Lower Colorado River project, and that experience coupled with the working relationships developed with the project principals—Charles C. McDonald, Omar J. Loeltz, and Franklin H. Olmsted—allowed the new model to begin almost immediately. Ultimately this effort became the largest modeling effort the Unit would undertake and would entail numerous meetings with Mexican authorities, high-level BOR personnel, and the IBWC's technical consultants, C.E. Jacob and John W. Harshbarger.

The Model Unit at this time was approaching its peak as both a service organization and a research facility. Of the 24 projects that had been started by this time, 13 were active, requiring a full-time staff of 7 and 10 to 15 part-time student aids (mostly from Arizona State University). Full-timers at the Model Unit not mentioned previously were Joseph W. Reid, Chester J. Kordylas, and Garth E. Ghering, Jr., electronics technicians, and Delores May Meyer (Wachtell), secretary. Of the many part-time aides who worked at the Model Unit, five became hydrologists and established careers with the WRD: Joseph W. Reid, William Meyer, Thomas W. Anderson, Stanley Leake, and Robert L. Blazs.

In 1966, total funding for Model Unit activities was about $160,000 derived from repay from the Districts for which studies were conducted, and from technical service funds and Federal research funds.

## Surface-Water Research

*By* Harry H. Barnes *and* reviewed *by* Robert A. Baltzer, Rolland W. Carter, Ernest D. Cobb, George W. Edelen, Frederick A. Kilpatrick, Nicholas C. Matalas, Henry C. Riggs, Vernon R. Schneider, *and* Donald M. Thomas

Research during the 1957–66 period was a subject of prime importance to the Division, and the results of that effort placed the USGS in a leadership position in the field of hydrology. However, research had been important to hydraulic and hydrologic activities of the SWB since systematic stream gaging began in 1888. Research efforts during the first half century were problem-oriented and ad hoc in nature. After World War II, research began to gain acceptance as a specific program element in the planning and budgeting process, and research results of the early 1950's set the stage for a formal program of SWB research supported by Federal funding during this period, 1957 to 1966. In addition to the federally supported work, a large program of surface-water research continued during 1957–66 with funding by other ongoing program elements.

Fiscal year 1957 marked the beginning of a formal SWB research program, a program that had two objectives: (1) to provide new and improved techniques, methods, and instruments in support of the data collection and analysis activities; and (2) to advance knowledge in surface-water hydraulics and hydrology. As work progressed on these two objectives, the SWB Research Section began to provide technical assistance to field personnel who had projects that were of an exploratory nature.

The federally funded research program in FY 1957 consisted of 19 projects which were underway or planned for a July 1956 start and which were funded from a budget of $280,000. It included projects at five universities: four at Georgia Tech and one each at Colorado State University, Harvard University, and the Universities of Iowa and Michigan. Each project was led by a WRD professional enrolled as a graduate student and working with a faculty advisor recognized as an expert in his specialty. In addition, six research projects were conducted in the Research Section at headquarters, four in the Instrumentation Unit at Columbus, Ohio, and one in the Champaign, Ill., District. Of the total of 19 projects, 8 dealt with the hydraulics of open-channel flows, 4 with hydrology, 5 with instruments, and 2 with computer applications.

Research at Georgia Tech begun in 1951 continued to flourish. The early work on flow through contractions by Professor Carl E. Kindsvater, Rolland W. Carter, and Hubert J. Tracy was recognized nationally by transportation engineers and soon became the basis for hydraulic analysis and design of bridge openings. The work of Kindsvater and Carter on sharp-crested weirs (ASCE Trans., 1955) earned them appointments as United States representatives to technical committees of the International Standards Organization (ISO), and the results of their research were quickly adopted as standards for flow measurements. Results of Tracy's studies of broad-crested weirs (Circ. 397, 1957) were incorporated into design standards of the COE and the SCS as well as becoming flow-measurement standards of the ISO and World Meteorological Organization (WMO). Similarly, Carter's laboratory investigations of flow through culverts (Circ. 376, 1957) became recognized as the most comprehensive work available on the subject and was utilized internationally for culvert design and for flow measurement. Carter's results were of special importance because they enabled Branch personnel to compute peak discharges at culverts by indirect methods, thereby allowing development of programs to evaluate the flood frequency characteristics of small streams—programs which had previously been limited by their dependence on direct-flow measurements or unverified indirect methods.

At the Georgia Tech Unit, now headed by Tracy with consulting advice from Kindsvater, a new project on mechanics of open-channel flow had the objective of developing a comprehensive flow formula. Such a formula was clearly needed. Despite considerable advances in knowledge of fluid mechanics and in laboratory experimentation, no comprehensive studies had been attempted since 1890. The early formulas of Manning and Kutter continued to be used despite their limitations. The Research Unit proposed to define a basic discharge equation based upon boundary geometry, fluid properties, and other measurable flow variables using data obtained in the laboratory and the field. Tracy was assisted at various times by Frederick H. Ruggles, P. Hadley Carrigan, Carl Lester, William W. Emmett, Russell W. Cruff, and Paul G. Mayer. Interim findings were reported by Tracy and Lester in WSP 1592–A (1961) and by Cruff in WSP 1592–B (1965). The project continued beyond the end of the 1957–66 period.

Also at Georgia Tech, Jacob Davidian assisted by Carrigan and John Shen studied flow through multiple-opening constrictions. Results of this 3-year project were published in WSP 1369–D (1962) and provided discharge coefficients for a wide range of abutment geometries, roughness conditions, and contraction ratios. The findings greatly improved accuracy of the computations of peak discharges and of backwater.

Another project of the Georgia Tech Unit was a field investigation of the relation between channel geometry and frequency of floods for streams in the Piedmont Province. Harry H. Barnes (flood specialist for the Southeastern States) and Frederick A. Kilpatrick reported results in WSP 422–E (1964).

Virtually all of the WRD personnel assigned to the Georgia Tech Unit during 1957 to 1966 earned advanced degrees.

At Colorado State University a study of the hydraulics of alluvial channels was jointly undertaken by the SWB and QWB. Daryl B. Simons and Everett V. Richardson directed the laboratory studies, which utilized Branch personnel and university faculty and graduate students financed by WRD. Laboratory studies focused on the relationship of sand-bed roughness to Reynolds number and grain size in a movable bed under equilibrium conditions. (See "Geomorphic and Sediment Processes.")

WRD supported a graduate student paired with a faculty advisor at each of the projects at Harvard, Iowa, and Michigan Universities. Nicholas C. Matalas studied the statistical distribution of low flows with Professor Harold A. Thomas at Harvard and reported results in PP 434–A (1963). Herman J. Koloseus studied the effect of roughness element spacing on energy loss and friction coefficients with Hunter Rouse at Iowa and results were reported by Koloseus and Davidian in WSP's 1592–C and 1592–D (1966). Robert A. Baltzer studied methods of obtaining a continuous record of discharge in tidal streams, initially with Professor Harold Henry at Michigan and later with Rolland Carter. Baltzer's work was reported in an open-file report, "Tidal flow investigations," (1959) and by Baltzer and Shen in PP 424–C (1961).

The mobilization of staff in the SWB Research Section at headquarters in 1956 was the start of a concerted program of hydrologic investigations. In the newly developing field of stochastic hydrology, Manuel A. Benson assisted by David R. Dawdy and D.B.Y. Chen studied improved methods of regional analysis of flood magnitude and frequency. Benson reported on this work in WSP's 1580–A (1962), 1580–B (1962) and 1580–C (1964). Rolland W. Carter suggested a method for estimating the effects of urban development on the magnitude and frequency of floods in PP 424–B (1961). Henry C. Riggs and Daniel G. Anderson began a study of methods of analyzing the magnitude and frequency of low flows as well as methods of estimating low flows at ungaged sites, as follow-up on Clayton H. Hardison's earlier work on station-analysis methods. Riggs reported on his work in PP's 424–B (1961), 501–B (1964), and elsewhere in following years. (See "Flood-Frequency Studies," "Regional Low Flow Analysis," and "Statistical Methods in Hydrology.")

Mark W. Busby studied the areal distribution of annual runoff and reported results in PP 501–C (1964) and HA 212 (1966). Vujica Yevdjevich reviewed and commented on flood routing of unsteady flows in open channels in WSP 1690 (1964). Alan V. Jopling analyzed streambed dunes and published findings in PP's 424–B (1961) and 475–B (1963).

At the Instrumentation Research Laboratory in Columbus, Ohio, Edward G. Barron, assisted by George F. Smoot and Harold O. Wires, continued work on a gas-bubbler gage for measuring continuous water levels; a single-point, continuous-recording, electromagnetic velocity meter; an ultrasonic meter to measure the mean velocity between a pair of transducers; and the redesign of the Price current-meter rotor so that mass-produced rotors would have a common rating within reasonable limits of accuracy. (See "Instrumentation.")

The only federally funded research project for 1957 to be sited in a District office was a small-streams study headed by William D. Mitchell in the Champaign, Ill., office. The project was to determine effects of embankment storage on peak discharge from small catchments and results were reported by Mitchell in WSP 1580–C (1962).

The development of procedures for the continuous measurement of unsteady flow in tidal streams essential to critical water-supply investigations in the Hudson, Sacramento, and Delaware Rivers in the early 1960's was based on research by Baltzer, Chintu Lai, John Shen, and Jacob Davidian.

The studies by Nobu Yotsukura, Bernard J. Frederick, Richard G. Godfrey, and others concerning turbulent diffusion, dispersion, and the uses of radioactive and fluorescent tracers provided a basis for development of time of travel and dispersion techniques now used extensively for predicting or monitoring the movement and fate of hazardous materials introduced into streams and for managing water-use withdrawals following spills. (See "Tracers in Hydrology.")

Research on stochastic processes continued at Headquarters throughout the 1957–66 period and provided significant contributions to highway drainage design, to the WRC efforts to standardize analytical techniques for estimating flood magnitude and frequency, and to the understanding of basic hydrologic relationships. Many, but not all, projects were federally funded. Among some of the pertinent results were the computer-based regional regression studies of Benson and Donald M. Thomas that provided simple relations for estimating a wide variety of streamflow characteristics at ungaged sites. The regression studies were documented in WSP 1975 (1970) and became the basis for national studies of the streamflow data-collection program as described later by Benson and Carter in WSP 2028 (1973). William J. Schneider and Gordon R. Ayer studied the effects of reforestation on streamflow in central New York as reported in WSP 1602 (1961). Daniel G. Anderson, working under Carter's direction, defined the effects of urban development on the magnitude of floods in northern Virginia as reported in WSP 2001–C (1970). Thomas developed a method for estimating the depth of floods of a given frequency (PP 501–D, 1965) that subsequently was used in a national program for mapping the approximate boundaries of inundation on 13,000 topographic quadrangles. Nicholas C. Matalas continued to apply formal statistical methods to hydrologic problems. Matalas and Barbara Jacobs defined conditions under which flow characteristic estimates could be improved by extending the length of streamflow records by cross correlation (PP 434–E, 1964), Matalas and Benson studied the effects of interstation correlation on regression relations (Water Resources Research, 1967), and Matalas and William J. Conover reported on a statistical evaluation of turbulence (Water Resources Research, 1965).

Also at Headquarters, Riggs and Donald O. Moore defined a method for estimating runoff from ungaged arid areas (PP 525–D, 1965). Clayton H. Hardison, assisted by John R. Crippen, James K. Searcy, and Robert O. R. Martin, investigated low-flow characteristics as reported in PP's 450–B (1962) and 475–B (1963) and WSP's 1669–G (1963) and 1669–N (1963). Ennio V. Guisti defined the distribution of river-basin size in the conterminous United States as reported in International Association of Scientific Hydrology Bull. vol. VIII (1963).

A field-centered project of note in deterministic hydrology was the work of David R. Dawdy, Terrance O'Donnell, Robert W. Lichty, and James M. Bergmann in developing a rainfall runoff model applicable to small streams. The model described later in PP 506–B (1972) was extensively used in the SWB Highway Program to extend the length of observed flood records on the basis of long-term rainfall records. Other surface-water research activities are described under specific topics in Part IV.

In attempts to broaden the comprehension and analytical capabilities of the SWB staff, several foreign experts were detailed to SWB offices to consult with SWB investigators. G.N. Alexander of Australia worked with Benson and Matalas on problems in stochastic hydrology. David Pilgram, also of Australia, visited several offices to discuss problems of infiltration and rainfall-runoff processes. Terrance O'Donnell of the United Kingdom worked with Dawdy on development of a deterministic rainfall-runoff model, and Peter Wolff, also of the United Kingdom, consulted with Hardison and others on various aspects of hydrology.

Hydrologic investigations in other parts of the world also were a part of surface-water research. Roy E. Oltman, Luther C. Davis, and Frank C. Ames made the first actual measurements of the Amazon River flows and sediment characteristics. Their findings were published in Circ. 486 (1964) and 552 (1968). Daniel G. Anderson visited Ellesmere Island in the Canadian arctic to obtain information on flow characteristics of stream channels in ice and, late in this period, Stanley A. Schumm conducted geomorphological research in Australia. (See "International Programs.")

Some 22 federally funded projects active in 1960 produced more than 60 reports. By 1961, the research budget of the Branch had grown to $567,000, including funds from other Federal and State agencies. Aside from increases in budget and personnel, the real evidence of program growth was in the wide range of hydraulic and hydrologic problems being investigated. A concurrent system of review and reporting kept project objectives within the overall program framework. The last year of the Branch's direct control of the surface-water research program was in 1962.

Beginning in late 1963, many of the surface-water research projects and associated personnel were shifted to the GHB. By mid-1966, virtually all research formerly lodged within the Branches was grouped in the three Area (Regional) offices at Arlington, Denver, and Menlo Park for administrative direction and support. Technical direction was provided by the Assistant Chief Hydrologist for Research and Technical Coordination through the Area (Regional) Research Hydrologist. Projects involving surface-water hydrology and hydraulics continued to grow in number and diversity through the close of the period, numbering about 40 projects in 1966.

### Analytical Techniques of Water Quality

*By* Marvin J. Fishman *and* reviewed *by* Robert Brennan *and* Victor Janzer

Research and development on water-quality analytical techniques from 1957 through 1966 expanded rapidly. Most analytical methods used in the WRD water-quality laboratories prior to 1952 were gravimetric, volumetric, and simple colorimetric techniques. Gravimetric techniques were generally tedious and time consuming. Volumetric analysis was usually more rapid than gravimetric analysis and attained greater sensitivity and precision. The water analyst was provided with truly precision instruments when spectrophotometers and flame photometers came onto the market in the 1950's. Both were well suited to and improved the precision of water analysis.

Atomic absorption spectrometry made its entrance into analytical laboratories in 1962. The Water Quality Methods Development group in Denver, headed by Marvin W. Skougstad, saw that this new instrumental technique was ideally suited to the analysis of natural waters, as constituents to be determined were in solution and very little sample preparation was required. The technique afforded a sensitive and rapid means of determining the major cations and many of the trace-metal elements found in water. In early 1964, two instruments were purchased, one for the Lincoln water-quality laboratory and the other for the Denver Methods Development Unit. Sanford C. Downs from Lincoln and Marvin J. Fishman from Denver coordinated their activities in the development of analytical methods for both major and trace-metal constituents in water using this new atomic absorption spectrometric technique. By 1966, all QWB laboratories had atomic absorption spectrometric capabilities. This new instrumental technique revolutionized water analyses.

Other highly specialized analytical equipment was adopted for use in QWB laboratories in the early 1960's. Equipment for determining pesticide and other organic constituents by gas chromatography was in place at the Austin, Tex., Washington, D.C., and Columbus, Ohio, laboratories and the Menlo Park and Denver research laboratories during the period 1964 through 1967. William L. Lamar, Donald F. Goerlitz, and Leroy M. Law provided many new techniques for determining pesticides such as DDT, dieldrin, aldrin, and others (WSP 1817–G, 1965).

The first spectrographic facility was set up in the Sacramento, Calif., QWB laboratory in 1956 under the direction of Richard P. Orth. Methods were developed by William D. Silvey and Robert Brennan for determining trace-metal elements. Silvey did an extensive study of trace-metal occurrence in California ground and surface water. A Denver spectrographic facility, under the direction of Joseph Haffty, was established within the Methods Development Unit in 1962. Some of the initial work dealt with the analysis of more than 100 public water-supply samples from throughout the United States. In August 1964, in order to offer the analysis of samples by this technique to other WRD personnel, 17 chemists from 13 QWB laboratories gathered in Denver for a demonstration of spectrographic techniques and the equipment used. This resulted in considerable increase in trace-metal determinations at the Denver spectrographic facility.

The late 1940's and early 1950's were years of nuclear weapon development and a proliferation of above- and below-ground testing. These tests resulted in widespread soil and water contamination, causing S. Kenneth Love to initiate the development of laboratory capabilities for analyzing radiochemical constituents in water. The first laboratory facility for determining uranium and tritium in water was developed in Washington, D.C., about 1953, under the direction of Leland L. Thatcher. A second laboratory was developed in Denver about a year later for the analysis of gross beta and gross radium in water, under the direction of John D. Hem and Franklin B. Barker.

Between 1954 and 1965, the laboratory in Denver analyzed five to six thousand samples. The laboratory's capability also expanded during this period to include gross alpha, radium-226, uranium, cesium-137, strontium-90, carbon-14 age dating of water, gamma spectroscopy, and tritium. Low-level tritium samples continued to be analyzed in the Washington laboratory. In 1964, Victor J. Janzer was put in charge of the new Radiochemical Surveillance Network Project and the laboratory's routine analysis program, and Kenneth W. Edwards was put in charge of a new Radiochemical Methods Project.

The first recording of multiparameter water-quality characteristics in the field was in 1959–60 when a water-quality monitor was installed in the Delaware River estuary at Philadelphia. The Philadelphia QWB

District tested and made innovative improvements to monitoring equipment for the next several years in cooperation with the city of Philadelphia and equipment manufacturers. In November 1962, a water-quality monitor was installed on the Cuyahoga River in Cleveland in cooperation with the Ohio Department of Health. By 1966, the Division reported that the digital recording of water-quality parameters was a link in the automated data-collection and processing system of the USGS. In 1965, the Tacoma District set up multiparameter monitors on the Duwamish River. The District reported that the pH, specific conductivity, and temperature data were comparable to laboratory measurements. Data obtained from dissolved oxygen compared with laboratory measurements within ±0.1 mg/L.

In 1959, the need for research in analytical methods development was ouitlined in a committee report by S. Kenneth Love which provided guides for selecting methods of analyses. As a result, a Methods Development Project, headed by Marvin Skougstad was set up in Denver in 1960. The project's responsibilities were: (1) development and approval of new or revised analytical methods for water analysis; (2) standardization and implementation of analytical methods in QWB laboratories; and (3) encouragement of QWB laboratories to help in the development and evaluation of new techniques.

Beginning in 1962, the Methods Development Unit began a Standard Reference Sample Program in which prepared samples of commonly determined constituents were analyzed by QWB laboratories. The results and performance of each laboratory in comparison with the mean values obtained by all laboratories were reported. This program has since been expanded to include trace metals and nutrients.

After initial analysis and statistical treatment of data to obtain the most probable values for each constituent in each standard reference sample, the remaining library of samples was made available to all the laboratories. This was a means of assuring them that their laboratory operations were functioning properly and that they were indeed producing analytical data of an acceptable high degree of reliability.

In March 1961, the Methods Development Unit started a monthly "QWB Analytical News" letter, distributed to all QWB laboratories and others in WRD who were interested in water-quality methodology. The newsletter contained information on the activities of the Methods Development Unit and the laboratories, proposed methods from the Methods Development Unit with a provision for feedback, and provided for the continuous exchange of information among all field offices involved in water-analysis operations.

To further the dissemination of information on new analytical techniques, symposia were held in Denver and Philadelphia in the fall of 1965 and 1966. All of the QWB laboratories were represented along with Method Development Unit personnel. Speakers from industry were invited to make presentations on advances in instrumentation.

A formal analytical-methods manual, WSP 1454, "Methods of Collection and Analysis of Water Samples," by F.H. Rainwater and L.L. Thatcher was published in 1960. Seventy-seven laboratory and field procedures were given for determining 53 water properties. WSP 1454 was well received in the United States and abroad. In 1966, Marvin J. Fishman and Sanford C. Downs prepared WSP 1540–C, a manual of procedures for determining calcium, copper, lithium, magnesium, manganese, potassium, sodium, strontium, and zinc in freshwaters and brines by atomic absorption spectrometry.

Many WRD individuals contributed to the advancement of analytical methodology during the 1957 to 1966 period. Radium was reported on by F.B. Barker and J.O. Johnson (WSP 1696–B, 1964); uranium by F.B. Barker, J.O. Johnson, K.W. Edwards, and B.P. Robinson (WSP 1696–C, 1965); beta activity by Barker and Robinson (WSP 1696–A, 1965); and strontium by C.A. Horr (WSP 1496–C, 1962), Johnson and Edwards (WSP 1696–E, 1967), and M.W. Skougstad (WSP 1496–B, 1961, and unnum. OFR, 1957). Minor elements were reported on by Joseph Haffty (WSP 1540–A, 1960) and W.D. Silvey (WSP 1540–B, 1961), and the metallic element aluminum by M.J. Fishman (WSP 1822, 1966). Fishman and Skougstad reported on phosphate in natural water (PP 525–B, 1965) and D.F. Goerlitz and W.L. Lamar on phenoxy acid herbicides (WSP 1817–C, 1967). The salt chloride was reported on in a 1957 WRD Bulletin article by Al Mattingly (p. 57–60), fluoride in a 1959 WRD Bulletin article by P.G. Rosini (p. 38), and iodine by C.G. Mitchell (WSP 1822, 1966). WSP 1822, incidentally, contained several "methods" articles using parts from automobiles (N.R. Harmon, p. 61–62; H.B. Wilder, p. 59–60) as well as use of a thermistor-thermometer (L.S. Hughes, p. 66–69) and the installation assembly for conductance cells (L.G. Toler and R.N. Cherry, p. 63–65). Another "how to" appeared in a 1959 WRD Bulletin article on the titration assembly for the Beckman model B spectrophotometer (Hughes and J. F. Blakey, p. 38). There may be other publications of importance not cited, and the writer apologizes for those articles overlooked.

### Geomorphic and Sediment Processes

*By* Richard F. Hadley *and* others as listed

During the years 1957 to 1966, WRD research in geomorphology and sediment processes increased greatly over that of earlier years. WRD officials who were instrumental in setting this trend included Paul Benedict, Rolland Carter, and George Porterfield. Luna Leopold, as Chief Hydrologist, encouraged research and publication of the results and conducted major research projects himself in stream geomorphology and sedimentation processes.

### *Sediment Transport*

*By* Garnett P. Williams, James K. Culbertson, *and* Harold P. Guy

Before 1957, sediment-transport research had been conducted by few investigators (for example, Bruce R. Colby and David W. Hubbell in Lincoln, Nebr., and George Porterfield in Sacramento, Calif.). After 1957, the number of studies and topics under investigation increased significantly. A notable example was the first-ever measurement of water and suspended-sediment discharge of the Amazon River by Roy Oltman and others in July 1963 (Circ. 486, 1964).

The following list of publications is representative of the scope of research in sediment-transport processes during 1957 to 1966. Two sediment-transport research projects, one in the field (Rio Grande conveyance channel, N. Mex.) and the other in a laboratory [Colorado State University (CSU), Fort Collins, Colo.], are described separately.


Bagnold, R.A., 1966, An approach to the sediment tranport problem from general physics: PP 422–I.

Colby, B.R., 1961, Effect of depth of flow on discharge of bed material: WSP 1498-D.

____1964, Practical computations of bed-material discharge: Jour. Hydraulics Division, ASCE, v. 90, no. HY2.

____1964, Discharge of sands and mean-velocity relationships in sand-bed streams: PP 462–A.

____1964, Scour and fill in sand-bed streams: PP 462–D.

Colby, B.R., and Scott, C.H., 1965, Effects of water temperature on the discharge of bed material: PP 462–G.

Culbertson, D.M., Young, L.E., and Brice, J.C., 1967, Scour and fill in alluvial channels: USGS Open-File Rept.

Culbertson, J.K., and Dawdy, D.R., 1964, A study of fluvial characteristics and hydraulic variables, Middle Rio Grande, New Mexico: WSP 1498–F.

Dawdy, D.R., 1965, Discontinuous depth-discharge relations for sand-channel streams and their effect on sediment transport: Proceedings Federal Inter-Agency Sedimentation Conference, 1963, USDA Misc. Publ. no. 970.

Guy, H.P., 1964, An analysis of some storm-period variables affecting stream sediment transport: PP 462–E.

Helley, E.J., 1969, Field measurement of the initiation of large bed particle motion in Blue Creek near Klamath, California: PP 562–G.

Hubbell, D.W., and Sayre, W.W., 1965, Application of radioactive tracers in the study of sediment movement: Proceedings, Federal Inter-Agency Sedimentation Conference, 1963, USDA Misc. Publ. no. 970.

Lustig, L.K., and Busch, R.D., 1967, Sediment tranport in Cache Creek drainage basin in the Coast Ranges west of Sacramento, California: PP 562–A.

Mundorff, J.C., 1964, Fluvial sediment in Kiowa Creek basin, Colorado: WSP 1798–A.

Nordin, C.F., Jr., 1963, A preliminary study of sediment transport parameters Rio Puerco near Bernardo, New Mexico: PP 462–C.

Nordin, C.F., Jr., and Beverage, J.P., 1965, Sediment transport in the Rio Grande, New Mexico: PP 462–F.

Nordin, C.F., Jr., and Dempster, G.R., Jr., 1963, Vertical distribution of velocity and suspended sediment, Middle Rio Grande New Mexico: PP 462–B.

Porterfield, G., and Dunnam, C.A., 1964, Sedimentation of Lake Pillsbury, Lake County, California: WSP 1619–EE.

Sayre, W.W., and Hubbell, D.W., 1965, Transport and dispersion of labeled bed material, North Loup River, Nebraska: PP 433–C.

Williams, G.P., 1967, Flume experiments on the transport of a coarse sand: PP 562–B.


### *Albuquerque, New Mexico, Field Research Unit*

*By* James K. Culbertson

In July 1964, the Albuquerque Field Research Unit was established with James K. Culbertson as project chief to study sediment transport and the mechanics of flow in a straight alluvial channel in which flow was relatively uniform and steady for long periods of time.

Cloyd H. Scott transferred to the project in August 1964. Vernon W. Norman, Jack D. Dewey, and Bruce M. Delaney of the Albuquerque QWB staff did most of the field and laboratory work for the project.

The reach of channel first selected to study was the Rio Grande conveyance channel near Bernardo, N. Mex. The reach began at a weir that had been installed in 1963 by the SWB. The special characteristics of the weir were described later in WSP 1898–A (1969), "Stage-discharge characteristics of a weir in a sand-channel stream," by D.D. Gonzalez, Scott, and Culbertson. A second reach of channel, on the Atrisco Feeder Canal near Bernalillo, N. Mex., was used to conduct experiments designed by Hugo B. Fisher and Nobuhiro Yotsukura on transverse diffusion.

Sediment researchers from Colorado State University (CSU) and from the QWB Field Unit at the university visited the project to observe the techniques developed and used by the project personnel.

The following reports documented the results of the work at both sites, and each report title is followed by observations on that phase of the investigation.

**(i)** Culbertson, J.K., Scott, C.H., and Bennett, J.P., 1972, Summary of alluvial-channel data from Rio Grande conveyance channel, New Mexico, 1965–69: PP 562–J.

Lack of the special instrumentation and samplers needed for the study led to the development of new equipment or modification of existing equipment. An ultrasonic sounder, developed at CSU, was modified for use from a boat to record channel bed configurations.

To measure and record vertical velocity profiles rapidly, five current meters equipped with magnetic heads were mounted on a specially built 3/4-inch sounding rod. A rechargeable 5-digit counter was designed and built for the project by the research group at the Interagency Sedimentation Project at St. Anthony Falls Hydraulic Laboratory. A hand-held point-integrating sediment sampler designed by George Porterfield was modified for more efficient use from a boat. Obtaining large sediment samples at a point required the project personnel to design and fabricate a special pumping sampler intake nozzle. A platform built between two boats accommodated the several investigators needed to man the equipment.

About 80 tons of sediment dredged from the Bernardo channel was shipped to the research Unit at CSU and placed in the large recirculating flume in an effort to replicate the Bernardo studies.

**(ii)** Rathbun, R.E., Kennedy, V.C., and Culbertson, J.K., 1971, Transport and dispersion of fluorescent tracer particles for the flat-bed condition, Rio Grande conveyance channel near Bernardo, New Mexico: PP 562–I.

A bed-material sampler, developed by Vance C. Kennedy, was used to obtain sediment samples moving at high velocity along the flat streambed.

**(iii)** Yotsukura, Nobuhiro, and Cobb, E.D., 1972, Transverse diffusion of solutes in natural streams: PP 562–C.

This study on the Atrisco Feeder Canal required developing special sampling techniques in order to simultaneously collect samples at the water surface at 2-foot intervals across the channel.

**(iv)** Culbertson, J.K., and Scott, C.H., 1970, Sandbar development and movement in an alluvial channel, Rio Grande near Bernardo, New Mexico: PP 700–B.

This was a 4-day study during which discharge in the Bernardo channel was increased daily and sonic records of the bed configuration in a 6,000-foot reach were obtained daily to determine relationships between flow characteristics and bed configuration.

Other short reports and papers were prepared by Culbertson, Fahnestock, Fisher, Nordin, and Scott during the course of the investigation.

#### *Fort Collins, Colorado, Research Unit*

*By* Harold P. Guy

The unit and its project were formed and operated in collaboration with CSU, Fort Collins, Colo. The investigations began in the fall of 1956 and continued through the period of this report. In its formative stages, the primary administrative and technical guidance was from Paul C. Benedict of the QWB, Rolland W. Carter of the SWB, and Maurice L. Albertson of the CSU Engineering Department. After 1964, the project was under the guidance of the Regional Research Hydrologist, RMA. [Author's note: Paul Benedict was the project's primary motivator. His background in sediment investigations for about the two previous decades' service to WRD reached back to 1938–40 when he worked on the Boise River Sediment Investigation. At Iowa City, Iowa, 1941–45, he worked half-time on surface-water investigations for the Iowa SWB District and half-time as the USGS representative to the Federal Interagency Project, "A study of methods used in measurement and analysis of sediment loads in streams." The work with the Interagency Project, in its collaboration with the Iowa Institute of Hydraulic Research at the University of Iowa, no doubt strengthened his concepts of the advantages of WRD research being done in association with a university. From 1946 to 1957 in Lincoln, Nebr., he guided extensive sediment investigations for the Missouri River Basin program (see "The Missouri River Basin program"), which produced more than 75 Geological Survey publications and 10 technical journal papers. The vast data-collection program in the Missouri River Basin demonstrated conclusively that measurement of the flow and sediment in alluvial streams was more difficult and less accurate than desired and led to Benedict's intense interest in improving the accuracy and efficiency of sediment measurements.]

Guidance for the project also came from others in the WRD and at CSU who were interested in the subject through formal and informal conferences. For example, there were three formal conferences held with R.A. Bagnold as a special guest where alluvial sediment-transport theory and flow-measurement problems were discussed (February 1958, April 1960, and April 1961). At the 1961 meeting, 12 of the attendees presented "critical experiment needs" on this subject.

The project required a multidisciplinary approach because it had become evident during the course of measuring the flow and sediment content of alluvial streams that both the mechanics of flow and sediment movement were the result of many changeable variables with interlocking relationships. In such alluvial streams, depth, velocity, and viscosity, as well as the particle size and sediment load, are all changeable with time. In the early years of the project, three WRD Branches contributed personnel and funds to the project.

The WRD full-time project personnel, their periods of service, and sponsoring Branches were: Donald L. Bender, August 1956 to 1959, QWB; Fred M. Chang, (service years unknown), QWB; Robert K. Fahnestock, September 1960 to September 1963, GHB; Harold P. Guy, August 1962 to __, QWB; William L. Haushild, November 1957 to June 1962, QWB; David W. Hubbell, September 1960 to September 1963, QWB; Frederick A. Kilpatrick, March 1963 to __, SWB; Carl F. Nordin, Jr., March 1963 to __, QWB; Ronald E. Rathbun, Aug. 1965 to __, QWB; Everett V. Richardson, August 1956 to __, SWB; and Daryl B. Simons*, August 1956 to __,QWB.

* Part-time August 1956 to May 1957 and after July 1963. No concluding date — means served through 1966.

Faculty members of the CSU Engineering Department and graduate students who served part-time included Maurice L. Albertson, A. Ray Chamberlain, George H. Splittgerber, William W. Sayre, George R. Alger, Herman J. Koloseus, Erich J. Plate, Glen E. Stringham, Richard H. Walker, and Darell L. Zimbelman.

The general objective of the project was to obtain comprehensive measurements of the flow-resistance and sediment-movement characteristics under flow conditions that approximated those occurring in natural channels, and to include a much wider range of pertinent variables than those available from previous and existing studies. This required measuring under a wide range of flow rates, bed material sizes, and bed slopes. Attention had to be given other variables, such as temperature, concentration and particle size of suspended sediment, and flume boundary as it affected the width-depth ratio.

Details of the flumes, the bed material, the kinds of measurements taken, and the extent of the auxiliary experimental and development work were described in the many reports and technical papers resulting from the project. The ranges in the key variables were: bed-material median diameters of 0.19 to 0.93 mm; mean flow velocities of 1.3 to 2.1 ft/sec; mean depths of about 0.3 to 1.3 ft; bed slopes from 0.00005 to 0.019 ft/ft; sediment concentrations from 0 to 50,000 ppm; water temperatures 8 to 33 degrees Celsius; and bed-forms of ripples, dunes, antidunes, and standing waves.

Published information, largely in USGS reports concerning the main body of the research effort, was extensive, such as Simons and Richardson (ASCE Proc., v. 86, HY 5, 1960), Simons, Richardson, and Haushild, (PP 424–C, 1961), and Guy, Simons, and Richardson (PP 462–I, 1964). Results of closely related experiments can be found in other reports such as: the effects of temperature (Hubbell and Ali, PP 424–D, 1961); the use of the sonic depth sounder (Richardson, Simons, and Posakony, Circ. 450, 1961); the effects of fine sediment in suspension (Simons, Richardson, and Haushild, WSP 1498–G, 1963); the response of the flume to changes in hydraulic and sediment variables (Rathbun, Guy, and Richardson, PP 562–D, 1969); and the behavior of large particles falling in quiescent liquids (Stringham, Simons, and Guy, PP 562–C, 1969). A report by Simons, Richardson, and Nordin in Society of Economic Paleontologists and Mineralogists, sp. publ. 12, (1965) was one of the first publications to explore the relation of sedimentary structures to their hydraulic environment.

The project was coordinated with the university graduate program in engineering, permitting work on the project to meet the research requirements for advanced degrees. Richardson utilized his close involvement with the project to meet the research requirements of the M.S. and Ph.D. degrees granted by CSU. Alger and Stringham worked part time for the project to meet the research requirements for their advanced degrees. A number of theses and dissertations resulted from the project.

### *River Morphology and Channel Geometry*

*By* Richard F. Hadley *and* Garnett P. Williams

The first major investigation that tested the hydraulic-geometry concepts of Leopold and Maddock was done by M. Gordon Wolman in the Brandywine Creek Basin of southeastern Pennsylvania (PP 271, 1955). Wolman's study and the work of Leopold and Miller (PP 282–A, 1956) on the hydraulic geometry of ephemeral streams in the Southwest, although they predate the period of this report, serve as the basis for the discussion of the several studies that followed.

In 1957, Luna B. Leopold and M. Gordon Wolman published PP 282–B on river-channel patterns. Their work indicated that channel cross section and pattern are controlled by the discharge characteristics and sediment load derived from the contributing drainage basin. Studies of channel geometry and flow characteristics were extended to investigations of river flood plains in 1957 (PP 282–C) by Wolman and Leopold. Most of their field work was done on small streams, but the results generally apply to larger streams in different environments. Walter Langbein helped pioneer the development of stochastic methods in regard to channel geometry. Others who studied and reported in USGS publications included R.A. Bagnold (PP 282–E, 1960), J.C. Brice, (PP 422–D, 1964), G.H. Dury, (PP 452–A and B, 1964, and C, 1965), F.A. Kilpatrick and H.H. Barnes, Jr., PP 422–E, 1964), and L.B. Leopold and others, PP 282–D (1960). In addition, others who published on the subject in outside journals included C.W. Carlston, W.W. Emmett, and W.B. Langbein.

### *General Geomorphology*

*By* Richard F. Hadley *and* Garnett P. Williams

Publication of the book "Fluvial processes in geomorphology," (Freeman, San Francisco, 1964) by Leopold, Wolman, and Miller had a major impact and set the trend for future directions in that field. Progress in geomorphology in the late 1950's had been hampered by a lack of data on geomorphic processes, especially as measured repeatedly over time at a given site. This lack of data led Luna Leopold to set up the so-called Vigil Network—a program whereby measurements of basic processes in small drainage basins or at individual sites would be made at discrete time intervals over many decades or longer, and the data would be recorded on standardized forms and kept on file at various repositories (Leopold, Circ. 460–A and IASH Bulletin, v. 7, no. 2, 1962).

William B. Bull, a ground-water hydrologist in the Sacramento GWB District, wrote a paper on alluvial fans which he sent to Leopold to review. Bull soon published his work in 1964 (PP's 352–E and 437–A). Leopold was favorably impressed and encouraged Bull to become a geomorphologist, which he did and later became a professor of geomorphology at the University of Arizona.

In 1961, Lucien M. Brush completed a study of basin geology, channel characteristics, and flows in central Pennsylvania (PP 282-F) which represented a broadening of the scope of studies to include the entire drainage basin. Many more studies of stream channels and drainage basins representing a wide variety of physical and climatic environments followed during the period of this report.

Stanley A. Schumm (PP 352–B, 1960) conducted a study relating alluvial channel characteristics to the sediment type in the channel perimeter. Schumm (PP 352–C, 1961) continued his research on the effect of sediment characteristics and channel erosion and deposition in drainage basins in the High Plains. Richard F. Hadley (PP 352–A, 1960) conducted an investigation of the erosional history of Five Mile Creek, Fremont County, Wyo., and with Schumm, a study of the upper Cheyenne River Basin (WSP 1531–B, 1961). In 1963, Schumm and Lichty published the results of a study of channel changes and the flood plain on the Cimarron River in southwestern Kansas that occurred between 1874 and 1960. This study (PP 352–D) reflects similar changes in channel morphology that have occurred in Great Plains rivers since the mid-19th century.

Schumm and Hadley studied the geomorphic processes responsible for the development of arroyos on semiarid rangelands of Wyoming and New Mexico (American Jour. Sci., v. 255, 1957). The results of their study included the role of discontinuous channels in building valley deposits.

Other investigators in this field of research who published during the period included C.W. Carlston, E.V. Guisti, W.J. Schneider, and W.B. Langbein.

### *Erosion and Sediment Yield*

*By* Richard F. Hadley *and* Garnett P. Williams

In 1961, Richard C. Culler, Richard F. Hadley, and Stanley A. Schumm completed a study of the Cheyenne River Basin in eastern Wyoming, northwestern Nebraska, and southwestern South Dakota that determined sediment source areas and hydrologic characteristics of upland basins (Culler, WSP 1531–A, 1961; Hadley and Schumm, WSP 1531–B, 1961). This was one of the first studies in the Division that utilized small stock ponds to gage volumes of surface runoff and sediment yield. The drainage-basin characteristics were correlated with hydrologic characteristics for more than 100 representative basins. Similar studies were done by Harold V. Peterson in Montana, Wyoming, Colorado, New Mexico, Arizona, and Utah and summarized in WSP 1475–I (1962).

A similar study of erosion and depositional processes in channels and on hillslopes, although comprising much more detailed measurements and data collection, was conducted near Santa Fe, N. Mex., from 1958 to 1965 (Leopold, Emmett, and Myrick, PP 352–G, 1966). The study area, known as Arroyo Frijoles, produced much new data on sediment sources, sediment transport, and geomorphic processes on hillslopes and in ephemeral channels. J.C. Brice studied erosion and deposition in the loess-mantled Medicine Creek drainage basin of Nebraska (PP 352–H, 1966).

There were two studies that were well known by hydrologists in the West because of their importance to understanding the relation of land-use practices to hydrology in a semiarid environment. Badger Wash Basin near Grand Junction in western Colorado was the location of an interagency study to determine the effects of grazing practices on runoff and sediment yield. The study began in 1953 and continued for 20 years with Gregg C. Lusby as the project chief for the entire period. The first results of the study were published in WSP 1532–H (Lusby and others, 1963) followed by several additional WSP's after this period.

A similar study to determine the effects of land treatment on hydrology was conducted in Cornfield Wash, northwestern New Mexico. Durl E. Burkham and Frank W. Kennon conducted the field studies that were published as WSP–1831 (1967).

### *Instrumentation—The St. Anthony Falls Interagency Project*

*By* Herbert H. Stevens, Jr.

This continuing project has been sponsored by the Subcommittee on Sedimentation of the Interagency Committee on Water Resources since its beginning in 1939. The primary objective of the project has been research in fluvial sediment, with special emphasis on the development of (a) field equipment for sampling suspended sediment and bed material, and (b) methods for making particle-size analysis. During the period 1957 to 1966, emphasis was on the development of systems for automatically collecting and analyzing suspended-sediment samples.

Byrnon C. Colby continued his leadership of the project, located at the St. Anthony Falls Hydraulic Laboratory, University of Minnesota, Minneapolis, until his retirement in 1965. John V. Skinner joined the project in 1962 and assumed leadership in 1965. Other full-time personnel assigned to the project during this period were Herbert H. Stevens, Jr. (1957 to 1962), Gordon H. Flammer (1957 to 1958), Howard A. Jongedyk (1957 to 1962), and Thomas F. Beckers (1960 to 1964).

Colby headed the development and calibration of the Visual-Accumulation-Tube apparatus for the sedimentation analysis of sands (U.S. Interagency Proj. Rept. 11, 1957), and he presented definitions and basic concepts of particle-size analysis (U.S. Interagency Proj. Rept. 12, 1957). Stevens initiated the development of pumping samplers (U.S. Interagency Proj. Repts. N and Q, 1960 and 1962), and Skinner continued the pumping-sampler project and developed the PS66 sampler. Colby and Skinner investigated pumping-sampler intake efficiencies (U.S. Interagency Proj. Rept. T, 1966).

Four projects were initiated in an attempt to rapidly measure suspended-sediment concentrations: Flammer (PP 1141–A, 1962) investigated the use of ultrasonics; Jongedyk investigated the use of a turbidimeter; Jongedyk, Stevens, and Colby tested three differential-pressure gages (U.S. Interagency Proj. Rept. D, 1961); and Beckers tested an electronic sensing instrument (U.S. Interagency Proj. Rept. R, 1964). The projects were discontinued because of insensitivity to low sediment concentrations or small particle sizes, or excessive time required to make the analysis.

[Author's note: Skinner in 1989 reported on the history of the Federal Interagency Sedimentation project at the ASCE International Symposium on Sediment Transport Modeling. His paper was published in the proceedings of that symposium.]

### *Geomorphic and Sediment Processes—The Rest of the Story*

*By* Robert M. Myrick *and* William W. Emmett

Luna Leopold is a personality that one does not easily forget; that is one of the reasons Bob Myrick so well remembers that early field season in 1958. Bob had just returned from a field trip to the District office in Ohio and was informed that at the request of the Chief Hydraulic Engineer, he was to leave early the next day on a flight to Santa Fe, N. Mex. Bob assumed the reason for the trip was an interview for a position as research assistant to Leopold. He landed in Santa Fe at night, several hours after the scheduled arrival. He scanned the lobby as he entered the terminal hoping that someone from the Santa Fe office would be there to meet him. However, everyone was engaged in conversation with the other passengers except for two men who appeared to be common laborers still dressed in their grubby work clothes and western hats. The man with a strange leather pouch attached to his belt walked up to Bob and introduced himself as Dr. Luna Leopold, and the second man was Dr. John Miller, professor at Harvard University and WAE Survey employee. On the trip into town Bob learned the reason for his being in Santa Fe was not for an interview, but to assist Luna and John in establishing the Arroyo de los Frijoles field site near Santa Fe. Bob found out later it was not just coincidence that Luna had designs to evaluate Bob's worth as his research assistant.

Early the next morning while waiting for the local stores to open so that Bob could purchase field clothes, Luna and John continued to mumble things geomorphic as they handed Bob publication after publication. Much of Bob's worthiness test came as they headed down a sandy arroyo and the truck became stuck. Luna and John set a mental timer as Bob set in with a shovel. Bob must have passed the digging test because he became Luna's assistant for the next few years.

Hard fun and hard work got the project at Arroyo de los Frijoles started. The project is best known for its thousands of painted rocks, but there were also tens of scour chains and hundreds of erosion nails. It would be unfair not to mention the help the project got from personnel of the SWB District office in Santa Fe, especially from Wilbur Heckler, Louis Reiland, and Leon Wiard. It was not known in 1958 that Arroyo Frijoles would become world renowned, but all that data combined to tell a pretty good story about erosion and sedimentation in a semiarid environment. Now Arroyo de los Frijoles is the classic story (Leopold and others, PP 352–G, 1966) for channel and hillslope processes in semiarid areas.

Sadly, John Miller died from bubonic plague immediately following the 1961 field season. John had returned to Boston where the symptoms of the plague were not recognized in time to save his life. Several hours after his death, law enforcement officers had separately found Luna and Bob in Arizona to alert them to the nature of the disease to which they had been exposed, but by then, if they were not dead, they would not be.

Subsequent to 1961, Bill Emmett became Luna's research assistant. Luna, Bill, and Bob continued to work Frijoles intensively until the mid-1960's. They periodically returned to make various observations and measurements.

Work at the Frijoles site was from a field camp on property known as Las Dos. In camp, Luna excelled in dutch-oven cooking on an open fire. His specialties included albondegast soup and hot sourdough bread. An after-dinner treat was Luna playing the guitar, frequently singing songs from past Pick and Hammer shows. Camp seemed to attract colleagues. Luna's Associate Chief, Ray Nace, showed up to "write." And there was Walter Langbein walking the terrain in a heavy rain, looking for overland flow.

One of the studies on perennial streams was at the Popo Agie River near Hudson, Wyo. For several years, Luna and Bob Myrick had been using a campsite among the cottonwoods along the stream while making high-water measurements during spring snowmelt. By 1963, Bill Emmett had been working with Luna for a couple of years, and Leon Wiard was SWB District Engineer in Wyoming. In June, the four of them were in camp when about 6 inches of rain fell during the night. Luna bragged about his lean-to tarpaulin, but it leaked like a sieve. For those in their sleeping bags, which took in water like a camel in the desert, some spots of water felt like an ocean. By daybreak, Leon was wrapped around the steering wheel in the truck trying to stay dry. A brief lull in the storm provided an opportunity to start a campfire. After wet pancakes for breakfast, all four were off to measure water-surface profiles and channel scour at high flow (Emmett and Leopold, U.S. Department of Agriculture misc. publ. 970, 1965).

Returning to the Popo Agie River about midafternoon, the four found much of the camp to be under water. Bill grabbed an air mattress as it started floating downstream. Some remaining camp gear was floated out on the mattress, leaving behind such items as submerged dutch ovens. (It turned out, a dutch oven makes a good trap for overbank sediment deposition.) Leaving the camp gear on the road shoulder, the field crew returned to making high-water measurements. Later that night, with wet sleeping bags and no cookware, Luna allowed as to how the group could stay in a motel. Though it was for but one night, it was a "first."

Camp was wrecked, the site was a mess. Luna's science then moved from the east flank of the Wind River Mountains of Wyoming to the west flank. Pinedale became the centerpiece. In the quarter century following the relocation to the Pinedale area, Luna, his associates, and students prepared more than 50 technical articles on aspects of the hydrology and river channels around Pinedale. If that is not a record, then the number of doctoral dissertations generated there probably is.

During the early 1960's, usually with Bill Emmett, Bob Myrick, and other associates, Luna began making river expeditions. At first, commercially operated float trips were made on the Green River and on the Colorado River upstream from Glen Canyon, but to float the Colorado River through the Grand Canyon, Luna had personnel of the GWB Field Unit in Phoenix assemble equipment and boats to do previously undone science. Herb Skibitzke and Howard Chapman put together two pontoon boats to float the big rapids and from which discharge could be measured and sediment samples retrieved.

The Grand Canyon trip was made in 1965 with Smuss Allen and Bruce Lium as boatmen. Although rumors emphasize the fun of such adventures, few rumors attested to the science involved. One product of the Grand Canyon trip was a first-ever sonar recording of depth through a couple of hundred miles of pools and rapids (Leopold, PP 669, 1969).

A highlight of the Grand Canyon float trip about which rumors abounded (but for which no two rumors were the same) was the resupplying of equipment and food by parachute drop. The truth of the parachute drops is that they did not always work as planned. Bags of bread seemed to land in the river, while large cans of fuel found their way to the cliffs above. Especially memorable was the block of ice and heads of lettuce in the same bag. The parachute did not open. The ice exploded on impact and shredded the lettuce. There was instant chilled-lettuce salad.

During subsequent years, primarily with Luna and Bill, the same and smaller boats were used for river expeditions from Alaska to Arizona. Mixed with the fun and tribulation was a healthy dose of science; probably a lot more about hydraulic and channel geometry is known because of such trips.

Luna was a pioneer in bedload research—theory, measurement, the whole bit. The ultimate contraption was a bedload trap, designed by Luna and the eminent British physicist, Ralph Bagnold. The stream where the trap was installed was the East Fork River at the Pinedale center of research. Through several trials and errors, the basic design remained essentially unchanged. The bedload trap consisted of a U-shaped trough placed across the streambed with trapdoors that could be opened or sealed. Bedload fell through the open doors into the trap, was moved shoreward on a conveyor belt, and deposited into a continuous weight-versus-time recorder. The measured bedload was then returned to the river downstream from the trap (see for example, Emmett, PP 1139, 1980).

Luna conceived the trap while he was Chief Hydrologist, but something about moving parts and sediment limited success during the 1960's. Although Bob Myrick oversaw the field design and construction of the first successful trap during 1972 and Bill Emmett was project chief for most of the operational phase throughout the 1970's, the idea was Luna's and he should rightfully receive credit for the conveyor-belt bedload trap on the East Fork River. It is not without reason that his bedload trap is known worldwide.

### Statistical Methods in Hydrology

*By* H. C. Riggs *and* reviewed *by* Clayton H. Hardison

The Division greatly increased its emphasis on the use of statistical methods in hydrology with the establishment of the SWB Research Section under the direction of Rolland W. Carter in 1955. Statistical applications were greatly abetted by rapid advances in computer technologies and services during the years following.

During 1957–66, many applications of statistical methods to hydrologic problems were proposed and evaluated. Notable ones are documented in PP 434 (1963–64) by Nicholas C. Matalas, who investigated the nonrandomness of time series, the theoretical distribution of low-flow extremes, the statistics of a runoff-precipitation relation, and the conditions under which hydrologic data could be augmented by correlation with a longer record.

Frequency curves, their preparation, interpretation, and reliability were studied and reported on by Tate Dalrymple, Manuel A. Benson, Walter B. Langbein, Clayton H. Hardison, and H. Charles Riggs. For example, Dalrymple described procedures for estimating flood-peak characteristics at ungaged sites by the index flood method (WSP 1543–A, 1960). An alternative method of regional analysis, regression on basin characteristics, was developed by Benson, who applied it to floods in New England (WSP 1580–B, 1962) and in the Southwest. Regression on basin characteristics was also used for flow characteristics other than floods and the effect of interstation correlation on regression analysis was investigated. Hardison developed a procedure for stating the reliability of an estimate from regression analysis in terms of equivalent years of record.

The results of these many studies were evaluated, and those procedures that appeared to be desirable for use within the Division were described in technical memorandums and recommended to District Chiefs and staff officials. Many of these procedures were included in a manual on statistical tools in hydrology (Riggs, TWRI book 4, chap. A1, 1968). Benson's work on frequency curves was the basis for the WRC's Bulletin 15, "A uniform method for determining flood flow frequencies."

Valid applications of statistical methods to hydrologic data result only when the analyst understands the available methods and their limitations. In order to promote this understanding in the Division, Riggs prepared a correspondence course, Elementary Statistics in Hydrology, in 1959. The course consisted of 19 lessons, most of which were keyed to specific chapters of a statistics textbook. The course was administered by the SWB Training Section which reported that by May 1960, students from 32 Districts and from all Branches of the Division were enrolled. By 1973, when the course was discontinued because the original edition of the key textbook was no longer available, about 450 students had completed the course. (See Part VI, "Correspondence Courses.")

## Snow and Ice Studies

*By* Wendell V. Tangborn *and* reviewed *by* Mark F. Meier, Austin S. Post, *and* Donald Richardson

During the 1930's and 1940's, glacier research within the USGS had been conducted by Francois Matthes of the then Topographic Division and before that by Harry Fielding Reid and others of the Geologic Division. Matthes died in 1948, leaving a gap in the field except for investigative glacier research carried out by Arthur Johnson of the then Conservation Division. Johnson's work consisted primarily of photographs and annual surveys of the Grinnell and Sperry Glaciers in Glacier National Park and Nisqually Glacier on Mt. Rainier. In 1956, the WRD, with the initiative of Luna B. Leopold, began a glacier research program with the hiring of Mark F. Meier, who was then a Fulbright Scholar in Innsbruck, Austria. Glaciology has been a truly interdivisional effort in the Geological Survey.

One of the primary goals of the WRD snow and ice research program was to determine how glaciers respond to climate change. It had long been thought that the indelible traces left by glaciers on the landscape in some way portrayed past climates. But the complex interaction of a glacier with its environment needed to be understood with greater precision before past climates could be deciphered from glacier imprints.

The seriousness of the impact of climate change on society was not a topic of great concern in the 1950's, as it is today, so the foresight that was shown in the development of this program is quite remarkable. From the very beginning there was a strong emphasis on understanding how a glacier responds to nearly imperceptible changes in climate, both on local and continental scales. A significant change in the Earth's climate did occur in the mid-1940's, and this appears to have been clearly documented in 1946–48 by Arthur Johnson's measurements on Nisqually Glacier in Washington (prog. rept., 1949) and subsequently by a reversal in the drastic retreat that most of the world's glaciers had undergone since the middle of the 19th century.

The snow and ice research during the 1960's and later was largely directed toward an improved understanding of how a changing climate would affect water supplies derived from snow and ice. Over much of the United States and many areas of the world, snow and ice are important sources of runoff. Because changes in the climate would alter both the seasonal snowcover and the size and extent of glaciers, and therefore have a significant effect on water resources, another goal of the research program was an improved understanding of snow and ice hydrology. Pioneering work on observation of seasonal snow was begun in the 1960's with some of the first work on the remote sensing of seasonal snowcover. Another important consequence of the snow hydrology research was the development of an improved streamflow forecasting model for mountainous basins by W.V. Tangborn and L.A. Rasmussen that is now used operationally by several water-use organizations in the Western United States and was reported later in Water Resources Research (v. 12, no. 2, 1976).

In 1957, the South Cascade Gacier, a small mass of permanent ice (1 square mile in area), situated in the North Cascade Mountains of Washington, was selected as the key research site for the snow and ice program, and a temporary streamflow gage was constructed at the outlet of the glacier's terminal lake. Snow accumulation and ablation measurements on the glacier were also initiated at this time.

In 1960, Wendell V. Tangborn, hydraulic engineer, transferred from the St. Paul, Minn., SWB District to the Glaciology Project. Austin Post, who worked part-time from 1957 to 1965, became a full-time hydrologist in 1966. William J. Campbell joined the project as a meteorologist in 1964, and Lowell A. Rasmussen began work (part-time at first) as a mathematician in 1965. In 1964, Post's research program of aerial photography of Western North American glaciers, sponsored by the National Science Foundation and administered by the University of Washington, was permanently transferred to the USGS and expanded.

The South Cascade Glacier program at first emphasized glacier dynamics and the ice and water balance of the glacier and the small catchment that contained it (Meier and Tangborn, PP 424–B, 1961). Considerable effort went into designing and constructing streamflow and precipitation gages that would operate year-round and withstand the harsh environment in which they were placed. [It is noted that Joe Witte, now (1990) the weather reporter on NBC's Today show, worked for the project as a Hydrologic Field Assistant in 1962 and 1963.]

Several significant findings regarding glaciers resulted from this project during the 1958–66 period. One of the early major contributions was a study by Meier and Tangborn of the time-varying flow and mass balance of South Cascade Glacier (Jour. of Glaciology, v. 5, no. 41, 1965)—a study that was designed to provide the observational setting for the first quantitative analysis (by Professor J.F. Nye) of the dynamic response of a glacier to its balance history, thus establishing the formal connection between glacier variations and climatic change (Proc. Royal Soc. of London, Ser. A, vol. 275, 1963). In addition, for the first time longitudinal profiles of ice discharge and thickness of a glacier were calculated using only surface measurements.

Another noteworthy accomplishment was the determination of the total water balance of a heavily glacierized basin. The capability to do this led to another important discovery later on when it was found that glaciers internally store a substantial amount of liquid water, as reported by Tangborn (Water Resources Research, v. 2, no. 1, 1966). Considerable skepticism in the glaciological community was first encountered by this finding; however, it has since been confirmed for many other glaciers the world over. Subglacial water now has to be considered in predicting the response of both a glacier and a large ice sheet to climate change.

On a larger scale, an inventory of the distribution of glaciers in the Western United States and Alaska was begun during this period and reported by Meier (IASH publ. 54, 1960). In addition, analyses of the net balance variations of these glaciers were conducted using the immense collection of aerial photographs taken by Austin Post during the previous decade. This particular contribution, reported by Meier and Post (IUGG, Comm. on Snow and Ice, publ. 58, 1962) has left its mark on the world literature of glaciological and Quaternary studies through the introduction of proxy measures of glacial conditions such as ELA (equilibrium line altitude) and AAR (accumulation area ration). A very significant contribution was Post's seminal grasp of the unusual behavior of what now are called surging glaciers, currently a subject of considerable international interest. Along with Post's observations of glacier surges (Journ. of Geophysical Research, v. 65, 1960, and Journ. of Glaciology, v. 8, no. 53, 1969), he was able to lay to rest the entrenched earthquake-advance theory for anomalous glacier advances (Science, v. 148, 1965). Outburst floods from glaciers were also documented and analyzed during this period (Post and Mayo, HA 455, 1971). Post, also, in his observations of Alaskan glaciers, first drew attention to the anomalous behavior of tidewater (iceberg-calving) glaciers. Current theories on the possible surge and disintegration of the West Antarctic Ice Sheet draw heavily on the concepts advanced by this group.

The surging and tidewater glacier research bore fruit in later years with several important discoveries regarding the instability of large glaciers. The observations of tidewater glaciers, together with field studies and numerical modeling, lead to the development of the concept of tidewater glacier instability and the successful prediction of the drastic retreat of Columbia Glacier in Alaska in the 1970's.

Another accomplishment of lasting value was the awakening of international interest in the hydrology of glaciers and mountain snowpacks, due to major programs of the International Hydrological Decade (1965–74) and the subsequent International Hydrologic Programme. This program was spearheaded by the Glaciology Project Office and involved workshops at South Cascade Glacier and the international exchange of glaciologists.

The Leopold years of 1957–66 were unusually productive for snow and ice research in the Water Resources Division and many of the results and publications, then and later and too numerous to mention herein, stem directly from this period.

### Role of Plant Growth in Hydrologic Studies

*By* Nicholas C. Matalas *and* Robert S. Sigafoos

The WRD had long appreciated the fact that hydrologic information could not be provided at an arbitrary location on a timely basis, and that historical hydrologic records might not coincide with "normal" climatic periods. The hydrology-climate-vegetation linkage was recognized as a cost-effective basis for extending hydrologic records in both time and space: natural vegetation provides evidence of extreme floods and of sediment deposition during periods of flood recession; mountain forests provide a history of past glacial activity; and tree growth responds both to climatic variation and to toxic chemicals in the environment.

To undertake research in the botanic-hydrologic field, the Division obtained the services of Robert S. Sigafoos, botanist, in 1957, who transferred to the General Hydrology Branch from the Geologic Division. Using data collected while with the Geologic Division, Sigafoos published in 1958 a "Vegetation map of northwestern North America" (Bull. 1061–E) to aid in permafrost and recent plant-fossils studies underway in that Division.

In WRD, Sigafoos began work on the Potomac River to bring tree growth within the scope of hydrologic analysis in his assessment of the age of flood-felled trees along the banks of the river. He demonstrated that, although trees in the direct path of floods are felled, lower trunks and roots remain alive. The downstream pointing of felled trunks attest to the flood event, and the ages of vertical sprouts and scars provide evidence of the year of the event. Wood from buried trunks which have characteristics of distinct root wood provide, by virtue of their age when felled, the year of burial. These studies, which allowed for dating past floods, corroborating historical floods and estimating the return period of floods, particularly in areas where flood records are not available, were reported in PP 387–A (1961), PP 485–A (1964), and elsewhere in scientific literature.

Further use of documenting the ages of trees was demonstrated by Sigafoos and E. Leroy Hendricks through their research on the slopes of Mount Ranier, 1958–60. Through an extensive collection of cores from trees, predominantly Douglas fir, on distinct ridges and moraines downvalley from active valley glaciers, Sigafoos and Hendricks were able to describe the dates of the recession of glaciers in terms of the ages of the trees, and thereby to provide evidence of climate change in the region (PP's 387–A, 1961, and 650–B, 1969).

Also in 1958, Sigafoos made a brief study of the effects of strip mining on forests as part of an interagency study in Kentucky on hydrologic impacts of strip mining. His work showed that trees irrigated by acid mine-drainage waters were growing significantly faster than before such irrigation or faster than trees not being irrigated.

These studies and others that followed served to motivate interest within the WRD in the role of dendrochronology in hydrologic studies. To expand its role in botanic/hydrologic research, particularly to further understanding of hydroclimatic factors affecting tree growth, the WRD established a tree-ring laboratory in Arlington, Va., in 1965. Through the laboratory, the Division was able to provide a more structured interface with other researchers in dendrochronology in improving the quality of tree-ring data, enhancing the storage and retrieval of data, and advancing statistical techniques of data analysis. An initial and continuing role of the laboratory has been the development of dendrochronologies for the Eastern United States to complement the western chronologies that have been the longstanding focus at the University of Arizona. Richard L. Phipps, botanist, who began his WRD career in Ohio in 1961 working on field studies with Sigafoos, transferred to Headquarters to head the tree-ring laboratory and to continue his research.

The laboratory has had as one of its primary goals that of providing supportive service to other botanical research activities within the WRD undertaken to provide information that complements or substitutes (at least partially) for more direct hydrologic information relating to such phenomena as floods, sedimentation, and glaciation and to environmental consequences of human activity, for example, mining.

### Hydrologic Remote Sensing

Reviewed *by* Donald R. Wiesnet

Hydrologic remote sensing during the Leopold years was spurred by two major factors: (1) internal interest in the Division, principally by Herbert E. Skibitzke of the Phoenix research office and by Luna Leopold and (2) the entry of the National Aeronautics and Space Administration (NASA) into the field of earth-oriented studies, including hydrology.

The following account of the development and role of remote sensing in WRD consists of two parts, the first describing the role of the Phoenix Research Office under the direction of Skibitzke and the second describing the work sponsored by NASA which was led by Charles J. Robinove in the Washington Headquarters. There is some overlap between the two, but the work at Phoenix went on during the entire period of this history while the NASA-sponsored work in WRD began later, in 1964.

#### *Airborne Remote Sensing Conducted by the Phoenix Office*

*By* Mary Lou Brown *and* reviewed *by* Herbert E. Skibitzke

Airborne remote sensing as a means of data collection was introduced into the WRD at least 10 years before it was acknowledged as a useful tool for hydrologic investigators—and long before the term "remote sensing" was coined. It began in 1949 with aerial photographs of the Sand Hills region of Nebraska made from a two-place Taylorcraft piloted by Skibitzke. Geologist Coyd Yost—a seasoned pilot in his own right—sat with his camera in the open doorway of the plane. The classic photos are in existence today.

The Phoenix Research Office was established in 1954, in a judge's cloakroom in the old U.S. Post Office and Court House Building, when Skibitzke's research efforts for the U.S. Atomic Energy Commission, under

C.V. Theis, required greater security than could be afforded in the subdistrict office. There, he wrote the finite-element equations that enabled the development of the analog computer to solve equations of groundwater movement. While the computer revolutionized hydrologic studies, it also highlighted the need for quantities of current, synoptic data to be used along with historical point measurements as computer input. Aerial photography had already been proved a superior means of obtaining large amounts of watershed information in a short time and at low cost.

In 1959, Luna B. Leopold, a proponent of modernization in analytical techniques, authorized acquisition of WRD's first airborne platform for aerial photography. A new program that would survive for 17 years, producing prodigious amounts of remotely sensed information for offices of the Survey, other Federal agencies, and cooperators throughout the United States, including arctic Alaska, and Panama, was underway.

"Airborne" is the key word describing the WRD remote sensing operation. Cameras and sensing equipment carried in airplanes at altitudes ranging from 500 feet above ground level to 35,000 feet above mean sea level acquired large-scale images of localized environmental situations as opposed to the very small-scale imagery of vast areas made from orbiting spacecraft. The two methods differ also in that airborne sensing is done when needed under optimum weather conditions, whereas space imagery is necessarily made on a rigid schedule of path and time generally without regard to cloud cover. Both methods provide valid and useful information, but for different purposes.

Purchasing aircraft, either new or used, was completely out of the question from a budgetary standpoint. However, aircraft and equipment surplus to military needs, yet more advanced than anything on the commercial market, had become available for "transfer without exchange of funds" to civilian Federal agencies. Thus, a Navy T–34B became the first of a number of aircraft acquired by WRD. During the life of the remote-sensing project, the Survey acquired aircraft and sensing equipment valued at many millions of dollars from the defense agencies. The monetary value of almost any single item exceeded the annual budget for the entire unit.

Acquisition of aircraft and sensors was only the first step in the operation. Those items were designed and built for military purposes; they had to be modified and adapted for scientific use, a process that would have been impossible but for the capabilities and versatility of the unit's technical personnel, under the leadership of Howard T. Chapman. For example, on one occasion the Air Force estimated the cost of modifications to install a camera system in a T–33 jet trainer at $1 million, and the time for the work at 1 year. Chapman and Electronics Technician Albert E. Robinson, aided by two or three Survey employees, accomplished the job in 2 months at a cost of about $2,500 (not including salaries).

The airborne platforms used by the unit were the smallest and most economical that would safely and effectively accommodate each sensing device. Each sensing method has its own operational requirements. For instance, thermal infrared sensing is most effectively used in the hours of darkness when the target area is not heated by the sun, while infrared photography is best done between 10:00 a.m. and 2:00 p.m., when the sun is at or near its zenith. Ultraviolet photography reveals the glint of oil on water when done at slant range from very low altitude, while other techniques require vertical orientation, higher altitudes, and greater speed. A large airplane, in which a variety of different instruments was installed to provide multispectral capability, was rented for a brief period. It did not prove to be economically feasible because repeated flights were needed to accommodate the requirements of the different techniques, increasing the costs of operation and maintenance.

A twin-engine Beech D–18, also from the Navy, was the second plane in the "fleet." The twin-Beech was the platform for a succession of thermal imagers with progressively better resolution and stability. The U.S. Army provided a Canadian-built DeHavilland U6A Beaver, a boxy, single-engine workhorse that served as a platform for a large camera, a thermal imager, or an ultraviolet imager. It could be and was used on wheels or on floats depending on the locale and type of operation. In subsequent years, more sophisticated aircraft such as a Lockheed T–33 jet trainer, a twin-engine Cessna 310, a single-engine Cessna 180, a twin turbine-engine Grumman OV–1B Mohawk, a Sikorsky H–19, and a Bell UH–1F jet-powered helicopter were added along with classified and extremely complex electronic equipment, including an AAS–22 thermal imager and an APS–24 Side Looking Airborne Radar.

The scientific, technical, and administrative personnel of the Phoenix Research Office were an effective working team. Hiring restrictions and budgetary constraints precluded adding additional employees to pilot the aircraft. Therefore, it appeared more reasonable to train incumbent personnel who were already involved with the program to perform flight duties than to replace them with pilots who had no knowledge of or abilities in the technical aspects of the Division's activities.

When President Lyndon B. Johnson initiated a program allowing Federal personnel to acquire training in order to upgrade their positions, several employees of the unit requested and received permission to take flight training in order to participate in the remote sensing program. Through that program, several key personnel, including Geraldine M. Robinson and William Meyer, Hydrologists, and Mary Lou Brown, Research Program Administrator, became instrument-rated pilots, a proficiency level required for project pilots. Flying skills were utilized along with the employee's primary job qualifications to facilitate project work, much as the ability to drive a car is used in land-based operations.

Innovative programs generally are targets for criticism and subjects of controversy. The remote sensing operation was no exception. There were no guidelines within the agency for the use of airplanes, helicopters, and sophisticated electro-mechanical and electronic sensing equipment. The pilot training program, aircraft acquisition, maintenance, and operation created turmoil within the Division and the Survey that persisted in various degrees of intensity as long as the project existed. Nevertheless, Leopold remained staunchly supportive of the group's efforts. Flight operations were conducted in accordance with Federal Aviation Regulations. Safety was the primary consideration, closely followed by respect for the Survey's professional and ethical reputation. The personnel voluntarily dressed in uniform clothing identified with USGS patches to avoid the appearance of impropriety in the operation of Government aircraft. Later, the unit was recognized by the Office of the President as a National Emergency Response Team, and by the Office of Management and Budget as a cost-effective data-collection group.

Equally as important as the data-collection phase of remote sensing was the laboratory processing of the film products containing the acquired data. Geneva Magness, a clerical worker, upgraded her position by increasing her abilities as an amateur photo processor to a professional level. That was a large order, because the film involved was 9 inches wide in rolls of 100 to 250 feet. The first crude laboratory was established in the crowded basement of the Ellis Building in downtown Phoenix; the offices—bulging with the expanding roster of personnel—were also in the old building. In 1961, the office and laboratory were moved across the street to the newly constructed Federal Office Building. Over the next 15 years, a film processing laboratory that was second to none in the area was developed. A wide variety of film products, such as black and white, normal color, infrared color, infrared black and white, and ultraviolet photos, and thermal and SLAR imagery, were processed regularly. The sizes and formats of the film ranged widely. Again, military surplus was the primary source of equipment, and again, the installation, maintenance, and operation of the equipment were performed by the crew. The reputation of the laboratory was such that film manufacturers provided test rolls of new types of film for project use in return for evaluation of the film and the development techniques recommended by the manufacturer.

NASA called upon Skibitzke for consultation on remote sensing projects in Mexico and Brazil, and in preparation for the orbit of the first manned satellite. Responding to requests from Headquarters, Regional, District, and subdistrict offices of the Survey, the unit conducted, among others, photo and imagery studies of changes in watersheds due to urbanization; eutrophying lakes and prairie potholes in Nebraska and Minnesota; meanders and sedimentation processes in rivers and streams; estuarine processes in the Potomac River and in Bolinas Lagoon on the coast of northern California; evapotranspiration losses due to phreatophytes in Arizona; extent of fires in coal mines of Pennsylvania; flood damages caused by the rampaging Brazos River in Texas as an aftermath of Hurricane Beulah; pollution in Lake Erie; saltwater intrusion in Puerto Rico and the Virgin Islands; and changes in the hydrology of central Alaska as a result of the 1964 earthquake.

In 1966, the WRD unit, offering a complete range of airborne remote sensing, had a staff or more than 30 employees. Most of them had upgraded their positions—and their value to the agency—by taking advantage of training opportunities. For the next 9 years, the group continued to develop and refine techniques for collection, processing, and interpretation of data remotely collected, applying them successfully to environmentally related projects of front-page importance for USGS offices, NASA, the Department of State, UNESCO, and other government entities. Budgetary constraints and problems pertaining to aircraft maintenance and operation rendered the project infeasible by the mid-1970's. The unit was disbanded in 1976.

#### *Remote Sensing Research Sponsored by NASA, 1964–66*

*By* Charles J. Robinove

In 1961, Charles J. Robinove, who was then in the Operations Section of the GWB, began work with William A. Fischer of the Geologic Division on the hydrologic applications of airborne thermal infrared measurements such as surface-water temperature measurement and the mapping of the discharge of ground water to surface-water bodies. This work was interrupted by Robinove's transfer to the St. Louis Regional Office in 1963.

In 1965, NASA began its "Natural Resources Program" under the direction of a geologist, Dr. Peter Badgley, in the Office of Space Science and Applications. As a result of negotiations between NASA and other Government agencies, the Geological Survey was given the responsibility for remote sensing and space flight research in four areas: geology, hydrology, cartography, and geography. Naturally, the hydrology responsibilities were centered in the WRD.

In FY 1965, the initial funding of $100,000 from NASA to WRD went to the Phoenix Research Office under Skibitzke to provide for coordination of the program and for support of the airborne research activities of the office.

By November 1965, it was obvious that, because of the large and continuing demands of NASA, the program needed to be coordinated directly from Washington to cope with the almost daily meetings with the NASA staff. Leopold asked Robinove to return from St. Louis to direct the program from a new Remote Sensing Hydrologic Applications Center. Robinove agreed and returned to WRD Headquarters.

The first task in the expanded program was to decide on the rationale for hydrologic remote sensing research. Two choices were faced: (1) concentrate research on hydrologic principles with a smaller number of projects and the help of high-quality researchers, or (2) provide for a large number of small empirical studies using anyone who would volunteer to undertake the studies and report on the results. The latter choice was made for the basic reason that, if the studies and research were successful, then the WRD would then a reasonable number of trained and experienced people ready to use remote-sensing data in hydrologic studies as such data became routinely available.

A description of the proposed program was sent to field offices with a request for project proposals. Eighteen proposals were received and several were selected for funding, limited only by the ability of the proposers and the available funds. Proposals included mapping of water and vegetation in the Florida Everglades, studies of the Salton Sea in California, and mapping of ground-water discharge to streams. To implement the proposals, money, and access to NASA data such as aerial photos, infrared images, radar images, and other types of remote-sensing data for the selected project sites were provided to the project leaders.

Not only airborne data were supplied. Space photographs from the Gemini and Apollo missions became the first space data to be used for hydrologic purposes. It was evident that data acquired from space could be of great benefit to hydrologic studies, particularly when comparisons of surface phenomena over large areas were needed.

By May 1966 the program was well underway. Projects had been selected, data were being acquired by NASA, preliminary ideas were being put together for future hydrologic space-flight experiments, coordination was underway with the other programs of the USGS and NASA, and meetings were being held with the Department of Agriculture (which was responsible for agricultural and forestry remote sensing) and the Naval Oceanographic Office (responsible for oceanic remote sensing).

These actions of the USGS, NASA, and the other involved Government agencies were spurred by the realization that a common base of data could and would be beneficial to all who studied or managed natural resources. Thus began, in a small way, the program of Earth observations from space that is continuing today on a worldwide basis. The WRD pioneered this effort, conducted some of its first research, and has been recognized as a leader in the field.

## Tracers in Hydrology

*By* Frederick A. Kilpatrick, Alfred Clebsch, Jr., Leland L. Thatcher, *and* James F. Wilson

The late 1950's and early 1960's could be considered the "boom" years of water tracing by WRD personnel. During this period, the use of radioactive tracers in hydrologic studies reached its zenith, then all but ceased as fluorescent dyes emerged as the tracers of choice. The use of tracers in hydrologic studies falls into four categories of measurement: (1) simulation of solute movement in streams to include both rate or speed of travel (time-of-travel) and dispersion; (2) measurement of water discharge by dilution techniques; (3) ground-water movement through both porous (dispersive) media and nondispersive media, such as karst and volcanic systems; and (4) simulation of waste movement and buildup in estuaries.

The tracers used in hydrology include (1) those deliberately introduced and (2) tracers of convenience, in which uncontrolled variations in concentration of a constituent, such as temporal changes in tritium concentration of precipitation, are used as a time marker. The surface-water discussion deals primarily with the former group. Ground-water applications embrace the latter category as well. Tritium has also been used, along with carbon–14, for age-dating ground water, but those applications are discussed elsewhere.

Encouraged by the AEC as part of the "Atoms for Peace" program, WRD engineers and hydrologists were actively using radioactive tracers in hydrologic studies by the late 1950's. In one of the first such tests, Eugene S. Simpson, W. Arthur Beetem, and Frederick H. Ruggles (AGU Trans. v. 34, no. 3, 1958) injected phosphorus-32 into the Mohawk River to measure the speed and dispersion of waste discharged from the Knolls Atomic Power Laboratory near Schenectady, N.Y. Richard G. Godfrey and Bernard J. Frederick (PP 433–K, 1970) performed 11 tests in five natural channels and one canal, onward from the late 1950's, using radioactive tracers to study dispersion. In 1964, Nobu Yotsukura, George F. Smoot, and Donald I. Cahal performed dispersion tests in a 150-foot flume using salt as the tracer (ASCE Hydraulics Div. Conf., 1964). The widespread use of radioactive tracers, however, was restricted by safety and licensing requirements.

In the early 1960's there was increased need for time-of-travel information on major streams by civil defense and public health agencies. This led to the estimation of time-of-travel using the continuity equation, or discharge/area approach of computation. Noteworthy were studies by Robert E. Steacy (Circ. 439, 1961) of the Ohio River and James K. Searcy and Luther C. Davis (Circ. 438, 1961) of the Potomac River. Estimates of time-of-travel computed by this method eventually were found to be greatly in error.

Also in the early 1960's, Rolland W. Carter and Charles W. Reck, SWB Research Section, became aware of the work of D.W. Pritchard and J.H. Carpenter (IASH, Bull. 20, 1960) of the Chesapeake Bay Institute, Johns Hopkins University, in oceanographic tracing using rhodamine dye and filter fluorometers. Pritchard and Carpenter must be credited with being the fathers of modern dye tracing. This marriage of highly fluorescent dyes and very accurate and sensitive fluorometers ushered in an era of time-of-travel studies nationwide by the WRD. Before dye tracing was adopted for routine use by WRD field offices, however, Robert R. Wright and Michael R. Collings (AWWA Jour., v. 56, no. 6, 1964), as well as others in the Research Section, investigated the potential applications of dye tracing, eventually recommending its use not only for time-of-travel studies but for dispersion and dilution-type discharge measurements as well.

SWB Memorandum 63.29 (December 14, 1962) officially passed further development from the Research Section to the Hydrologic Studies Section, advocating it as a means of obtaining "coefficients of correction" of computed discharge/area results. It was soon recognized, however, that actual time-of-travel measurements using dye could be performed accurately and inexpensively, so the coefficients were never developed. The Hydrologic Studies Section as well as certain Districts (particularly New York) proceeded to develop operational procedures, concentrating on two areas: (1) improvements in instrumentation and dye technology and (2) field performance methodology.

While it is not possible to assign to any individual complete credit for any one development, certain names stand out: John R. Kreider, Bernard Dunn, and James F. Wilson were involved deriving means to estimate dye quantities. Dunn and Donald E. Vaupel (PP 525–D, 1965) investigated temperature-fluorescence effects; Ernest D. Cobb, Wilson, James F. Bailey, and Frederick A. Kilpatrick developed fluorometer calibration techniques. One of the first TWRI training manuals "Fluorometric procedures for dye tracing" by Wilson (book 3, chap. A12, 1967) evolved from the efforts of these and others.

Field techniques evolved from the hands-on performance of dye-tracer type time-of-travel measurements. While the list is long, most prominent were Kreider (WRD Bull., May 1963), Dunn, Thomas J. Buchanan (ASCE Proc., v. 90, no. SA3, 1964), Wilson, William J. Schneider, and Eric L. Meyer.

Space limitation precludes detailed discussion of the more salient time-of-travel measurements made by Division personnel through 1966. Measurements on three rivers, however, deserve special mention: the Potomac, the Mississippi, and the Missouri.

The Potomac River measurement of May 1964 was the first truly large-scale, long-reach time-of-travel measurement. Maryland District personnel led by William E. Forrest and assisted by SWB personnel and others, decided on short notice to do the dye study after the graphs of Searcy and Davis (1961) proved inaccurate for predicting movement of an oil spill in the river. Dye was injected simultaneously at six locations over a 189-mile reach ending at Washington, D.C. The lessons learned in planning, organizing, and supporting such an operation were soon applied elsewhere.

When Hurricane Betsy sank a barge carrying 600 tons of liquid chlorine in the Mississippi River on September 10, 1965, SWB personnel of the Louisiana District and Headquarters responded with a measurement of time-of-travel between Baton Rouge and New Orleans (Mack R. Stewart, HA 260, 1967). Personnel, dye, and equipment were flown in from many cities, and on the night of September 15, 20 WRD employees on a barge attached to a towboat dumped 2 tons of rhodamine B as a single slug into the river at Baton Rouge (the Coast Guard insisted it be done in the dark). The river discharge was 240,000 cubic feet per second ($ft^3/s$). The dye arrived in New Orleans in about 2.4 days and took another 3 days to pass. The Louisiana

District received a unit award "for excellence of service" for this effort.

Two multiple-reach measurements on the lower Missouri River from Yankton, S. Dak., to St. Louis, Mo., were made in 1966 (James E. Bowie and Lester R. Petri, HA 332, 1969). These measurements involved the tracing of rhodamine dye through 10 subreaches for a combined distance of 806 miles. In the first measurement, 10 injections totaling 2,306 pounds of dye took a cumulative time of 13.5 days to travel the reach at a river discharge from 31,000 $ft^3/s$ to 42,000 $ft^3/s$. In the second measurement, 10 injections totaling 2,425 pounds of dye took a cumulative time-of-travel of 16.75 days at discharges of 10,500 $ft^3/s$ to 33,000 $ft^3/s$. Five States were involved in each study with more than 100 WRD personnel participating. In addition, the U.S. Army Corps of Engineers, the FWPCA, the USWB, and 16 State and municipal agencies assisted.

Dilution methods of measuring discharge have been known since at least 1863 (Spencer and Tudhope, IWE Jour., v. 12, 1958). Until about 1960, chemical salts were generally used as the tracer injected into the stream with attendant problems due to density differences. Radioactive tracers were used successfully by Frederick, Reck, and Carter (PP 450–D, 1962) to measure the flow in a 2-inch pipe. Frederick followed this by the successful measurement of turbine discharge at the Dale Hollow Dam near Celina, Tenn., using gold-198 as the radioactive tracer (Frederick, open-file rept., 1964).

With the successful use of filter fluorometers and fluorescent dyes to accurately measure very low concentrations of tracers, dilution gaging appeared finally worth serious consideration. In Virginia, Wilson, Cobb, and Bailey, SWB, experimented initially with rhodamine B and later with the more conservative rhodamine WT; in Colorado, Kilpatrick did much the same, successfully using Pontacyl Pink dye. In both Virginia and Colorado, efforts were made to obtain reliable, portable, constant-rate-dye injection apparatus. Pneumatic-powered chlorine injectors (Cobb, WSP 1892, 1968) or mariotte constant-head tanks were tested and used until the mid-1970's, when battery-driven fluid-metering pumps were found to be superior to the others for injecting dye at a constant rate.

In the East, Cobb and Bailey performed dye dilution measurements during 1964–66 on a number of small streams, including Robertson Creek and Scott Run in Virginia and Seneca Creek in Maryland. Also, a number of dye dilution/diffusion tests were run by Frederick and others in the Clinch River, Tenn. (see "Clinch River Study"). At the same time, Kilpatrick was performing successful dye-dilution measurements on the Colorado River, Colo., Middle Loup River, Nebr., Green River, Wyo., the Rio Grande Conveyance Channel, N. Mex., and on a number of small streams in the Rocky Mountain States. In 1966 in Wyoming, Kilpatrick, Kenneth D. Wahl, James G. Rankl, and Terry J. Perkins (Wyoming District) (WRD Bull., Oct.-Dec., 1967) performed dilution-discharge measurements of flow under ice on the Laramie River. Rankl went on to use dye-dilution measurements to verify the stage-discharge rating curves for two gaging stations on streams in the Medicine Bow Mountains, Wyo. In Colorado, Kilpatrick was successful in measuring unsteady flow in the Charles Hansen Canal by using dilution techniques. This experience led to the publication of the training manual on dye-dilution gaging by Cobb and Bailey (SW Tech., book 1, chap. 14, 1965).

Tracers used in ground-water studies have included chemical solutes (sodium chloride, for example), fluorescent dyes, and radioactive ions. Radioactive tracers have been used to best advantage in ground water. Because of the wide variety of chemical identities available in radioactive tracers, it is often possible to select one that is relatively immune to reaction with the geochemistry of the aquifer, thus minimizing tracer loss by sorption and reaction. Tritium is the only radioactive tracer wherein the tracer atom is a constituent of the water molecule (an intrinsic tracer)—all others are solute tracers—hence, tritium is a superior tracer. This has been abundantly confirmed in comparative tracer tests in a variety of media. A second advantage of radioisotopes is the extreme detection sensitivity, which means that minute amounts of tracer are used, and there is minimum effect on physical properties of the water slug.

The development of analytical capability to a very high degree of precision under Leland Thatcher gave impetus to the use of tritiated water as a ground-water tracer and in age-dating studies. (See "Radiohydrology.") An excellent example of work in that program was that of Charles W. Carlston, Leland L. Thatcher, and Edward C. Rhodehamel in 1960, who identified both thermonuclear and natural tritium in a small New Jersey sand aquifer. High tritium at the water table clearly indicated recent recharge. Stratification was identified by the vertical distribution of tritium content. It was shown that only the topmost layers of ground water contributed to the flow of an effluent stream.

Another Survey-funded project involving surface-water/ground-water relations was conducted in New Mexico. Bernard J. Frederick, assisted by William F. Curtis and others, spiked Lake McMillan, on the Pecos River north of Carlsbad, with 50 curies of tritiated water. Relatively complete mixing brought the tritium concentration in the lake up to 2,000 tritium units

(T.U.). Harold Reeder and Leland Thatcher (USGS TEI–839, 1963) followed the progress of this tracer through the Seven Rivers Formation into the Major Johnson Springs area about 3.5 miles distant. Travel-time was 2.75 to 3 months.

In a very significant paper, Charles V. Theis, International Atomic Energy Committee, Tokyo symposium (1963), made a detailed examination of an early project at Carrizozo, N. Mex., wherein the author offered two alternative conclusions based almost entirely on tritium data. Theis showed that both conclusions were illogical. He further showed that introducing the concept of hydrologic dispersion into evaluation of the tritium data resulted in a tritium-based interpretation that was fully consistent with a logical hydrological interpretation.

Theis' influence on WRD's research on ground-water tracers was profound. In addition to the previously cited paper, he provided technical guidance to WRD personnel working at AEC installations in Idaho and South Carolina and provided the conceptual design for laboratory experiments using dye tracers to illustrate the effect of geologic inhomogeneities on the dispersal of a dye plume (Theis, AEC Proceed., TID–7628, 1962). In that work, carried out in Phoenix, Ariz., by James Cahill and Howard Chapman under the supervision of Herbert E. Skibitzke, physical models simulated the effects of highly permeable lenses within a granular aquifer. It was demonstrated that flow lines are refracted at permeability boundaries and that velocity is highly accentuated and dispersion is magnified.

The most extensive use of tracers in ground-water hydrology during the 1957–66 period was in connection with work supported by the AEC. In addition to the opportunity for detecting extremely low concentrations of radioactive species (and under some circumstances in-situ detection using downhole instruments), tracers afforded a means of determining rates of flow under known hydraulic gradients and change in concentration due to hydrodynamic dispersion that was critical to understanding the migration of wastes emplaced or infiltrated into the ground-water flow system.

At the National Reactor Testing Station (NRTS) near Idaho Falls, Idaho, Paul H. Jones of WRD and W. Scott Keys, then of the AEC, assisted by Don A. Ralston applied radioactive tracers to solve various ground-water problems. Both Jones and Keys were specialists in borehole geophysics (indeed Keys transferred to WRD in 1963 to head the Denver-based borehole geophysics research project) and they developed methods for measuring velocity and direction of flow within a borehole (Keys and McCary, TWRI book 2, chap. E1, 1971) to locate permeable zones penetrated by a well. The technique uses a logging tool with gamma-ray detectors at each end and a small reservoir of solution containing iodine-131 near the center. A small pump, controlled from the surface, ejects a pulse of tracer into the well, which moves up or down the well hole in response to hydraulic gradients, either natural or artifically imposed by pumping a nearby well. The technique was developed out of a need to define individual permeable zones within the thick sequence of basaltic rocks underlying the Snake River Plain into which aqueous wastes from the reprocessing of nuclear fuels were discharged through a disposal well. Introduced tracers and constituents of the waste stream as tracers had been studied at NRTS since the mid-1950's, when Peckham in 1959 found that some chemical constituents in the waste were moving through the Snake Plain aquifer at rates of 15 to 50 feet per day <u>at a substantial angle</u> to the hydraulic gradient inferred from water-level measurements.

Tritium was found, almost accidentally, to be a constituent in the wastes in 1960, leading to its intensive study as a tracer to determine velocity and direction of flow from the injection well to a number of sampling wells at different distances and in different directions. This permitted a heightened appreciation, if not a thorough understanding, of hydrodynamic dispersion in the basalt aquifers, which was augmented by detailed subsurface logging (including trace-ejector logs) that enables thin permeable zones to be defined and correlated. It also demonstrated on a field scale the effect of adsorption of certain cationic waste constituents, such as strontium-90, resulting in a greatly reduced velocity of movement. Similar studies were made by Warren E. Teasdale and others of the migration of tritium in a perched alluvial aquifer from a waste-disposal pond near the test-reactor complex. Donald A. Morris (AGU monograph series 11, 1967) provided a broad overview of the Idaho work.

One of the difficulties in using tracers to study ground-water flow is the slow velocity of movement. An innovative way to circumvent this problem was devised by I. Wendell Marine (AGU monograph series 11, 1967) of WRD and his associates of the DuPont Company, the prime contractor operating the Savannah River Plant, near Aiken, S.C. They conducted a test using two wells that penetrated the same fracture zone in the crystalline metamorphic rocks that lie about 1,500 feet below land surface. By pumping water from one well and piping it to the other, where it was tagged with 300 curies of tritium and injected, they imposed a very steep hydraulic gradient between the two wells, 1,765 feet apart, thus increasing the velocity of flow. Even so, the tracer experiment ran for 2 years. Further analysis of the test data by Webster, Procter, and

Marine (WSP 1544–I, 1970) refined the hydraulic characteristics of the permeable zone (porosity and transmissivity) and produced a dispersion coefficient (mixing length).

Dye tracers have not been widely used for tracing flow through granular aquifers in consolidated rocks; dyes have been used successfully in karst areas or where flows were through open fractures, tubes, or solution channels. In 1963, Francis A. Kohout used rhodamine B to trace flow from the Biscayne Aquifer into Biscayne Bay. In Puerto Rico, Kilpatrick and Bailey, using rhodamine WT dye, successfully traced runoff from a copper mining waste-disposal area through the underlying karst and into the Arecibo River. In California, Thomas W. Robinson and Donald E. Donaldson (Water Resources Research, v. 3, no. 1, 1967) used dyes to measure the uptake of water by phreatophytes. In Louisiana, Russell L. McAvoy used dyes to check drilling cores for the presence of drilling mud and to determine circulation times of the mud (oral commun., McAvoy to J.F. Wilson).

Estuaries have not escaped the tracers efforts; John R. Williams (PP 575–B, 1967) used rhodamine B dye in the Duwamish River Estuary in Washington to study time-of-travel and dispersion.

In 1966, a paper mill was planned for construction near Riceboro, Ga., and the mill effluent was to be discharged into Riceboro Creek, a part of the Newport River estuary system. In the first waste-simulation/dye-tracer study by the Survey, 200 pounds of rhodamine WT were injected at the proposed waste discharge site and observed for 70 total cycles in the estuary. Using the superposition principle and observed dye concentrations, the effect of the proposed mill discharge was simulated (Thomas R. Dyar, Gary D. Tasker, Robert L. Waite, and others, in USGS report to Georgia Water Quality Control Board, 1972). Assisting in this major effort were Kilpatrick, Yotsukura, Bailey, and Wright. This estuary-tracer study was the forerunner of numerous such studies to be performed in East Coast estuaries in the 1970's.

A history of dye-tracing work by WRD would not be complete without mentioning the memorable first conference and training session on the subject held April 19–21, 1966, in Estes Park, Colo. Original plans calling for a conference in February were set aside in favor of the April date when fair weather could be expected. As the scheduled date for the start of the conference approached, one unequivocal fact was forcefully brought to the attention of the planners; don't try to outguess Colorado weather! A major spring snowstorm hit the Rocky Mountain area, closed the Denver airport, and virtually stopped all vehicular traffic in the area. Nevertheless, 44 of 45 scheduled attendees made the trip to Estes Park, truly indicative of the dedication of WRD personnel. Fifteen States, the District of Columbia, and Canada were represented. Snow continued to fall through the night and the next day. Never has there been a more captive audience than those who were the who's-who in dye tracing.

Since the inception of modern dye tracing, other Federal and State agencies have used dye-tracing techniques occasionally. Hydrologists of the WRD, however, continue to apply dye tracing operationally and experimentally nationwide, building on the pioneering efforts of both Headquarters and District personnel during the 1960's.

### *Tracers in Hydrology—The Rest of the Story*

*By* Bernard J. Frederick

Previous articles have quite adequately presented, complete with authors' names, names of principal investigators and/or consultants, and references, what is usually discussed in Survey publications about tracer investigations. However, few, if any, of the many field personnel who actually performed the work are named, nor is any mention made of incidental happenings that make life interesting or relieve the tension that is nearly always present in research. The following comments are a long-overdue tribute to at least some of the individuals who actually did the work that made it possible for researchers to publish!

A is for Anderson, S. Grady, the soft-spoken (he always whispered and could be clearly heard half-a-mile away) stream gager in charge of the Marion, Va., subdistrict office. Incredibly, Grady never owned a watch (unless he received one at the time of his retirement). While he was on "active duty" in the field, he carried an alarm clock!

The natives of the hills of southwestern Virginia trusted Grady, a fact which made life easier during the eight dispersion studies carried out in that area. For example, the first Clinch River site-selection reconnaissance group, of which Grady was not a member, was greeted at one point by a rather large man who carried a very evident "horse pistol." The man said, "Last week I told you government men to stay off my property, and I meant it. Now git!" The group leader made a rather futile attempt to discuss the situation (because none of his people had been in the area last week), but he was easily discouraged by a couple of waves of the pistol. The group meekly boarded their vehicles and drove to another map-selected site, hoping for a more congenial welcome. Grady joined the group that evening and was told of the day's happenings. He suggested that "you folks just don't understand the language of these hills" and we should go back and let him talk to the man. Again, we were met by "horse pistol," but within a very few minutes he was telling the history of his granddaddy's pistol to Grady over a cup of coffee in his store. Not only were we allowed on his property, but he also said he would spread the word down the valley that "these government men were O.K."

On the other side of the coin, consider the following episode. A couple of men on site reconnaissance got rather hopelessly lost in the maze of unmapped dirt-track roads in the boondocks and wandered around several hours before finally "locating" themselves on a map. It was already 7 p.m. and getting dark, and their "location" was nearly 3 hours' driving time over more back roads from the country hotel where they had arranged to spend the night. Nonetheless, there was little choice but to give it a shot at trying to get to the hotel. Unfortunately, a hard rainstorm came up and they got stuck in the mud, with the ultimate result being that they did not arrive at the hotel until midnight. The only light evident was at the door, but they were so wet, tired, and discouraged that they went to the door anyway. Under the light was a note telling them to go in and go up the stairs and into the first room on the right, which they did. In the room they found another note which told them that the fireplace was ready to be lit—simply light the newspapers under the coal using the dry matches left on the bureau; that the fuel would last about an hour, which should be long enough to "get shed of the damp" and let you get a good night's sleep in the feather bed (look in the bottom drawer for extra blankets); and breakfast would be on the kitchen table by 6 a.m. And so a long, miserable day turned into an event remembered for its kindness. (The Biblical phrase "I was a stranger and you took me in" comes to mind!) Would the men have fared as well at a big city hostelry?

Another incident involving Grady occurred at the cleanup of the most downstream site of the first Copper Creek test. After the tracer plume had passed, the equipment was loaded (by the light of the bonfire that had been burning several hours for light and warmth). Grady then dipped water from the stream to extinguish the fire, stepped back to inspect his handiwork, caught his heel on a tree root, and fell back into the stream. His coworker helped him out and then ran to the car to turn on the headlights. Grady was soaked, of course, and had no change of clothes. However, there was a white lab coat in the vehicle, so Grady stripped to the buff and put it on. All the way into town—about 20 miles—he grumbled about going through the "Big War" without getting his wallet wet like this, or talked about what explanation he might give if they were stopped by the local constabulary and were asked why two men, one of whom was practically naked, were riding around at 11 o'clock at night! His coworker had a somewhat warped sense of humor, and when they got to town he decided to go to a drive-in with curb service and get a hamburger and coffee before they went back to the rooming house. Grady, of course, was grumbling all the time, and holding the front of his lab coat together, especially during the time the curb girl was taking his order.

B is for Byrd, F. Dave, a laconic, completely unflappable Kentuckian from the Williamsburg office. In the initial stages of the first Copper Creek dispersion study, the project leader was standing in the stream, near the bank, and reached out behind to grab a tree root to steady himself. Dave calmly and firmly said to him, "Don't move a muscle, not even your eyes to see what I'm doing," in such a tone that the group leader obeyed without question. The next sounds were the swish of a machete, a thud when it hit, and Dave's voice saying "It's O.K to move now." The leader turned to see the severed head of a snake in a tangle of roots less than 2 inches from his handhold and Byrd calmly wiping blood from the blade of his machete. Byrd never mentioned the incident again—it was just one of those things good men do.

Another Williamsburg office employee, the office chief, Chester A. Minehan, should be recognized because of the extraordinary quality of his discharge-measurement notes. Their clarity, accuracy, and completeness exceeded every recognized standard, and to describe them in such a simple term as "beautiful" (which they were) would be an understatement.

C is for Curtis, William F., of the Albuquerque, N. Mex., office. Bill was the person primarily responsible for the design of, and who piloted, the boat used for injecting 150 curies of tritium into Lake McMillan for a tracer (and leakage) study. On the day of the injection, Lake McMillan had a surface area of 6 square miles and an average depth of 4.5 ft, for a total volume of 17,400 acre-feet, or 5.7 billion gallons. The tritium arrived at the site packaged in 50-milliliter (0.0132 gallon) bottles at a concentration of $1 \times 10^6$ microcuries/milliliter, or about $3.3 \times 10^{10}$ times the maximum permissible concentration (1959 MPC regulations) for a lifetime exposure. Initial dilution in the 55-gallon, especially designed mixing tank reduced the concentration to only 88,000 maximum permissible concentration (MPC), and average concentration of 26 samples taken from the lake during the injection operation was only $3.7 \times 10^{-4}$ microcuries per milliliter (about 0.1 MPC), or a $3 \times 10^{11}$ times reduction from the "as shipped" condition. The fact that about half of the injection was carried out during the night (the work was started at 10 p.m. because of high winds and waves in the afternoon) with no evidence of contamination to personnel, clothing, or equipment (according to personnel from the Los Alamos Scientific Laboratory, who monitored the entire operation) is remarkable, and a tribute to well-trained and exceptionally competent people—like Bill Curtis.

And then there is Lewis C. McWilliams, senior technician of the Knoxville, Tenn., subdistrict office. It is impossible to describe "Mac's" ingenuity in arriving at a practical solution to logistical problems or equipment malfunction problems in a field situation, and his services were indispensable during all 11 dispersion studies as well as in the turbine flow-measurement exercises and the Clinch River study. He was also a "take charge" kind of man if the situation so warranted. Case in point, the Powell River dispersion study. It was necessary to ford the river downstream from the third observation point and run the last three points on the opposite side of the river from the road, a maneuver which presented certain difficulties. After ensuring that the first two observation points were operating satisfactorily, Mac returned to the injection site to assist in that operation. After the injection was completed, he was to visit sites 3 through 6 to assist as needed. Site 3 was doing fine, but when he broke over the hill leading to the ford he was surprised (a bit of understatement here) to see that the vehicle that was to carry the equipment to site 4 was floorboard deep in the river about 50 feet out from the near shore. (The vehicles carrying the equipment for sites 5 and 6 had already gone ahead.) Realizing that there was only a short time before arrival of a plume of radiogold, he suggested (another understatement) that the site-4 personnel walk to the site with the necessary equipment and get set up so that important data would not be missed, and let him worry about the vehicle and prepare an explanation if it should become contaminated. As soon as the people were on their way, Mac removed the distributor cap and plug wires from the car, dried them off and replaced them, removed the fan belt to prevent the fan from spraying water on the plugs and cap and get them wet again, then started the vehicle and backed it to shore—before the leading edge of the tracer plume had even reached site 3. No problem. Because this tracer test was late getting started, and because the plume did not travel as fast as expected, it became obvious in midafternoon that it would be dark before the plume had passed the most downstream sites. The decision was made to remove all except the radiation-detection equipment from the last two sites, get the vehicles and all except two people from each site back across the ford before dark, and let the remaining people remove the equipment and go downstream in two boats to another ford about 0.5 mile below the last site. (Because of the shallow depths and low velocities, this was not too dangerous, but the many rocks and boulders in the stream would make the trip rather nerve-wracking if the night was very dark. And it was, with visibility so poor that rocks more than 10 feet away could not be seen.) Shortly after the journey started, light appeared from an unexpected, almost incredible, source. Fireflies started to appear, and within minutes thousands of them—maybe tens of thousands—lit up the valley so much that rocks as far as 30 feet away could easily be distinguished. Except for several slight bumps, the trip was made without incident. Rather than being nerve-wracking, it was actually enjoyable!

One last story about Mac. Even though he worked in the Knoxville office, he was a Mississippi man through and through, and it was with some reluctance that he agreed to make the trip to California for the Coachella Canal dispersion test. But once he resigned himself to the fact that he was not going to get grits for breakfast, or turnip greens and/or blackeyed peas for supper, he enjoyed the trip. His love for Mississippi was apparent on the return trip, however, because as soon as he crossed the State line he stopped the car to get out and rub his hands in the dirt!

A couple of items of interest during the Coachella Canal test were: (1) during 3 days in the desert along the canal, the only animal life seen were humans, who should have known better than to be out in the noonday sun (Englishmen, maybe, or mad dogs) and one crazy duck (what it was doing the desert, we'll never know); and (2) a representative of the California Department of Public Health, who had been trying to catch a fish to examine for radioactivity and had a stroke of luck when he saw one of the local fishermen catch one just as the peak concentration of the radioplume was passing the most downstream site. He immediately negotiated a purchase, but we do not know the price, nor were we informed of his findings concerning the fish's assimilation of radiogold.

## Instrumentation

*By* George F. Smoot *and* reviewed *and* contributed to *by* Russell H. Brown, Herman R. Feltz, A. Ivan Johnson, Francis C. Koopman, *and* Eugene Shuter

The expanding role of hydrologic analyses, problem-solving investigations, and research in WRD forcibly brought to the forefront the necessity of automating the processing of data. Personnel would be freed from the drudgery of manually processing analog charts. Data would be made available in a variety of useful forms and in a more timely manner. Consequently, a new program of extensive proportions was launched to develop reliable instrumentation for obtaining data in a form suitable for automatic data processing. Initial attempts at automation began in 1953 to develop optical scanning of gage-height analog charts (SURWAC)—see Ferguson, Volume V, p. 231. But by 1958, because of persistent scanning and electromechanical problems, the development project was terminated.

At about that time, a punched, paper-tape recorder that had originally been developed by the Fisher-Porter Company as a traffic counter was tested for use as a water-stage recorder. This recorder was basically a device for encoding and digitally recording on punched-paper tape the rotational position of an input shaft. Testing was conducted over the next several years, and even though there were minor problems (especially difficulties with the timer) the recorder was sufficiently successful for the Division to embark on an extensive program to replace the old strip-chart recorders.

Because of the recognized need to develop new instrumentation and to make existing instruments compatible with the automatic data processing (ADP) systems, the SWB established the Instrumentation Research Unit in Columbus, Ohio, in the mid-1950's. Edgar G. Barron and Harold O. Wires initially staffed the unit and were joined by George F. Smoot in 1956. One of their first major projects was the development of the servomanometer (commonly referred to as the bubble gage). This was one of the more significant instruments developed during the period.

High priority was given to the development of a device which would give a continuous measurement of velocity in situ. Much time and effort were devoted both in-house and by contract to two techniques which appeared to hold much promise:

The first, the electromagnetic probe, consisted of a strut with an embedded electromagnetic coil and two buttonlike electrodes on the surface. As flowing water cut through the field of flux, an electromagnetic force was generated and was picked up by the electrodes, the output of which was proportional to the velocity of the water. The U.S. Navy used this device as its primary ship's log; however, in freshwater the signal was found to drift as the electrodes became contaminated.

The second, the ultrasonic flowmeter (acoustic velocity meter), generated an acoustic wave which was transmitted diagonally across a stream in an upstream direction and returned from the receiving point to the transmitting point. The difference in traveltime was proportional to the integrated water velocity along the path. This device has been used on a number of rivers in the United States and in Europe.

Other instruments developed by the Instrumentation Research Unit included:

- The VADA (velocity-azimuth-depth assembly), which combined a sonic recorder with a remote-indicating compass and current meter to measure depth, direction of flow, and velocity at any point in a stream or estuary. The sonic transducer and compass were sealed in a streamlined, 149-pound, brass sounding weight. A seven-conductor slip ring and swivel assembly on the top of the hangar allowed the weight and meter to rotate independently of the supporting cable so that they would be properly positioned even in velocities as low as about a tenth of a foot per second.
- A vane-type current meter that uses four vertical vanes rather than cups and does not fill with slush as do the cups on a Price meter when operated beneath ice. The yoke, pivot, bearing, and contact chamber were of similar design to the Price meter.
- A weight assembly designed for cable-suspension discharge measurements through 5-inch-diameter or larger holes in the ice cover of streams.
- The Model A recorder, a battery-operated, continuous, float-actuated recorder designed to obtain flood hydrographs at crest-stage gage sites. The float operated in a 3-inch pipe, and stage was recorded on a circular disk that made one revolution every 24 hours. The range of the recorder was 10 feet with an accuracy of 0.1 foot.

Paul C. Benedict was a driving force in establishing the St. Anthony Falls Research Laboratory. With Brynon C. Colby as leader of the project, significant progress was made in designing and calibrating sediment sampling devices. (See "Geomorphic and Sediment Processes.")

In a written communication to Hudson, February 20, 1990, Eugene Shuter recalled several milestones in the in-house development of equipment for groundwater investigations. In 1956 and 1957, Francis C. Koopman, William J. Drescher, and the Columbus (Ohio) Equipment Development Unit were working independently on equipment to continuously record water-level changes in small-diameter observation wells. By 1958 or 1959, each effort had produced a workable prototype. The Koopman "Ferret Gage" provided the best results although it was prone to electrical failure and was difficult to repair in the field. Following Shuter's return to Denver in 1963 as Chief, Equipment Development and Service Unit, GWB, he conducted further tests of the "Ferret Gage" and in 1965 had 20 units manufactured for installation in a special ground-water study area at the Savannah River Plant of AEC near Aiken, S.C. It worked successfully but was made obsolete with the development of the servomanometer or bubble gage.

In 1959, Shuter had the task of obtaining hundreds of water samples from specific points in wells for chemical and radioactive analyses. Equipment then used for such sampling was the Foerst Thief Sampler, which was not always reliable. During the next several years, Shuter worked with Don A. Ralston, borehole geophysical logging equipment operator, and with Joe Sena, electronics technician, to develop a more reliable point sampler. Ralston devised a brass tube with rubber stoppers that could be positively closed from the surface by activating a 12-volt solenoid control mounted in the sampler. Three were manufactured and used at the National Reactor Testing Station in Idaho, the Hanford Site in Washington, and the Savannah River Plant in South Carolina. In 1964 or 1965, Sena made further improvements and the sampler became standard equipment for borehole geophysical loggers.

Water quality and pollution had become an area of great national concern, and the use of electrochemical sensors for in-situ measurements held promise. In the late 1950's and early 1960's, rapid advances in the reliability of pH electrodes were achieved by several manufacturers and found favor with a large number of investigators. Also in the early 1960's, considerable effort was devoted to testing solid-state electrodes for field measurement of sodium, chloride, and ammonia. These electrodes had poor detection limits but were found to be useful as reconnaissance tools. Some of the early pioneers in adapting commercial laboratory instruments for field applications were David McCartney and the staff of the Philadelphia QWB District and George W. Whetstone and Charles R. Collier of the Ohio QWB District.

S. Kenneth Love and Walton H. Durum, Chief and Assistant Chief of the QWB, quickly recognized the need to improve sensors, standardize systems, and adapt them to the Division's data-processing system. They called upon Smoot and his staff to pursue these goals and significant progress was made.

Herman R. Feltz demonstrated in 1965–68 that automated wet-chemical analyzers could be operated successfully in the field to continuously monitor nitrate, nitrite, ammonia, and phosphate. Although feasible, they required frequent attention and were practical only under special circumstances.

The practicality, quality, and quantity of work produced by automated wet chemistry having been demonstrated, the equipment was placed in a specially built trailer (Midas) and the mobile laboratory used for reconnaissance and repeated analysis of samples for projects on Long Island, in Georgia, and in Florida.

[Editor's note: Less-formal research and development of instrumentation was (and is) carried out in the field and at Headquarters offices to meet specific, ad hoc needs of research or investigative projects. Results or products of some of these efforts have been widely used throughout the Division and by the hydrologic community elsewhere. Instrumentation research of this type is mentioned in other sections of Volume VI but generally without citable references. Documented and informal research in instruments and other equipment used in sediment studies are discussed in "Geomorphic and Sediment Processes."]

## Operations Research

Contributed to *and* reviewed *by* Harry H. Barnes, Jr., Irving E. Anderson, Clyde S. Conover, *and* Walton H. Durum

Along with rapid technological advances in the 1950's came more sophisticated approaches to management. Earlier applications of time-and-motion studies and other types of efficiency analysis grew into a new broader concept involving applications of scientific methods to overall management problems and systems. The objective of this new science was to optimize an entire system for overall effectiveness. The associated "buzz word" of the day and extending onward into the 1960's was "operations research."

The objectives of this concept appealed to the leadership of the WRD. The SWB appeared to have initiated the first efforts when Rolland W. Carter, John E. McCall, and Charles W. Reck presented an operations-research proposal to the first meeting of the SWB Research Council in April 1956. The Council responded positively and rated the activity as first priority of a group of 20 surface-water research projects being recommended for FY 1957. Branch Chief Joseph V.B. Wells approved the Council's program, as did the Division, but it was July 1957 before funding and staffing became available to formally start the project. The GWB and the QWB also budgeted and staffed their operations research projects later in that fiscal year.

The operations-research efforts were assigned to and conducted by the three operating Branches, each with its particular problems. The project leaders in each Branch formed a coordinating committee to keep abreast of and share in the planning and results of their work in order to assure a coherent Divisionwide program.

Irving E. Anderson, formerly District Engineer, Mississippi District, SWB, assumed the leadership of the operations-research group at SWB headquarters in July 1957. Reck, of the Branch's Planning Section, completed the team. The two remained with the project for its duration through 1960 when Anderson was reassigned to head the Division's Planning Section. Reck remained on the Branch Chief's staff after that, finishing assignments begun under the operations-research project.

The sole concern of the project was surface-water basic data—types and forms of data products needed, accuracy requirements for the data, and data dissemination modes and formats (SWB memorandum, August 15, 1957). The SWB District offices were called upon for assistance in providing information and conducting field surveys and tests in support of these major study components.

Questionnaires completed by SWB District offices, supplemented by Anderson's extensive personal interviews with officials of water-management agencies and water-resources consultants in nine States, proved highly useful in identifying problems and data needs. A wide array of data deficiencies and statistical data formats desired for water-resources planning, project design and construction, project operations, and regulation were identified.

By late 1958 the group began concentrating on accuracy requirements, which according to Anderson (internal report, 1958) involved two questions: (1) "What accuracy in hydrologic design data such as flow-duration curves, flood-frequency curves, and the like is required to produce the optimum project," and (2) "What is the effect of accuracy of our basic data on design data." Though these questions could not be finitely answered in all aspects, they led to critical analysis of several elements involved in data collection, computation, and processing. This work, in turn, led eventually to significant changes in field and office practices that achieved economies without significant sacrifice in accuracy, such as mathematical checking of discharge measurements, frequency of making discharge measurements, methods of velocity observation, and final records review.

Perhaps the greatest impact of operations research on Divisionwide programs was that of data publication. Time requirements to prepare, review, obtain Bureau approval, and publish reports in the formal Survey series had greatly increased in the 1950's, much to the concern of the Survey's information-using constituency and even the Congress. All three Branches used the Water-Supply Paper series as the traditional mode for publishing basic data, and those reports were organized by major drainage basins or regions (14 parts, plus Hawaii and Alaska for surface-water records). Most reports, therefore, had to await receipt and review of records from several Districts, thus prolonging the time required to publish—usually several years after the end of the water year. Anderson and Reck, after analyzing and evaluating the entire process of computing, reviewing, and publishing records, recommended that basic data be released in new series of reports prepared and printed, State by State. The proposal was approved by the Chief Hydrologist and the Director and implemented nationally for surface-water basic data beginning with water year 1961. Along with this change in publication mode, procedures in computing and reviewing surface-water records were modified. As a result, time-to-publish was reduced immediately to less than 1 year in most Districts. Later, ground-water and quality-of-water data were added to the State reports.

As a culmination of their operations-research effort, Anderson and Reck conducted a thorough examination of personnel use in the SWB, with special examination of the increased use of technicians in lieu of professionals. Adrian H. Williams reported on this study at the Dallas SWB conference in December 1960. According to SWB Memorandum 61.84, May 24, 1961, the study projected key personnel replacement needs, 1961–85, and recommended an accelerated recruiting program for professional employees, increased use of technicians in basic-data programs to free more professionals for other programs, and greater support for career development and training of technicians. All these efforts were effected, Divisionwide, in the years following.

Fundings for operations research in the SWB averaged about $30,000 per year for the four fiscal years 1958–61.

The operations-research project in GWB was formally launched when George H. Taylor, Regional Engineer at Lincoln, Nebr., was reassigned to the position of Research Hydraulic Engineer effective December 29, 1957, without a change in headquarters. Records are sparse as to specific efforts undertaken by Taylor. He apparently concentrated on project planning and managing and preparing the reports, including report-review processes. Throughout the period of this history, he continued to oversee and review the queue of ground-water reports stemming from the preceding years of the Missouri River Basin (MRB) program. His work in operations research seemingly stemmed from problems he encountered in dealing with the backlog of MRB reports.

In an administrative report of October 1959 on GWB activities for FY 1960, the operations-research objective was stated as follows:

> The ever-increasing demands upon the Branch dictate that a continuing analysis be made of branch procedures and operation. Accordingly, the objective of the "Operations Research" project is to examine critically the responsibilities and operations of the Branch and to search for ways and means to improve the Branch's efficiency in meeting these responsibilities adequately.

In a similar GWB report of December 1960 that outlined the program for FY 1961, the final year of operations-research funding, accomplishments were summarized as follows:

> Accomplishments to date are: development of a card-filing system for report control, now adopted by the Division; development of a new manuscript routing sheet and checklist, which helps in insuring adequate report review; recommended installation of shelf filing to reduce space requirements for filing manuscripts; recommended continuance report-flow record to improve control; recommended checklist to replace or supplement interview sheet to enable analysis of data uses and users; recommended field release of written statements to the press; responsible for instituting photocopy system of preparing corrected file copies of manuscripts in less time than formerly; and research on pen and pencil types suitable for photocopying. Effort in 1961 is directed particularly toward a study and evaluation of the operations and planning aspects of the Branch.

Clyde S. Conover, who served as Assistant Chief of the Branch during those years of operations research, recalled (oral commun., June 1990) that Taylor's development of documents for project planning, progress reporting, and report reviewing were adopted by the Branch and have largely continued to be used by the Division.

One aspect of improving the documentation of progress and completion of projects was the "blackboard" list kept in the Operations Section of the Branch to track the status of investigations by Districts. Whenever a District supervisor visited the Washington office, he was personally shown the list and asked about the status of his investigations, particularly those that were behind schedule. This operation was significant in bringing overdue projects up to schedule.

Funds expended in the GWB operations research effort, FY 1958–61, amounted to less than $80,000.

Herbert A. Swenson, District Chemist at Portland, Oreg., transferred in February 1958 to the Office of the Chief, QWB, to head that Branch's operations-research project. One of Swenson's first efforts was to prepare a statement on operations research (June 1958) to define the program and its objectives, first in general terms and then specifically for the QWB. For the latter he stated:

> The operations research project of the Quality of Water Branch will evaluate our present position and effectiveness in the field of water quality. We hope to obtain answers to such questions as: Who uses water-quality records and for what purposes? Are there many potential users of our product who are unaware of what we are doing? Have we given proper attention to the consideration of water as an environment for geological and biological processes or for chemical and physical reactions? Are we occupying fully the field of water quality and are we recognized as leaders in this division of applied science? Replies to these and other questions may give us a measure on how well we are doing the job in water quality.

Subsequent activities involved historical review of water-quality activities of the Survey and user surveys and assessments of water-quality information needs and uses. The latter were categorized operationally as to chemical, sediment, and temperature, and informationally as to basic data, analyzed data, and interpretive data. In these activities Swenson drew heavily on assistance from the QWB field offices.

A summary of research activities of the QWB for FY 1960 described the significant results of the operations research project as being a series of administrative reports, all emphasizing "means to enhance the Survey's reputation and leadership in the field of water quality...." The reports all personally authored (or coauthored as in number 4) by Swenson, none of which are now on file, were listed as:

- Water quality—a study of utilization, problems, publications, and field of activity
- Operations research (the June 1958 statement cited above)
- Leadership in water quality

- Writing about water, by I.E. Anderson, G.H. Taylor, and H.A. Swenson
- Water quality and the Geological Survey
- An examination of costs incurred in water analysis (in review)

Walton H. Durum (written commun., August 1990) expressed the opinion that the very successful series of USGS primers on water, such as Swenson and Baldwin's Primer on Water Quality (1965), was a result of the operations research efforts to identify a type of publication that would be informative to the nontechnical public.

Funding for operations research in the QWB probably totaled about $60,000 over the 4-year period, extrapolated from the $15,000 allotment as documented in records for FY 1960.

All in all, the operations research projects afforded opportunity for serious self-examination of operational problems and improvements needed throughout the Division. The effort involved reassessment of roles, objectives, operational and technical procedures, and dissemination of hydrologic information. This, in turn, provided an improved baseline for operations policy and management as the Division moved toward making major changes in program direction and organizational structure.

## Computer Applications in Hydrologic Data Processing and Analysis

*By* Charles R. Showen with assistance from Solomon M. Lang, William L. Isherwood, *and* Charles O. Morgan

The acquisition of a general-purpose digital computer by the Geological Survey in 1956 provided a new tool for use by engineers and scientists in hydrologic studies and data processing. The earliest and largest project undertaken to take advantage of the power of this new computer was the automation of streamflow records.

Streamflow records were originally computed from a record of stage and recorded in analog form on a strip-chart and from a stage-discharge relation that was defined empirically by current-meter measurements. Many of the steps in the data-reduction process required tedious and time-consuming work that could be accomplished more efficiently by digital computers. Records from strip-chart recorders were not suitable for direct input into digital computers, nor were manual computation procedures particularly efficient when transferred directly to machine processing. Consequently, the search for applicable automation techniques involved changes in the basic method of recording information as well as changes in computation procedures.

Efforts to automate streamflow records began in 1952. Initial steps were toward the development of a device that could automatically read graphic strip charts and convert the position of an inked line representing gage height into a discharge record by means of a special-purpose computer that was partly analog and partly digital (see "Instrumentation"), but by 1958, the effort was not deemed successful. Instead, an analog-to-digital recorder (ADR) was developed under contract with the Fischer and Porter Company to record water levels at gaging stations. The instrument was a slow-speed paper-tape punch that recorded a four-digit gage height on a punched tape in a configuration of holes in a single transverse row across a tape 2-1/8 inches wide. The timers for the ADR could be set to punch at 5-, 15-, 30-, or 60-minute intervals. The prototype of the recorder, delivered in December 1958, was subjected to extensive tests in an environmental chamber to determine its performance under extremes of temperature and humidity. After minor modifications, 100 production models were distributed for trial in actual field installations. The first deliveries to the field (20 recorders each to Massachusetts, Alabama, Kansas, and California, with 20 in reserve) were in February 1960. Later, 400 slightly modified instruments were purchased, of which 200 were delivered to the field in October 1960 and 200 were held in reserve. Field trials of the production models revealed only minor problems with the recorder itself but immediately pointed up the need for additional work in design of the timer unit. During the first 18 months of field operations, three different types of timers were tried, none of which gave satisfactory performance. Finally in May 1961, satisfactory timers were obtained and delivered to field offices in November 1961. Continuation through May 1962 of field tests indicated that the ADR and timer performed acceptably.

The paper-tape compact format of the ADR was a parallel-by-character arrangement, an arrangement that required only a minimum of recording equipment and battery power in the field installation, whereas digital computers required a serial-by-character coding in paper tape for direct input. The system developed for use in the Survey used the compact form of basic recording by interposing a translator equipped with pinboards to produce serial-by-character tape in any 5- to 8-channel coding and any digit arrangement required. This translator was intended to preclude the obsolescence of thousands of field recorders whenever it should become necessary or desirable to change computers.

In April 1962, a work group was activated to evaluate the ADR pilot operation and to consider the expansion of the system to the streamflow network. The work group, made up of WRD and Administrative Division (AD) personnel, consisted of Rolland W. Carter, Chairman, William L. Isherwood, Charles R. Showen, and Winchell Smith of WRD and Kevin W. Rolfe and W.L. Anderson of AD. Recommendations of the work group were reported in Circular 474 (1963).

The computer programs to process records from simple stage-discharge relations were prepared by Isherwood. A somewhat more complex computer program prepared by Isherwood was for "slope stations" where gage heights are recorded by two separate instruments at the ends of a selected reach of channel and the interrelationships between stage, fall, and discharge are used to compute discharge. In addition, he prepared a program for "deflection meter" stations, where a movable vane mounted in a fixed position in a channel gives an index of velocity and direction of flow, and discharge is computed as the product of an area and a point velocity/mean velocity relationship.

The basic ADR was later modified to accommodate electrical as well as mechanical inputs and to record multiple parameters in sequence along the tape. As sensing devices for chemical quality generally used electrical outputs, the digital recorder became a versatile instrument for recording many water parameters.

Other computer programs developed for surface-water hydrologic analyses included:

- The conversion of all past mean-daily streamflow values into machine-readable form, using punched paper tape. These values were then used to prepare flow-duration tables (discharge values in relation to percent of time) and low- and high-flow sequences summaries of 1, 7, 14, 30, 60, 90, 183, and 274 days duration. This was the beginning of a computer-formatted national data base of streamflow values, which required many years to complete.

- The development of a tidal-flow computer program by Robert A. Baltzer and John Shen that used stage records at each end of a reach of tide-affected channel to compute discharge. For each 15-minute time interval, the unsteady flow condition could be computed.

- In 1965, William P. Somers and Gary I. Selner developed a computer program to compute discharge based on the slope-area measurement technique.

- A computer program was prepared to compute back-water profiles in open channels from field survey data. This program aided in defining stage-discharge relations for flood levels at a particular site.

- Manuel A. Benson and Donald M. Thomas used computer techniques to establish regression relations between numerous streamflow indices and the physical and climatic characteristics of contributing drainage areas.

Beginning in 1963, the Kansas GWB District began the development of a punch-card system for the storage and retrieval of ground-water data. This system, known in the WRD as the "Kansas System," initially consisted of a two-card format for basic water-well data. By early 1965, the system had been expanded to include water-quality, water-level, and lithologic-log data for wells and other ground-water sources.

The "Kansas System" evolved from efforts by Jesse M. McNellis, in early 1963, to computerize procedures for the analysis of aquifer tests. McNellis and Charles O. Morgan began, in late 1963, to design and implement the computerized system for the storage of basic ground-water data. The easy access to a computer at the University of Kansas that was made available by the District's principal cooperator, the Kansas Geological Survey, allowed for unimpeded development of the "Kansas System" and the many FORTRAN programs for the manipulation and display of these data. Complementing and expanding upon the Kansas work, a punch card system for storage and retrieval of ground-water data was developed for the GWB for nationwide use by Solomon M. Lang and Alvin R. Leonard in 1964. The system was tested in the Wyoming, Iowa, and Florida Districts prior to nationwide implementation. The procedure was reported by Lang and Leonard in TWRI book 7, chap. A (1967).

As a result of the pioneering work in computerizing ground-water data, the Kansas District was requested in 1965 to present the first of eight nationwide seminars for WRD district personnel on "Computer Applications to Ground-Water Data." More than 200 professionals were informed on ground-water computer techniques at these seminars. (See Part X, "Kansas.")

A procedure was established for the automatic collection, processing, storage, and retrieval of data for publication in the annual data report series on the quality of water. This effort was led by Granville A. Billingsley and DeForrest E. Weaver and resulted in establishment of record processing centers in North Carolina, Ohio, Nebraska, and California. The quality-of-water laboratories recorded the results of chemical analyses on special coding forms for computer input.

These computer applications are representative of the applications during this period of history. Many computer applications were developed locally on computers operated by cooperators and universities and are not described herein.

# PART V—BUDGET AND APPROPRIATIONS

Reviewed *by* Russell H. Langford

## The Process In General

The budget-development process, an annual cycle, continued throughout the period of Volume VI essentially as described by Ferguson in Volume V. Each cycle included two phases of budget proposals and examinations within the Executive Branch—"estimates" and "justifications"—followed by Congressional hearings and appropriations. Estimates generally were finalized about 12 months before the start of a fiscal year, by summer of 1958 for FY 1960, for example, and justifications, the final numbers in the President's budget proposals, by late fall of the year before the start of the fiscal year. Congressional hearings generally were held in February or March preceding the start of the new fiscal year, customarily first by the House Appropriations Subcommittee for Interior followed closely by the counterpart Senate Subcommittee. Additional hearings on supplemental budget requests were held in most years, some very late in the current fiscal year.

The "budget-estimates" level during the early phase of development of each budget represented a consensus of earlier iterations of program proposals, initially between the Division and the Director and later with the Department of the Interior (DOI) and Bureau of the Budget (BOB) staffs. Further reviews by and hearings with the DOI and the BOB resulted in final allowances used in the "justifications" that were forwarded to the Congress as part of the President's annual budget proposals.

During the years of this volume, the House Subcommittee was chaired by Michael J. Kirwin, Ohio, through FY 1965, and by Winfield K. Denton, Indiana, thereafter. Senator Carl Hayden, Arizona, chaired the Senate Subcommittee for the entire period covered by this history. The Secretaries of the Interior, Fred A. Seaton, through the hearings for FY 1961 and Stewart L. Udall, thereafter, introduced the proposed Departmental program budgets each year.

The structure of the USGS budget underwent little change throughout the period. All of its activities were classified under the general program title "Surveys, investigations, and research" (SIR). For FY 1958, SIR consisted of six activities: (1) topographic surveys and mapping, (2) geologic and mineral-resource surveys and mapping, (3) water-resources investigations (WRI), (4) soil and moisture conservation (S&MC), (5) conservation of land and minerals, and (6) general administration including special-purpose buildings. By FY 1967 SIR activities aggregated nine elements, the new ones being minerals explorations (beginning FY 1966), marine geology and hydrology (beginning FY 1963), and special-purpose buildings (separated from general administration), beginning FY 1963. Funds for the activities of WRI and S&MC were assigned to, managed, and obligated by the WRD.

Sources of funding for these activities continued to be: (1) direct Federal appropriation, (2) non-Federal cooperative funds, and (3) funds from other Federal agencies (OFA) and from Federal Power Commission (FPC) licensees. For the WRI activity, Congress continued to earmark a specific dollar amount of the Federal appropriation for cooperation with States and municipalities for water-resources investigations, with the proviso, "that no part of this appropriation shall be used to pay more than one-half the cost of any topographic mapping or water-resources investigations carried on with any State or municipality." Neither topographic mapping nor geologic activities contained specific dollar amounts earmarked for cooperation, nor was the Geologic Division program limited to the 50-percent stipulation.

Both the Executive Branch and the Congress maintained review and control over numbers of personnel during the period. Each annual budget presentation included employment counts. Hearing records evidenced interest ranging from the meeting of employment needs to controlling excessive rates of employment growth.

## Funding Highlights of the Period

Available annual funding of the Survey's total program of SIR and WRD's activities of WRI and S&MC is summarized in table V–1. The SIR "Federal" column shows the Federal appropriation for each

Table V–I. Annual funding available for the USGS and the WRD, in dollars, fiscal years 1958–67

[SIR, surveys, investigations, and research; WRI, water-resources investigations; S&MC, soil and moisture conservation]

| Fiscal year | USGS (SIR) | | WRD (WRI plus S&MC) | | | |
|---|---|---|---|---|---|---|
| | Federal | Total | Federal | Coop[1] | OFA[2] | Total |
| 1958 | 40,812,876 | 59,566,161 | 10,681,546 | 5,872,790 | 4,513,245 | 21,067,581 |
| 1959 | 42,218,876 | 63,650,114 | 11,451,879 | 6,858,110 | 4,628,267 | 22,938,256 |
| 1960 | 42,350,000 | 65,328,255 | 11,850,256 | 7,414,375 | 5,042,753 | 24,307,384 |
| 1961 | 45,956,000 | 71,349,150 | 13,031,828 | 7,895,596 | 5,625,991 | 26,553,415 |
| 1962 | 49,820,000 | 77,695,545 | 14,267,428 | 8,715,245 | 6,206,693 | 29,189,366 |
| 1963 | 57,943,000 | 86,605,703 | 16,089,884 | 8,876,835 | 6,767,620 | 31,734,339 |
| 1964 | 64,267,088 | 96,389,968 | 18,626,981 | 10,615,960 | 7,076,270 | 36,319,211 |
| 1965 | 70,384,000 | 105,401,000 | 21,094,926 | 11,772,095 | 7,748,753 | 40,615,774 |
| 1966 | 73,190,870 | 113,761,344 | 22,865,597 | 12,553,308 | 8,536,004 | 43,954,909 |
| 1967 | 81,609,000 | 124,088,000 | 24,860,519 | 13,922,865 | 8,849,586 | 47,632,970 |

[1]Non-Federal, including miscellaneous sources.

[2]Includes FPC licensees.

year, including supplemental appropriations and comparative fund transfers (transfers in budget base from other Federal agencies). The SIR "total" column contains final annual obligations of funds from all sources—Federal appropriation, non-Federal agencies, and other Federal agencies.

WRD funds shown in the table are the obligated funds from Federal appropriations, from cooperating non-Federal agencies of State and local governments (Coop), and from other Federal agencies (OFA). Fiscal year 1967 was the last year the budget was prepared under Leopold's direction.

Between FY 1958 and FY 1967, SIR Federal appropriations doubled; total SIR funding a little more than doubled. A somewhat larger relative growth in funding for WRD activities took place—Federal appropriations increased by a factor of 2.33, cooperative funding by 2.37, OFA by 1.96, and total funding by 2.26. In retrospect, though the water activities were given a modest edge in priority, it was evident that Survey programs overall were strongly supported by the Executive Branch and the Congress throughout the period. It was equally evident that the Congress, and especially the Senate, ensured reasonable adequacy and parity of WRI Federal matching funds for the cooperative water-program offerings.

Real program growth, of course, was considerably less than the growth in dollar figures, largely due to pay raises for Federal employees and overall inflation. Contributions to employee fringe benefits added significantly to personnel costs as agencies were mandated by law to directly share in the cost of the Federal retirement program beginning in FY 1958, in the Federal employee health-benefits program beginning in FY 1960, and in compensation payments beginning in FY 1965. Allowances provided by the Congress during the period for pay raises and fringe benefits amounted to about 40 percent of the SIR increase of $41 million. After applying the Gross National Product (GNP) price deflator index to the remainder of the dollar increase for the period, real program growth amounted to about 50 percent between FY 1958 and FY 1967, plus perhaps an unknown credit for increased productivity. Nevertheless, program growth of 50 percent during the 9 years represented a high degree of public interest and support for and accomplishments in the Survey's programs.

As for water-program funding, the real program growth was in WRI as the S&MC activity remained constant except for pay-cost adjustments. The Federal appropriation component of WRI increased from $10.5 million in FY 1958 to $24.7 million in FY 1967; total WRI from $20.9 million to $47.4 million (see "Annual Budget Cycle").

Throughout the period, with the Director's support, Leopold pressed relentlessly for increased Federal program funds to enlarge the Division's capacity and competence for hydrologic analysis and interpretation and for supporting research, all the while maintaining the basic-data program. Helping to justify these increases were reports of the President's Advisory Committee on Water-Resources Policy (1956), and the Senate Select Committee on National Water Resources (1961), both of which recommended strengthened Federal support of the Survey's water-program objectives. Division policy similarly emphasized these priorities in the cooperative program as well, which grew in funding (both sides) from $12.0 million in FY 1958 to $26.9 million in FY 1967.

Table V–2. WRD total funding by primary program objectives, fiscal years 1958 and 1967

| Program element | Funds ($1,000's) | Collection of basic records (percent) | Analysis and interpretation (percent) | Research (percent) |
|---|---|---|---|---|
| | | Fiscal year 1958 | | |
| Federal | 4,531 | 41 | 29 | 30 |
| Federal and State Coop | 12,024 | 68 | 29 | 3 |
| OFA | 8,513 | *79 | *4 | |
| Total | 21,068 | 65 | 26 | 9 |
| | | Fiscal year 1967 | | |
| Federal | 11,866 | 38 | 27 | 35 |
| Federal and State Coop | 26,917 | 54 | 33 | 13 |
| OFA | 8,850 | 70 | 23 | 7 |
| Total | 47,633 | 52 | 30 | 18 |

*Partially estimated—exact totals not available.

An analysis of funds expended among the three program objectives—(1) collection of basic records (CBR), (2) hydrologic analysis and interpretation, and (3) supporting research—reveals considerable success in achieving the leadership efforts, as shown in table V–2.

The analysis and interpretation and the research objectives not only received greatly increased funding during the period but became relatively strong and well-entrenched components of the total program. This was accomplished along with a steady growth of funding in data-base activities, including significant advances in automation.

As WRD programs grew and became more complex, the needs for strengthened program planning and evaluation, program management, supporting technical services, and career development and training required increased resources. To meet such needs, the Washington office technical service charge (WOTSC) was increased in FY 1963 from 7.5 percent to 9 percent of all WRI and S&MC appropriated funds and for the non-Federal cooperative funds. The service charge to OFA funds was increased from 11.5 percent to 12.75 percent, including the continuing 3.75 percent Bureau-level assessment. The Chief Hydraulic Engineer's memorandum of October 19, 1961, to WRD Councils justified the increase as necessary "(1) to strengthen technical support of cooperative and collaborative projects; and (2) to equalize charges for technical support against all sources of funds." These increases seemingly had no negative effects on budgetary resources for the remainder of the period in spite of initial "wailing and gnashing of teeth" from many WRD District heads (the author [J.S. Cragwall] being one of those at the time) and some cooperating officials.

Control over positions (commonly referred to as "slots") continued to be exercised by the Executive Branch and the Congress throughout the period. In such manpower-intensive programs as the Survey's, position allowances were as important as funds. Table V–3 summarizes manpower resources for SIR during the period. Although similar annual data on positions in WRD were not available, source materials available indicate that the Division's permanent positions grew from about 2,600 in FY 1958 to about 3,200 in FY 1967. This increase of approximately 23 percent was about the same as for the Survey as a whole.

Total Survey personnel compensation of $41 million in FY 1958 increasing to $87 million in FY 1967 required 70 percent or more of total funds for personnel throughout the period. Management concerns about employment numbers were expressed in most years of the period, according to the hearings records, but for different reasons. Early in the period the Survey had problems filling its vacancies, presumably due to prevailing shortages of engineering and science graduates and less-than-competitive Federal pay scales. In the mid-to-late 1960's, with rapidly increasing budgets, position allowances grew commensurately, aided by intensified recruiting, so much so as to cause concern over excessive employment among congressional committee members and Executive Branch management. This concern, of course, later led to imposition of rigorous personnel controls beginning in the late 1960's and continuing for many years thereafter.

The presentation and content of Survey's budget-justification statements changed noticeably during the

Table V–3. Geological Survey employment (actual)

| Fiscal year | Permanent positions (number) | Other positions (full time equivalent) | Employees (average number) | Average GS grade level | Average salary ($) |
|---|---|---|---|---|---|
| 1958 | 6,764 | 667 | 7,228 | 7.8 | 5,623 |
| 59 | 6,700 | 663 | 7,230 | 7.9 | 6,378 |
| 60 | 6,950 | 708 | 7,449 | 8.0 | 6,405 |
| 61 | 7,020 | 649 | 7,489 | 8.1 | 6,994 |
| 62 | 7,146 | 720 | 7,758 | 8.3 | 7,140 |
| 63 | 7,615 | 765 | 8,177 | 8.5 | 7,719 |
| 64 | 7,792 | 803 | 8,498 | 8.6 | 8,205 |
| 65 | 7,940 | 710 | 8,595 | 8.8 | 8,653 |
| 66 | 8,122 | 733 | 8,769 | 8.8 | 9,095 |
| 1967 | 8,271 | 798 | 8,977 | 8.9 | 9,584 |

Table V–4. WRD funding balance among WRI subactivities, fiscal years 1958 and 1965

| Sub-activity | Fiscal year 1958 | | Fiscal year 1965 | |
|---|---|---|---|---|
| | Federal (percent) | Federal-State (percent) | Federal (percent) | Federal-State (percent) |
| Surface-water investigations | 53 | 55 | 43 | 53 |
| Quality-of-water investigations | 24 | 8 | 18 | 11 |
| Ground-water investigations | 23 | 37 | 39 | 36 |
| Total funding ($1,000's) | 4,365 | 12,024 | 9,733 | 22,936 |

period of Volume VI, probably reflecting the style and interests of Executive Branch management and the Congressional Appropriations Committees. Very significant was the change in the length of the justification statements. The House Committee report on Survey's SIR for FY 1958 totaled 28 pages, and by FY 1965 the length had increased to 78 pages. Extensive use of graphics and greatly increased narrative and funding details of subactivities increased the Hearings record length to 108 pages for FY 1966 and to 152 pages for FY 1967. The greater volume of justification material in these later years undoubtedly reflected not only program growth but the concerns of the Appropriations Subcommittees about previous inadequacies of submissions (see Annual Budget Cycle, FY 1965) and the policy of the Executive Branch leadership to require more rigorous program analysis as part of the oncoming formalized planning, programming, and budgeting system (PPBS).

The detail of WRI justifications well illustrates the foregoing changes in the budget-development process during the period. Through FY 1965, the WRI activity contained a subactivity structure of three principal parts: (1) surface-water investigations, (2) quality-of-water investigations (sediment and chemical quality), and (3) ground-water investigations. This subactivity structure was used to justify and report on both program components—the Federal program and the Federal-State cooperative program.

Fiscal years 1966 and 1967 brought about a complete change in justification format. The Federal program was broken down into 13 subactivities, explicit as to proposed funding for each (see Annual Budget Cycle—FY 1967). On the other hand, the Federal-State cooperative program contained no structured subactivity breakdown in FY 1967—program content was quite generally described without specific funding components except as to estimating cooperative offerings, State by State, and approximate percentage of funds allotted to basic data, 50 percent; ground-water resources areal studies, 25 percent; and hydrologic studies of special problems, 25 percent. This later mode of WRI presentation undoubtedly reflected also the transition of WRD program management and execution from a Branch to a Division-level basis and the new priorities related to the reorganization.

Because of changes in subactivities structure during the period and the lack of funding amounts related to subactivities in some years, data were not available to reconstruct WRI subactivity level funding year by year. The following table V–4 attempts to summarize approximate subactivity sharing of funds for

WRI in FY 1958 and FY 1965 to indicate resource allocation among surface-, quality-, and ground-water activities prior to major reorganization of the Division.

Overall subactivity balance in the cooperative program changed very little during the period except for an increase in water-quality work, portending more to come in later years. In the Federal program, ground-water investigations showed considerable expansion compared to the other subactivities. It should be noted that the above table does not represent fund allocations to the Branches as such, for the GHB was assigned responsibility and funds for all projects involving two or more of the subactivities shown. GHB, therefore, shared significantly in the subactivity funding shown in the table.

All in all, the Survey's water programs received priority funding during the Leopold years, maintaining WRD as the largest Division in total funding and in personnel throughout the period.

## The Annual Budget Cycle

Each annual budget-development cycle, FY 1958–67, is summarized for WRD from initial estimates to final appropriations and obligations in the following sections. A tabular presentation of WRD funding by source of funding program elements introduces each fiscal-year discussion. The narrative attempts to recount enough about Survey's SIR budget development to compare and relate water-program funding to the Survey's total funding and also to make reference to other Survey activities of interest and relevance to WRD history.

Fiscal Year 1958.—Ferguson (Volume V) described the budget justification cycle for FY 1958 up to the regular appropriation bill of July 1, 1957, which provided $36 million for SIR, plus a reappropriation of unspent building funds from FY 1957 of $415,000. The bill stipulated $5,800,000 for matching cooperative offerings for water-resources investigations. Total WRI, according to the FY 1959 justification, was $9,823,000 (Ferguson reported $10,085,000 which probably was a later internal adjustment within Survey's SIR). S&MC was allowed $160,000. A later supplemental for a general pay raise increased SIR to $38,003,100 and comparative transfers from the AEC and Interior's Office of Oil and Gas raised the final total for SIR to $40,812,876. Final allocation for WRI and S&MC are unclear from the record but must have approximated the actual obligations of $10,516,048 and $165,489, respectively.

Total funds available for SIR in FY 1958 from all sources amounted to $59.6 million—for WRD, $21.1 million. Division funding was 35 percent of the total for SIR. Of the WRD funds, 51 percent was from Federal appropriation, 28 percent from non-Federal cooperating agencies, and 21 percent from other Federal agencies.

Fiscal Year 1958

[WRD budget cycle summary for fiscal year 1958 (in dollars; dashed where not applicable)]

| Program element | Estimate | Justification | Initial appropriation | Final appropriation | Obligations |
|---|---|---|---|---|---|
| WRI-Federal | 5,730,000 | 5,610,000 | 4,023,000 | * | 4,365,265 |
| WRI-Federal Coop | 5,800,000 | 5,800,000 | 5,800,000 | * | 6,150,783 |
| S&MC | 190,000 | 190,000 | 160,000 | * | 165,498 |
| Non-Federal Coop | 5,800,000 | 5,930,000 | -- | - | 5,872,790 |
| FPC | - | 141,000 | -- | - | 223,648 |
| OFA | - | 3,858,000 | -- | - | 4,289,597 |
| Total | - | 21,529,000 | -- | - | 21,067,581 |

*Exact amounts for subactivities not available but approximated obligations.

Fiscal Year 1959

[WRD budget cycle summary for fiscal year 1959 (in dollars; dashed where not applicable)]

| Program element | Estimate | Justification | Initial appropriation | Final appropriation | Obligations |
|---|---|---|---|---|---|
| WRI-Federal | 4,300,000 | 4,235,000 | 4,235,000 | 4,680,000 | 4,634,991 |
| WRI-Federal Coop | 6,750,000 | 6,035,000 | 6,950,000 | 6,950,000 | 6,642,888 |
| S&MC | 160,000 | 160,000 | 160,000 | 174,000 | 174,000 |
| Non-Federal Coop | 6,950,000 | 6,225,000 | -- | - | 6,858,110 |
| FPC | - | 190,000 | -- | - | 210,102 |
| OFA | - | 3,837,900 | -- | - | 4,418,165 |
| Total | - | 20,682,900 | -- | - | 22,938,256 |

Fiscal Year 1959.—The budget estimate of $11,050,000 for WRI was reduced to $10,270,000 in the BOB's request to the Congress, an increase of $447,000 over the FY 1958 amount then currently available. The Federal program increase of $197,000, to $4,235,000, proposed more emphasis on analysis and interpretation of data and on research, a continuing response to recommendations of the President's Advisory Committee on Water Resources Policy (printed as House Document 315, 84th Congress, Second Session, January 17, 1956). An increase of $250,000 to $6,035,000 was requested for the Federal-State cooperative program in spite of a projected shortfall of $915,000 to match total estimated offerings. The request for S&MC funding continued level at $160,000. Except for these increases for the water program, the Survey's total request for SIR remained an essentially level $36,750,000.

The FY 1959 budget request for the DOI reflected Secretary Seaton's position of reduced spending for the Department, making the Survey's no-increase budget request look relatively strong when compared to the cuts in other Departmental programs.

At the House of Representatives Appropriation Subcommittee Hearing on January 16, 1958, Director Nolan's opening statement reflected his continuing concern about adequate housing for the Survey, saying "A solution of the Survey's housing needs in the Washington area continues to be one of our most critical problems. A facility that will meet the physical requirements of the Survey's operations and provide a means of attracting and retaining skilled employees is urgently needed."

House Committee comments and questions about water centered on the requested increases, but also on reasons for and nature of work for the AEC and the SCS. The Committee also examined the status of the continuing National Flood Frequency Analysis Program and the Survey's work on sediment load of streams. Luna Leopold attended and participated in the hearing for the first time as Chief Hydraulic Engineer.

According to the Senate Subcommittee on Appropriations which held the Survey hearings the following March, the House had recommended reducing their allowance for SIR to $36 million. The Department requested full restoration of the $750,000 reduction, which had been applied to uranium research of the Geologic Division. Much of the hearing was concerned with this item. In the WRI portion of the hearing, Director Nolan ably responded to Chairman Hayden's interest and questions on the Verde River project of vegetation management for water-loss reduction, the Lake Mead evaporation study and lake-evaporation suppression research, the streamgaging network analysis, the $915,000 estimated shortage to match cooperators' offerings, and the S&MC work.

The Senate Subcommittee proposed $36,915,000 for SIR, the additional $915,000 to match the expected offerings for cooperative water studies. In conference, the $36,915,000 figure was agreed to and appropriated by the Congress June 4, 1958, thus providing a final total of $6,950,000 for cooperation with the States and municipalities for water-resources investigations.

A later supplemental appropriation added $1.5 million the to Survey's SIR for the Department's long-range minerals program. In addition, comparative transfers from other agencies for work in Geologic and the Conservation Divisions of another $0.7 million, plus classified and professional pay-raise adjustments of about $3.0 million resulted in a final total appropriation for FY 1959 of $42,218,876 for the SIR activity. The final WRI Federal obligations totaled $11,277,879; S&MC, $174,000.

Total funds available to SIR from all sources aggregated $63.7 million. WRD funding totaled $22.9 million; 36 percent of the SIR total and was derived 50 percent from Federal appropriation, 30 percent from

Fiscal Year 1960

[WRD budget cycle summary for fiscal year 1960 (in dollars; dashed where not applicable)]

| Program element | Estimate | Justification | Initial appropriation | Final appropriation | Obligations |
|---|---|---|---|---|---|
| WRI-Federal | 4,680,000 | 4,680,000 | 4,525,000 | 4,525,000 | 4,524,222 |
| WRI-Federal Coop | 7,700,000 | 7,450,000 | 7,450,000 | 7,450,000 | 7151,209 |
| S&MC | 175,000 | 175,000 | 175,000 | 175,000 | 174,825 |
| Non-Federal Coop | 7,700,000 | 7,640,000 | -- | - | 7,414,375 |
| FPC | - | 250,000 | -- | - | 230,478 |
| OFA | - | 4,529,000 | -- | - | 4,812,275 |
| Total | - | 24,724,000 | -- | - | 24,307,384 |

non-Federal sources, and 20 percent from other Federal agencies.

*Fiscal Year 1960*.—The allowed budget estimate for WRI was $12,380,000: $4,680,000 for a no-increase Federal program and $7,700,000 for the Federal-State program, increased by $750,000 to meet estimated cooperator offerings. The budget justification allowance by the BOB limited the requested Federal-State program increase to $500,000 for a total WRI budget request of $12,130,000. The S&MC request continued with essentially no change at $175,000. No substantive changes in program content were proposed.

The total Survey-justified request of $42,517,600 for SIR provided only for the $500,000 increase in WRI and a $150,000 increase for increased workload in the Conservation Division.

Interior Secretary Seaton's opening statement before the House Subcommittee on January 27, 1959, reflected the Administration's tight budget stance and its desire to attain a balanced Federal budget for 1960. The Secretary continued to stress, however, his high priority for the saline-water conversion program and proposed some increases to expand that research.

Director Nolan in his opening statement before the House Subcommittee the following day reflected on his third year as Director and his high regard for the Survey by stating:

> "...throughout the 80 years of its existence, its work has been characterized by major contributions to the resource picture of the country. These contributions have been made through the application of high standards and new concepts developed by the exceptionally able scientists and engineers who have been attracted to work in the Survey. The Survey continues to stress technical excellence as well as the economical and efficient production of its reports and maps; current events have demonstrated that in scientific and engineering fields the United States must use excellence and intelligence in this competitive world if we are to retain our present position. The country must rely in large part on doing its job better than its competitors. The men and women of the Survey do their share in achieving these objectives...."

In discussion that followed, Chairman Kirwin expressed concern about the time required to review, process, and publish Survey reports, and with reference to WRI funding, cited the 2 to 2.5 years currently taken to publish the streamflow basic data Water-Supply Papers. Director Nolan pointed out that immediately making available the current basic water data, qualified as preliminary, to those who need it for water-management purposes was standard practice of the Survey's field offices; that formal data reports are primarily for planning and design and historical uses (see Part IX, "Publications").

Other interests and concerns of the Subcommittee relevant to water and responded to by Director Nolan included water utilization, conservation and control, ground-water recharge, and coal-mine water problems. In management and administration, the subcommittee seemed concerned about the lack of consistency of service charges among the several Divisions of the Survey, the internal audit system, personnel numbers, and allocation of positions between scientific and administrative duties.

The House Subcommittee report recommended an appropriation of $42 million for SIR, disallowing the requested $500,000 increase in the Federal-State cooperative program, saying, "The Congress provided an increase of $915,000 for this program for the current year and it is believed that continuation of the current

Fiscal Year 1961

[WRD budget cycle summary for fiscal year 1961 (in dollars; dashed where not applicable)]

| Program element | Estimate | Justification | Initial appropriation | Final appropriation | Obligations |
|---|---|---|---|---|---|
| WRI-Federal | 4,525,000 | 4,554,000 | 5,004,000 | 5,271,000 | 5,270,085 |
| WRI-Federal Coop | 7,450,000 | 7,490,000 | 7,490,000 | 7,620,000 | 7,577,431 |
| S&MC | 176,000 | 176,000 | 176,000 | 185,000 | 184,312 |
| Non-Federal Coop | 7,490,000 | 7,770,000 | -- | - | 7,895,596 |
| FPC | - | 240,000 | -- | - | 303,268 |
| OFA | - | 4,556,400 | -- | - | 5,322,723 |
| Total | - | 24,787,000 | -- | - | 26,553,415 |

level at a cost of $7 million will provide for all essential studies." It stipulated further that, "The committee is concerned about the delay being incurred in the completion of research projects and in the preparation and publication of reports and expects that appropriate action will be taken by the agency to remedy the situation."

The Department appealed for restoration of this and other agency reductions before the Senate Subcommittee in May 1959. At the Survey hearings on May 18, Director Nolan assured Chairman Hayden of the need of the $500,000 increase to meet cooperating agency offerings. Leopold accompanied Director Nolan to both the House and Senate hearings for FY 1960.

Final action by the Congress appropriated $42,350,000 and involved minor adjustments of other programs to allow the full amount of $7,450,000 originally requested for the Federal-State cooperative program. The WRI allowance totaled $11,975,000, incorporating a reduction of $155,000 from the Federal program to help offset the restored cooperative funding.

Fiscal Year 1961.—The Survey's SIR appropriation totaled $42,350,000. Obligations of the Survey in FY 1960 ultimately totaled $65.3 million; of WRD, $24.3 million. WRD financing constituted 37 percent of the Survey's, and was derived 49 percent from Federal appropriations, 30 percent from non-Federal cooperative funds, and 21 percent from other Federal agencies.

The Survey's budget request for WRI was a no-increase allowance of $11,975,000. This allowance was adjusted upward in the justification cycle to $12,044,000 to cover the personnel costs of the Federal Employee Health Benefits Act of 1959. The resulting Federal program request was $4,554,000; the Federal-State program, $7,490,000. No substantive changes in program content were proposed. Similarly, the S&MC program, at requested funding of $176,000, provided no substantive changes in funding or activity.

The Survey's SIR request was equally constrained, totaling $43,365,000. The only program increase above the health benefits item of $265,000 was $400,000 for the Conservation Division, mandated by increased workloads on oil and gas leases supervision and mineral classification.

Director Nolan's opening statement before the House Subcommittee on Appropriations on January 14, 1960, generally reviewed the activities and progress of the Survey. He highlighted WRD's programs and plans for instrument conversion to the digital recorder and its integration into the Survey's computer facility to expedite the processing and publishing of water data. He cited the establishing of a Publications Division last July 1, 1959, to centralize and expedite the processing and publishing of Survey reports. He reported progress in the accounting and property-management fields, and touched upon progress towards a Survey building. The General Services Administration (GSA) had indicated its intention to proceed with site acquisition and building design in accordance with provisions of the Public Buildings Act of 1959 with funds provided in the Independent Offices Appropriations Act of 1960. Leopold was present at this hearing.

There were no specific questions on the proposed water-program funding. Upon inquiry from Chairman Kirwin, the Director summarized some aspects of the Division's work on mechanics of underground flow, radiochemical monitoring of ground water, and continuing water-utilization studies.

Later in the hearing, Subcommittee member Denton requested that a statement on the Nation's water problems be inserted in the record. A comprehensive statement entitled "The Water Situation in the United States," encompassing report pages 339–350, categorized major water problems, presented needs and possible solutions to those problems, reported what the

Survey was doing about them, and broadly summarized the variability and quality of our water resources—a very substantive statement considering the breadth of Congressman Denton's request.

In response to another question, the Director declined to voice an opinion on the influence of pesticide contamination of streams on fish, pointing out that the Public Health Service is primarily concerned with and has jurisdiction over organic pollution of water. (Author's note: This early "policy stance" was to change significantly in the late 1960's and early 1970's as the Survey was called upon to become more directly and heavily involved in environmental impacts, fact finding, and assessment in almost every facet of its earth-sciences activities, organics in water included.)

The House Subcommittee had not reported its recommendations for Survey funding when the Senate held its hearing on February 9, 1960. Again, Leopold accompanied the Director, who personally responded to all questions from the Subcommittee. After being assured that the Federal-State program funding request would be adequate to meet anticipated offerings, Chairman Hayden focused on an item not included in the budget request. He referred to it as "the proposal for investigations in the lower part of the Colorado River basin by the Geological Survey." Nolan responded that it was a recent development, it would assess the interchange of surface and ground water along the course of the stream with particular emphasis on quality of return irrigation flows, and would encompass the main stem of the river from Davis Dam to beyond the Mexican boundary. A proposal presumably prepared earlier by the Survey was reproduced in full in the hearing record on page 409. The work would require 8 to 10 years at a cost of about $300,000 per year, total estimated cost, $2,500,000. The hearing record also included a joint comprehensive supportive statement for this study by the Survey from officials of the Arizona Interstate Stream Commission and the Central Arizona Project Association (page 870) but both expressed preference for appropriation of funding through the BOR as the responsible water-management agency to ensure relevancy of the Survey's work to the needs of the BOR. A resolution from the Imperial Irrigation District also supported the Survey proposal (page 874).

An exchange between Hayden and Nolan revealed that the Senate Committee on Public Works had recently deferred action on approving a new Survey building in the District of Columbia. Nolan proffered his opinion that there may be a preference for a site on the periphery of the District rather than in the downtown area and expressed his disappointment over another delay in the Survey's 15-year effort to improve its housing.

The House Subcommittee recommended $43 million for SIR, accepting the proposed funding for water activities. The Senate Subcommittee recommended an SIR of $45,650,000, including an increase of $1 million for the WRI Federal program to implement recommendations of the Senate Select Committee on Water Resources. Adopting the conference report, the Congress appropriated $43,650,000 for SIR, increasing WRI Federal funds by $450,000 and Conservation Division activities by $200,000.

In its second supplemental appropriation on September 8, 1960, the Congress added $300,000 to SIR to match a like amount offered by the Kentucky Legislature to begin a statewide geologic mapping program there. Later in its third supplemental bill of March 31, 1961 Congress appropriated an additional $2,006,000 for SIR to fund increased pay costs, making the final SIR for FY 1961 $45,956,000; final WRI, $13,031,828.

Total obligations of the Survey in FY 1961 amounted to $71.3 million. About 37 percent of that

Fiscal Year 1962

[WRD budget cycle summary for fiscal year 1962 (in dollars; dashed where not applicable)]

| Program element | Estimate | Justification | Initial appropriation | Final appropriation | Obligations |
|---|---|---|---|---|---|
| WRI-Federal | 5,600,000 | 5,600,000 | 5,600,000 | 5,700,000 | 5,694,649 |
| WRI-Federal Coop | 8,430,000 | 8,430,000 | 8,430,000 | 8,430,000 | 8,388,363 |
| S&MC | 185,000 | 185,000 | 185,000 | 185,000 | 184,416 |
| Non-Federal Coop | 8,680,000 | 8,690,000 | -- | - | 8,715,245 |
| FPC | - | 255,000 | -- | - | 306,099 |
| OFA | - | 5,498,000 | -- | - | 5,900,594 |
| Total | - | 28,658,000 | -- | - | 29,189,366 |

total, $26.6 million, was expended on water programs; of that amount, 49 percent was derived from Federal appropriation, 30 percent from non-Federal cooperative funds, and 21 percent from other Federal agencies.

*Fiscal Year 1962*.—An allowed budget estimate of $14,030,000 for WRI held up through the justification process with the BOB; $5,600,000 for the Federal program, $8,430,000 for the Federal-State program. The S&MC program request maintained level at $185,000. The then-indicated $329,000 increase in the Federal program was justified for increased research in the Branch research programs and for carryover pay-cost increases. The requested increase of $810,000 in the Federal-State program was needed to match estimated cooperating agency offerings. The stepped-up interest of cooperators for water-quality work was noted. Increased pay costs would require $264,000 of the Coop increase.

The budget request for SIR funding totaled $50,165,000, an increase of $4,209,000 over the total available in FY 1961. Other proposed increases were for quadrangle mapping (plus $1.5 million), geologic mapping and research (plus $1.2 million), classification of Federal lands (plus $0.2 million), and general administration (plus $0.1 million). Increased pay costs resulting from pay-scale increases in 1961 accounted for a total of $687,000 of the total SIR increase.

In the course of the House Subcommittee hearing on March 1, 1961, Director Nolan stressed the need for increased funding for hydrologic research and called attention to the urgings of the Senate Select Committee on National Water Resources in this regard. He reported progress on the national basic-data compilation efforts, the series of regional flood-frequency studies and reports, and flood-inundation mapping, all currently underway as part of the Federal program. In answer to Chairman Kirwin, he summarized the current interests and effort of the Department to convince the BOB of the need for a flood emergency fund—a no-year contingency fund to finance emergency field work of flood-survey teams immediately following major floods, and to prepare special reports thereon. Kirwin challenged the need for the Water Resources Division to maintain four separate program branches in the field. The Director defended the current organizational structure in a written statement to the record as best fitting the work to be done and hence the most effective and efficient arrangement. Later, Subcommittee member Fenton requested the Director to furnish for the record an overall statement of the Survey's accomplishments for the last 4 or 5 years and his recommendations on future needs. The resulting statement was comprehensive and incisive, and for water (pages 504–506), reported that research had risen from 1 percent of the total water program in 1955 to 10 percent in the current year. Many specific accomplishments were cited. The Division forecast a need to double its program in the next 5 years to satisfy foreseeable demands for information on water. The House Subcommittee recommended an SIR appropriation of $49,500,000, a reduction of $665,000 in the budget request. The House declined to restore a portion of the pay-act increases and disallowed any increase for general administration.

In its hearing before the Senate Subcommittee on April 27, 1961, the Survey requested restoration of $329,000 of the $665,000 House reduction, $220,000 to WRI for pay costs in the Federal-State program and $109,000 for general administration imperatives. Director Nolan cited strong justification of the need for these increases and Chairman Hayden seemed sympathetic, especially for the water item. This proved so as a final SIR appropriation by the Congress, August 3, 1961, provided $49,720,000 for SIR and $14,030,000 for WRI, including $8,430,000 for water cooperation, as originally requested. The appropriation act authorized "...acquisition of lands for gaging stations and observation wells..." with the wording "and observation wells" added for the first time.

In September 1961, as part of a supplemental appropriations bill, the Senate Subcommittee proposed and the Congress appropriated an additional $100,000 to the Survey's SIR for FY 1962 "...to initiate a study to determine methods of phreatophyte control and water salvage in arid areas." The Gila River was recognized as an opportune location for the research. Total program costs were estimated as $900,000 over a 10-year period.

The final 1962 SIR appropriation therefore totaled $49,820,000; actual obligations totaled $77,695,545, including non-Federal and other Federal agency funds. Final WRI plus S&MC funding totaled $14,267,428; total obligations amounted to $29,189,366, including non-Federal and other Federal

Fiscal Year 1963

[WRD budget cycle summary for fiscal year 1963 (in dollars; dashed where not applicable)]

| Program element | Estimate | Justification | Initial appropriation | Final appropriation | Obligations |
|---|---|---|---|---|---|
| WRI-Federal | 7,000,000 | *6,100,100 | 7,000,000 | 7,108,000 | 7,094,806 |
| WRI-Federal Coop | 8,930,000 | 8,430,000 | 8,430,000 | 8,910,000 | 8,806,078 |
| S&MC | 185,000 | 185,000 | 185,000 | 189,000 | 189,000 |
| Research Institute | 1,900,000 | *2,800,000 | 0 | 0 | 0 |
| Non-Federal Coop | - | 8,690,000 | -- | -- | 8,876,835 |
| FPC | - | 337,000 | -- | -- | 341,572 |
| OFA | - | 6,024,000 | -- | -- | 6,426,048 |
| Total | - | 32,566,000 | -- | -- | 31,734,339 |

*$900,000 of Federal base to be transferred to proposed program of Institute of Water Research.

agency funding. About 38 percent of total Survey financing was expended in the water program, with those water funds derived 49 percent from Federal appropriation, 30 percent from non-Federal agencies, and 21 percent from other Federal agencies.

*Fiscal Year 1963*.—The budget presentation related ongoing and proposed elements of the Division's program to recommendations of the Senate Select Committee on Water Resources (Senate Report 29, 1961). The allowed estimate for WRI was $15,930,000—$7 million for the Federal program and $8,930,000 for the Federal-State program. The estimate for the S&MC program remained the same as in 1962 ($185,000). A new activity, Institute of Water Research, was proposed for funding at $2,800,000—$900,000 from the Federal program component of WRI and $1,900,000 of new funding.

In the justification process, the BOB allowed $14,530,00 for WRI ($6,100,000 Federal program and $8,430,000 Federal-State program) plus $2,800,000 for the proposed Institute of Water Research. Most of the Division's basic hydrologic research would be centered in the Institute.

The Survey's SIR request totaled $59,900,000, a significant increase of $10,080,000 over that available for 1962. Increases were proposed in all ongoing activities and for two other new activities: a marine geology and hydrology program ($1 million) and a special-purpose building ($1,100,000), a laboratory in Denver for research in isotope geology and hydrology involving unusual levels of nuclear radiation.

In his appearance before the House Subcommittee hearings on January 17, 1962, Secretary Udall stressed the need for an Institute of Water Research to carry out the research recommendations of the Senate's Select Committee on Water Resources. Other related water interests of the Subcommittee and Secretary Udall concerned the saline-water conversion program and the need to give attention to the problems of acid-mine drainage.

On the following day, Director Nolan, accompanied by Leopold and other key Survey officials, appeared before the House Subcommittee chaired temporarily by Congressman Magnuson. Nolan's opening statement highlighted and strongly supported the Institute and the marine geology and hydrology program proposals. He lamented the continued lack of progress on getting a Washington-area building for the Survey.

The Subcommittee expressed interest in, and Nolan and Leopold discussed, the Division's ongoing and planned efforts to train hydrologists, both in universities and within the Division (see Part VI, "Training").

Most of the hearing on the water programs focused on the need for and cost of personnel required to establish the Institute of Water Research. Additional detailed information on research content and cost was furnished for inclusion in the House record (pages 516–518). Subcommittee members' comments and questions ranged from strongly supportive to critically negative on the Institute concept. Concerns over the apparent fractionalization of water research among a large number of Federal agencies were quite strongly expressed.

At the Senate subcommittee hearing on March 1, 1962, Chairman Hayden pressed Director Nolan for comprehensive and detailed information on the proposed Institute of Water Research, which was supplied

Fiscal Year 1964

[WRD budget cycle summary for fiscal year 1964 (in dollars; dashed where not applicable)]

| Program element | Estimate | Justification | Initial appropriation | Final appropriation | Obligations |
|---|---|---|---|---|---|
| WRI-Federal | 7,600,000 | 9,286,000 | 8,399,000 | 8,557,000 | 8,556,392 |
| WRI-Federal Coop | 10,100,000 | 10,150,000 | 10,150,000 | 10,150,000 | 9,877,635 |
| S&MC | 400,000 | 193,000 | 189,000 | | 192,954 |
| Research Institute | 2,800,000 | 0 | 0 | 0 | 0 |
| Non-Federal Coop | - | 10,450,000 | -- | - | 10,615,960 |
| FPC | - | 361,000 | -- | - | 326,988 |
| OFA | - | 6,647,000 | -- | - | 6,749,282 |
| Total | - | 37,087,000 | -- | - | 36,319,211 |

for the record (pages 355–362). Discussion also centered on the new phreatophyte-eradication program (first funded by a $100,000 supplemental appropriation for 1962) and on the proposed Federal program increase for stepped-up reconnaissance of ground-water supplies.

Final action by the Congress appropriated $56,100,000 for Survey's SIR and later approved a supplemental appropriation of $1,940,000 for pay increases for a 1963 final total of $58,040,000. Final funding for WRI, including pay-cost adjustments, was $15,900,884 ($7,094,806 Federal program, $8,806,078 Federal-State program). The S&MC program, with pay cost adjustments, was provided $189,000).

Funding of $1,900,000 for the Institute was denied by both Houses of Congress pending further study of water-research activities and needs governmentwide. The marine geology and hydrology program increase was held to $500,000, and $100,000 was provided only for planning and design of the isotope laboratory in Denver, with urgings to reduce the cost to less than $1 million.

Total financing available to the Survey in FY 1963 amounted to $86.6 million including non-Federal and other Federal agency funds. WRI plus S&MC funds totaled $31.7 million, 37 percent of Survey's total, and derived 51 percent from Federal appropriation, 28 percent from non-Federal agencies, and 21 percent from other Federal agencies.

*Fiscal Year 1964*.—Funding allowed in the budget-estimate cycle totaled $17,700,000 for WRI, an increase of $2,410,000 over 1963's available financing, as known at that time (mid–1962). The proposal provided $7,600,000 for the Federal program (plus $740,000) and $10,100,000 for the Federal-State program (plus $1,670,000). Ongoing and increased elements of the Federal program were again related to recommendations of the Senate Select Committee on Water Resources. Increases included funding for new digital recorders, expansion of primary and benchmark data networks, hydrologic education and training, hydrologic systems analysis, and areal ground-water studies. The Federal-State program request was based on estimated cooperating agency offerings across the breadth of surface, ground, and quality-of-water activities. In addition, estimates included $2,800,000 for the Institute of Water Research, which Congress failed to fund in the 1963 appropriation. Its program would be threefold: research in fundamental hydrology, clinical hydrology (scientific aspects of specific water problems), and principles of water management.

The BOB finally requested in the President's budget to the Congress a total of $19,436,000 for WRI, an increase of $3,418,000 over 1963, including $208,000 for full annualization of pay cost for new 1963 positions. Though the Institute proposal as such was not identified, increased funding was proposed for an enlarged program of inhouse research. This new level of funding proposed $9,286,000 for the Federal program and $10,150,000 for the Federal-State program. The S&MC activity was continued at a proposed $193,000, increased only for pay costs.

SIR was proposed for an appropriation of $68,015,000, including $1,415,000 for pay cost and $8,560,000 for program increases. In addition to the requested increase for water, there were additional amounts for ongoing programs of mapping, geology, conservation, and administration. Relevant to water, $806,000 was included for expanding marine research and equipment and $1,675,000 for construction of the Denver isotope laboratory and for designing and constructing other special facilities at Menlo Park and Denver.

In his prepared highlight statement before the House Subcommittee on January 28, 1963, Secretary Udall emphasized the need for increased water research and data collection by the Survey. It is interesting to note that Representative Julia Hansen of

Fiscal Year 1965

[WRD budget cycle summary for fiscal year 1965 (in dollars; dashed where not applicable)]

| Program element | Estimate | Justification | Initial appropriation | Final appropriation | Obligations |
|---|---|---|---|---|---|
| WRI-Federal | 13,005,000 | 9,997,000 | 8,943,000 | 10,031,286 | 9,733,406 |
| WRI-Federal Coop | 11,000,000 | 10,800,000 | 10,900,000 | 11,420,000 | 11,164,053 |
| S&MC | 195,000 | 195,000 | 193,000 | 198,000 | 197,467 |
| Non-Federal Coop | - | 11,278,000 | -- | - | 11,772,095 |
| FPC | - | 385,000 | -- | - | 445,193 |
| OFA | - | 6,737,000 | -- | - | 7,303,560 |
| Total | - | 39,392,000 | -- | - | 40,615,774 |

Washington State was introduced as a new member of the Subcommittee; she was later to become Chairman and a strong advocate of Survey programs.

Director Nolan met with the subcommittee on February 4, accompanied by only three other Survey managers, one being Luna Leopold. Surprisingly, Committee members asked relatively few questions considering the substantial increases for all components of the Survey's program. Principal interest in the water programs other than the size of the requested increases centered on better coordination of water research to reduce proliferation of excess activity among a spectrum of Federal agencies. In the closing exchange, reference was made to the Anderson bill, which would create a federally administered water-resources research program supporting a system of State university water-research institutes. Also noted was a proposal for a proposed water-resources planning function coordinated by a Water Resources Council. Both of these initiatives stemmed from recommendations of the 1961 Senate Select Committee report.

The Senate hearings were led off on February 26, 1963, by Secretary Udall who repeated his strong support for the substantial Survey program increases. Director Nolan, accompanied by the Division Chiefs and other key staff members, briefed the Subcommittee on March 12, stressing the increased research needs to prepare for the Nation's long-range problems in resources management. Nolan was asked to discuss and furnish a comprehensive statement on the new marine geology and hydrology program, and also on the phreatophyte-removal project. There was the usual "no progress" report on a Survey building for the Washington area, even though the Public Works Committee of both the House and Senate had approved the project last year. Funding for site acquisition and design requested in this budget cycle had not been included by the BOB in the current budget.

The appropriation (Public Law 88–79, July 26, 1963) provided $63,700,000 for Survey's SIR, with $10,150,000 stipulated for the Federal-State program. This was a House recommendation even though the Senate had recommended $64.8 million. The allowance for WRI was $18,549,000; $8,399,000 for the Federal program and $10,150,000 for the Federal-State program; S&MC was a status quo $189,000.

Later internal budget adjustments resulted in actual 1964 financing of $64.3 million by SIR and $96.4 million for the total program including non-Federal and other-Federal-agency reimbursements. Final financing available for WRI was $18.4 million; for total program, $36.3 million (38 percent of Survey's total) including S&MC and all reimbursables. Sources of total water funding were 51 percent Federal, 29 percent non-Federal, and 20 percent other Federal.

Fiscal Year 1965.—The Division's budget estimate for WRI was $24,005,000, an increase of $5.3 million over 1964; $1,298,000 was within the budget-estimate allowance set by the Department and $4 million was over ceiling. Increased pay costs accounted for $288,000 of the allowed estimate increase. The S&MC request for $195,000 provided $2,000 for pay-cost increase.

The Federal program, estimated at $13,005,000, proposed an expansion of the primary gaging-station network from 2,800 to 3,400 stations and purchase of 5,000 digital recorders. It also would enlarge the number of studies of ground-water and basinwide systems, increase the benchmark-station network, and improve national coverage of water-quality information. The Federal-State program increase of $850,000 over 1964 to $11 million would be needed to match offerings of more than 300 State and local agencies that needed water information.

For the President's request to the Congress, the BOB allowed a WRI total of $20,797,000, an increase of $2.1 million over 1964; $9,997,000 for the Federal program and $10,800,000 for the Federal-State program. The Federal program increase of $1.4 million would be used for strengthening the primary and benchmark gaging-station networks and for more work on describing major ground-water systems and on basinwide water-resources studies. The initiatives to greatly enlarge the primary gaging-station network and to purchase digital recorders had to be deferred.

The Survey's SIR request totaled $69,223,000—an increase of $5.5 million over 1964, including $1.0 million for pay cost. In addition to the water increases, work would be resumed on the National Atlas and increased on geology, marine, and other activities. An amount of $0.8 million was included for construction of the isotope laboratory at Denver.

Secretary Udall's statement before the House Subcommittee on January 28, 1964, again strongly supported the Survey's budget request. He also briefed the Committee on the status of Senator Anderson's Water Resources Research Act, which at this time had passed the Senate and was awaiting House action, which was expected soon.

On February 6, Director Nolan, accompanied by his key associates including Chief Hydrologist Leopold, appeared before the Subcommittee. Chairman Kirwin expressed concern about the Survey's rapid growth, citing its total program financing as exceeding $100 million for the first time, and also questioning its growth in numbers of employees.

As part of his water-program statement, the Director included a statement on water-data needs as identified by a large group of Federal agencies which assembled on January 13–14, 1964, in a meeting called by the new Office of Water Data Coordination. The hearing record also included a comprehensive statement on manpower control and utilization, Division by Division. Throughout the hearing, Committee members voiced concern about overlapping and duplicating studies especially in water investigations and research—voicing particular criticism over multiagency activities, including the Survey's, in the Lower Colorado River Basin. Chairman Kirwin (page 722) was particularly critical of previous justification materials about water-research activities and cited omissions and inaccuracies in that material.

In his appearance before the Senate Subcommittee on February 19, 1964, Director Nolan cited the recently completed Survey long-range plan (USGS Special Publ., 1964) which attempted by systematic analysis to identify future needs for Survey's SIR programs and projections for accomplishment. Committee discussion centered on the need for, content of, and potential cost recovery through sales of the National Atlas, for which the Congress disallowed funds in 1964. Interaction between the Committee and Director Nolan, aided by Associate Chief Hydrologist Hendricks on the water-program activities, was quite extensive including adequacy of cooperative matching funds, the Lower Colorado River investigation, water losses by phreatophytes, reservoir evaporation research, ground-water problems, and automation of streamflow measurements.

The proposed Washington-area building for the Survey was again reported on; some preliminary design work had been done, but the GSA had made little progress on procuring a site and planning the facility.

President Johnson, on March 9, 1964, recommended to the Congress reductions in his original budget request for FY 1965, such reductions resulting from agreed-to cuts within the Executive Branch agencies in manpower allowances. The Survey share of the total reduction was a modest $600,000 in SIR.

The House Subcommittee report of March 13, 1964, recommended only $65,930,000 for SIR; the Senate report recommended $67,682,000. Conference action provided basis for an appropriation (Public Law 88–356, July 7, 1964) of $67,165,000, with $10,900,000 made available for cooperative water-resources investigations. Final allowance for WRI totaled $19,843,000, thus providing $8,943,000 for the Federal program. Funds of $1.0 million were provided for the Denver Nuclear Research Laboratory.

A supplemental appropriation (Public Law 88–365, October 7, 1964) provided $90,000, in lieu of a requested $160,000, for investigating and reporting on floods in Montana, requiring the Survey to use $70,000 from available funds to repair or replace gaging stations. Another supplemental request of $385,000 for followup work on the Alaska earthquake of March 1964 was denied by both Houses.

A second supplemental appropriation (PL 89–16, April 30, 1965) provided $550,000 to SIR (WRI) to remain available until June 30, 1966, for rehabilitating gaging structures after the catastrophic floods of December 1964 in the Pacific Northwest. Title II of this second supplemental added $500,000 to SIR for geologic and mineral-resource surveys and topographic mapping in the Appalachian area, also to remain available until June 30, 1966. Title III added $2,790,000 to SIR for increased pay cost incurred by the Federal Employees Salary Act of 1964 (PL 88–426, August 14, 1964).

Final SIR appropriation for the fiscal year totaled $70.4 million; final obligations from all sources totaled $105.4 million. Final water–program obligations were

Fiscal Year 1966

[WRD budget cycle summary for fiscal year 1966 (in dollars; dashed where not applicable)]

| Program element | Estimate | Justification | Initial appropriation | Final appropriation | Obligations |
|---|---|---|---|---|---|
| WRI-Federal | 10,421,000 | 10,313,000 | 10,513,000 | *10,695,000 | 10,836,265 |
| WRI-Federal Coop | 11,600,000 | 11,550,000 | 11,550,000 | 11,924,000 | 11,828,332 |
| S&MC | 198,000 | 198,000 | 198,000 | 201,000 | 201,000 |
| Non-Federal Coop | - | 12,420,000 | -- | - | 12,553,308 |
| FPC | - | 395,000 | -- | - | 455,861 |
| OFA | - | 7,516,000 | -- | - | 8,080,143 |
| Total | - | 42,392,000 | -- | - | 43,954,909 |

*Carryover of $368,289 from FY 1965 not included.

$40.6 million (39 percent of Survey's total), derived 52 percent from Federal appropriations, 29 percent non-Federal cooperating agencies, and 19 percent from other Federal agencies.

*Fiscal Year 1966*.—The Division's WRI budget estimate proposed $22,021,000, an increase of $1,049,000 over the financing then estimated to be available for 1965. The proposed Federal program of $10,421,000 would provide initial funding for the Office of Water Data Coordination (OWDC), an increase for basic water information including the benchmark areas, basinwide water-resource studies, hydrologic research emphasizing principles and techniques, ground water-surface water relationships and chemical relations within ground-water bodies, the International Hydrological Decade, and education and training. The proposed Federal-State program of $11,600,000 would provide an increase of $180,000 over 1965 after accommodating pay-cost adjustments carried through from 1965. The S&MC program would continue level at $198,000.

The WRI budget justification, as approved by the BOB, provided program increases of $1,320,870, offset in part by program savings and nonrecurring items of $429,870 to permit a total WRI request of $21,863,000 to the Congress. Of this amount $11,550,000 was earmarked for the Federal-State program, providing a nominal increase of $130,000 above pay-cost adjustments to meet increased offerings from cooperating non-Federal agencies. The Federal program net increase of $775,870 would be used among the elements described above, but dollar allocations were not specifically identified. (Author's note: At that time, budget justifications seemed to have been written with less specificity than heretofore, seemingly to the point of prompting the budget examiners to ask "...how much will be spent on this?...or that?" Why this change in budget strategy, if indeed it was purposeful, remains unclear but it did not sustain—see FY 1967.)

The BOB recommended an SIR budget request of $72,826,000, a net increase of about $2.4 million over 1965 after adjusting for nonrecurring items and program savings. An increase of $1.0 million would institute a new research effort in earthquake seismology, a reaction to the Alaska quake of March 1964. The remaining increases were nominal and spread among the mapping, marine, and administrative functions.

In his statement before the House Subcommittee on February 11, 1965, Director Nolan reported on growth of water-data networks stressing water-quality activities and conversion to digital recorders currently totaling 2,700 in operation out of a planned 8,200. He also stressed automating the computing, processing, and publishing of data records. He reported on the Division's national assessment of mineralized ground water and its work on the water resources of the Appalachian region. Chief Hydrologist Leopold and other key officials were present.

Committee interests, concerns, and questions generally voiced by Chairman Denton, centered on the need for such rapid growth in the Survey's program, on earthquake studies and coordination with the Coast and Geodetic Survey in such activities, on coordination of water data and water research, and on cooperative offerings for water information (Leopold participated in these latter discussions). Director Nolan also reported on plans for a major reorganization of the Water Resources Division (p. 673), which the Department had approved that past December. For the first time he could report some beginning work on siting and designing the Survey's Washington-area building with six sites being considered.

Fiscal Year 1967

[WRD budget cycle summary for fiscal year 1967 (in dollars; dashed where not applicable)]

| Program element | Estimate | Justification | Initial appropriation | Final appropriation | Obligations |
|---|---|---|---|---|---|
| WRI-Federal | 10,099,000 | 10,966,000 | 11,378,000 | 11,678,000 | 11,671,903 |
| WRI-Federal Coop | 12,550,000 | 12,850,000 | 12,950,000 | 13,170,000 | 12,994,537 |
| S&MC | 198,000 | 201,000 | 201,000 | 203,000 | 194,079 |
| Non-Federal Coop | - | 14,010,000 | -- | - | 13,922,865 |
| FPC | - | 505,000 | -- | - | 414,816 |
| OFA | - | 8,601,000 | -- | - | 8,434,770 |
| Total | - | 47,133,000 | -- | - | 47,632,970 |

Representative Hansen posed specific questions about the Alaska earthquakes, northwestern U.S. flood studies, and other activities of the Survey. Other members' questions concerned water-quality stations, application of Survey's information in urban land-use planning, and mined-land subsidence.

Chairman Hayden of the Senate Subcommittee heard the Survey's program on February 18. Water-program questions largely reflecting parochial interests of Senators Hayden and Mundt, included status of reconstructing stream-gaging facilities on the Colorado River at Lees Ferry in Grand Canyon, the Gila River phreatophyte study, water management at Lake Poinsett, S. Dak., and liaison with Bureau of Reclamation and the U.S. Army Corps of Engineers. In response to an inquiry about status of the Survey headquarters building, a statement furnished by Director Nolan (p. 240) summarized recent actions on selecting a site, with most serious consideration then being given a tract near Great Falls, Md.

Public Law 89–52, June 28, 1965, appropriated $71,680,870 for SIR, including $11,550,000 designated for the Federal-State program. The final WRI allowance totaled $22,063,000, including a Senate add-on of $200,000 for sediment removal in the Gila River phreatophyte project area, thus providing $10,513,000 for the Federal program. Funding for S&MC amounted to $198,000 as requested. Again, both the House and Senate Subcommittees strongly supported the water activities of the Survey.

A pay-cost supplemental later in the fiscal year added $1,510,000 to SIR for a total of $73,190,870 and resulted in a final Federal program in WRI of $10,836,265, a Federal-State program of $11,828,332, and for the S&MC, $201,000.

Final total Survey financing available in 1966 was $113.8 million of which $44.0 million was for water programs, 39 percent of the Survey's total. Water-program funds were derived 52 percent from Federal appropriation, 29 percent from non-Federal cooperators, and 19 percent from other Federal agencies.

Fiscal Year 1967.—This year's budget development and presentation to the Congress was the final cycle under Chief Hydrologist Leopold's direction. Water estimates reflected a tightened budget and a restructuring of program elements as a result of the Department's instituting a new objectives-oriented planning, programming, and budgeting system (PPBS).

The WRI estimate was $23,450,000, an increase of $1,018,711 over the currently available 1966 financing, but the Federal program was held basically level at $10,099,000 including increases of $700,696 offset by nonrecurring items and internal priority adjustments. A proposed increase of the Federal-State program of $1 million would provide a total of $12,550,000 for cooperative matching. S&MC was proposed for no change at $198,000. A decrease of $568,000 from completion of the Gila River phreatophyte clearing and special flood studies in the Pacific Northwest permitted moderate increases in several of the other program components.

The BOB allowed $23,816,000 for WRI in the budget justification to the Congress: $10,966,000 for the Federal program and $12,850,000 for the Federal-State program. S&MC was continued about level at $201,000. The slight increases over the budget estimates were in part for pay cost for new 1966 positions rather than for substantive program change.

The Survey's SIR proposal to the Congress totaled $73,920,000 for new authority plus $584,000 of prior-year unobligated balance. This represented a generally hold-the-line budget except for the WRI increases.

The written justification to Congress, based on essentially the same program elements used to present the budget estimates to the BOB, was much more comprehensive and detailed than heretofore and for WRI, contained detailed narrative and budgets for the 13 program elements in the Federal program, plus employee compensation payments, as follows:

1. Water-data coordination, $420,000
2. Basic-data collection and analysis, $2,516,000
3. Regional water resources studies, $270,000
4. Analysis of water-resources of basins, $586,400
5. Analysis of lake resources and problems, $147,000
6. Flood and drought problems, $432,696
7. Development and application of modern scientific methods, $671,500
8. Research on data use and automatic data processing, $463,100
9. Research on basic hydrologic principles, $2,542,461
10. International Hydrological Decade, $205,000
11. Education and training, $608,000
12. Publications and support, $2,049,000
13. Nonrecurring items, $0
14. Employee compensation payments, $54,843

(Author's note: The very explicit display of activity elements and related dollar proposals for FY 1967 is in stark contrast to the previous year's vague and devious-appearing justification materials. The change will become even more pronounced in the years to follow as increasingly rigorous and analytical budget-development techniques are adopted within the Executive Branch in an effort to control budget growth and improve program-planning effectiveness.)

At the House Subcommittee hearing on February 3, 1966, Director Pecora headed the Survey delegation for the first time. Hendricks attended as Acting Chief Hydrologist along with other Survey officials. Congressman Denton, Chairman, cordially welcomed Pecora and requested insertion of his biography into the record (p. 73). The Director's opening statement was quite general and laudatory of Nolan and the Survey as he entered as its new head.

In the discussion that followed, Chairman Denton challenged the Survey's request for Federal funding of pay-cost increases for the non-Federal side of the Federal-State cooperative program incurred in the first year of such federally awarded increases. In spite of strong justification by Pecora for this practice which had been previously acceptable to the Subcommittee, Denton stood firm and declared "I want to go on record at this point by stating that such procedure is contrary to the wishes of the Committee, and I suggest that you advise the Committee within the near future of the action you have taken that will preclude the necessity of your bearing the total pay-cost increases in the future."

In reviewing the WRI part of SIR, Committee discussion and questions (chiefly Chairman Denton's) involved the program increases and activities and seemed to be more for his desire to better understand the program elements than to challenge the need for them. Later general discussion included water-research coordination, especially with Interior's new Office of Water Resources Research (OWRR); role of the Survey in the Delaware River court decree; university relations; and coordination with other agencies.

Senator Hayden convened his hearing on the Survey budget on February 28, 1966. Again Hendricks as Acting Chief Hydrologist accompanied Director Pecora and other key Survey officials. Pecora reviewed the principal program components of SIR, broadly summarizing and answering questions on most of them until reaching the WRI portion of the hearing when he called upon Hendricks. Discussions and questions about water centered on the principal Federal program increases—flood-hazard mapping in Appalachia, water-data coordination, flood and drought problems, the phreatophyte study project, the International Hydrological Decade, education and training, acid pollution of streams in Appalachia, mine-water pollution, underground waterways in West Virginia (an interest of Senator Byrd), hydrology of arid lands, university relations, and coordination with other agencies.

Other program matters discussed included mapping, minerals exploration and strip mining in Appalachia, minerals work related to the Wilderness Act of 1964, the National Atlas, earthquakes and volcano studies and predictions, and oil-shale potential. The extent of dialogue and the interaction of Committee members and the Survey spokesmen at this hearing seemed to be much more extensive than at previous Senate hearings, probably due to the more comprehensive details on program activity provided by the justification material.

The House report on the SIR request allowed $72,782,000, reduced mapping by $400,000 and WRI by $638,000—$500,000 for cooperative matching and the remainder divided between the Appalachian flood mapping and the IHD program. Conservation Division funding was also reduced by $100,000. The Senate report restored the House's mapping cut and added a new item forwarded by the President as an amendment after the House hearing of plus $6,600,000 for "...exploration and discovery programs related to heavy metals in short supply in the United States." The Senate also recommended increases totaling $1,550,000 for WRI over the House allowance: an additional $900,000 for cooperative matching, including $50,000 for a hydrologic survey of the Delmarva Peninsula, and $650,000 for phreatophyte clearing along the Gila River project area in Arizona.

House-Senate conferees agreed to an SIR of $80,032,000 providing more than $6 million for heavy metals, more than $600,000 for cooperative matching, and $650,000 for phreatophyte clearing in WRI, all of which was incorporated into the appropriation act, Public Law 89–435, May 31, 1966. Funding for WRI totaled $24,328,000 with $12,950,000 earmarked for the WRD cooperative program.

A later pay-cost supplemental added $1,577,000 to the final 1967 SIR appropriation of $81,609,000; final for WRI was $24,848,000, including $13,170,000 for the WRD cooperative program, and $203,000 for S&MC.

Total financing available to the Survey in FY 1967 was $124.1 million from all sources; for the Water Resources Division, $47.6 million (38 percent of Survey's total)—derived 52 percent from Federal appropriation, 29 percent from non-Federal cooperating agencies, and 19 percent from other Federal agencies.

# PART VI—HYDROLOGY AND PROFESSIONAL DEVELOPMENT

With contributions *by* Raymond O. Abrams *and* A. Ivan Johnson

## Introduction

Among Luna Leopold's goals for the WRD was its recognition as the premier national and international scientific water-resources organization. Attaining that goal depended on enhancing the technical skills and competence of existing staff by internal and external training and on attracting, screening, and employing new professionals who were especially well trained in the basic sciences and in those disciplines that comprise the hydrological sciences. Successful recruiting, in turn, depended on the development of a national reservoir of university-trained hydrologists.

This part of Volume VI documents the emergence of hydrology as a science and its recognition by the CSC and by academe. It also documents the enhancement or creation of training opportunities for hydrologists both within and outside the Survey during the period from 1957 through 1966.

Training, career guidance, and recruiting new employees were established functions of the WRD Branches as this period of history opened, but it was due to the interest and personal involvement of Leopold that these functions were reinforced and became critical building blocks in his goal of achieving scientific eminence for the Division.

Establishing university degree programs in hydrology, creating a job classification for hydrologists by the CSC, and subsequently reclassifying most professional members of the Division as hydrologists were products of this period. Establishing the National Training Center in Denver came soon after this period of history closed, but its genesis was clearly in the Leopold years.

## Career Guidance

Although a formal system for career-development planning and management in WRD did not begin until after 1966, the groundwork was laid for career guidance prior to and during the Leopold years. The need to satisfy and merge the personnel requirements of the Division with the career interests and ambitions of individual employees was recognized early and led to the use of employee-comment and employee-appraisal forms in the Branches that later served as a data base for career guidance at Division level.

Before 1963, each Branch, except GHB, designed and used its special forms to document and evaluate the experience and potential of each technical and professional employee. The GHB, with its relatively small staff, evidently felt no need for such formal documentation.

The GWB used a simple, one-page form in 1957 which was replaced, probably in late 1958, with a much more detailed set of evaluation and appraisal forms that were to be completed semiannually by each professional employee and his supervisor. It appears, from the sparse records available, that the semiannual evaluation form and questionnaire were replaced in late 1959 or early 1960 by a redesigned "Annual Appraisal of Professional and Technical Employees" and a "Professional and Technical Employee Information and Comments" to be completed by the employee. An apparent reason for the change was to include the growing numbers of technical, nondegree employees.

The year when QWB first used an employee evaluation form is unclear; however, records available indicate such a form was being used in 1961. A "Supplemental Professional and Technical Employee Comment" form was completed by the employee. His supervisor then completed a "Supplemental Professional and Technical Employee Appraisal" and forwarded both to Headquarters.

In 1959, SWB began the use of the form "Professional and Technical Employee Appraisal" that was completed by the employee's supervisor, accompanied by the questionnaire, "Professional and Technical Employee Comment," completed by the employee. Although these forms were marked WRD-Exp. 9-17-59, they were changed in 1961 to give greater emphasis to technical, human, and conceptual skills. These forms were used until 1963 when Division-level career-documentation forms came into use.

The career-tracking forms devised for Division-wide use in 1963 were used through 1966 and beyond. The Division forms, "Professional and Technical Employee Comment and Data Form" was completed by the employee and "Appraisal of Professional and Technical Employees" by his supervisor.

Also in 1963, all professional employees were asked to prepare a concise autobiography accounting for their major career milestones and a bibliography. Both were to be kept up-to-date, but updating usually had to be prompted by a supervisor when a change of assignment or promotion was being considered.

In about 1964, the Division developed a family of curves that illustrated median as well as faster and slower promotion rates for each Branch by age, years in grade, number of published reports, and years since entering on duty. They were used for comparative purposes when a request for promotion reached headquarters.

Employee interest in foreign assignments was not overlooked. In 1958, a questionnaire was distributed by the Foreign Hydrology Section to determine WRD employee interest in working in foreign countries. There is no record of this inquiry being repeated in subsequent years.

None of the career documentation forms stood alone when a promotion or change in assignment was being considered for a WRD professional or technical employee. Training records, citations and awards, and letters relevant to their performance as Division emissaries were also used.

TWELFTH GROUND WATER BRANCH SHORT COURSE, UNIVERSITY OF OKLAHOMA
NORMAN, OKLAHOMA
MARCH 3–16, 1957
UNITED STATES GEOLOGICAL SURVEY

Donsky Boggess Zimmerman Summers Stacy Cragwall H. Thomas Lohman Leopold Miller Mayo
Husky Cochran Spiser Scott Galloway Upperco Titus Walters Weist
Sun M. Davis Longwell Langbein Mink Feulner Garber Chipps Hosman Peckham
Leonard Hsu Callahan Ogillbee Rosenau Gose Cotter Durfor Kulp Twenter Jackson Oriel
Van Lewen Sayre Wilmoth Tarver Tanaka Taylor Johnson Hopkins Morgan R. Thomas Berry

Figure VI-1. Attendees at GWB short course, Norman, Okla., March 3–16, 1957.

## Training

### Intramural

#### *Branch Short Course*

As noted in Volume V (Ferguson, 1990) in-service training was initially the responsibility of each Branch. Before 1957, GWB, SWB, and QWB began series of short courses or training schools of 1 to 2 weeks' duration.

From 1957 through 1961, GWB held short courses 12 through 20. Delmar W. Berry, Chief of the Branch Training Section, was the staff officer responsible for arranging each of the nine short courses held during this period. Group photographs of the attendees and instructors showing location and dates of each follow as figures VI–1 to VI–9.

THIRTEENTH GROUND WATER BRANCH SHORT COURSE (SECOND ADVANCED COURSE)
UNIVERSITY OF WYOMING SCIENCE CAMP, CENTENNIAL, WYO.
JULY 21—AUGUST 3, 1957
UNITED STATES GEOLOGICAL SURVEY

Robinson Harshbarger Knight Carlston Lohman Waite Nace
Stallman Meyer Hendrickson Lane Thomasson Robinove
Jackson Mundorff
Remson Roberts Davis Hale Ferris Steinhilber Poland
Thomas Deutsch G. C. Taylor G. H. Taylor Worts Otton Richardson Siple
Dennis Skibitzke Sinnott Bennett Morris Berry

Figure VI-2. Attendees at GWB short course, Centennial, Wyo., July 21 to August 3, 1957.

FOURTEENTH GROUND WATER BRANCH SHORT COURSE, LOUISIANA STATE UNIVERSITY
BATON ROUGE, LOUISIANA
FEBRUARY 16—MARCH, 1 1958
UNITED STATES GEOLOGICAL SURVEY

Norvitch Miller Gallaher Sinclair Carswell Farvolden Petersen Lohman Hodson Eudaly Thomas
Spieker Price Owen Cline Motts Chapman Pistrang LaSala Stulik
Newton Prill Bingham Jensen Whitcomb Crooks
Drescher Davis Pusey Bermes Meffley Austin Kapustka Page Adolphson Coskery Colburn
Seaber Cohen Edds Rollo Kinnison Riggs Fowler Bieber Hall Harris Wilson
Johnson N. Sayre E. Sayre Berry

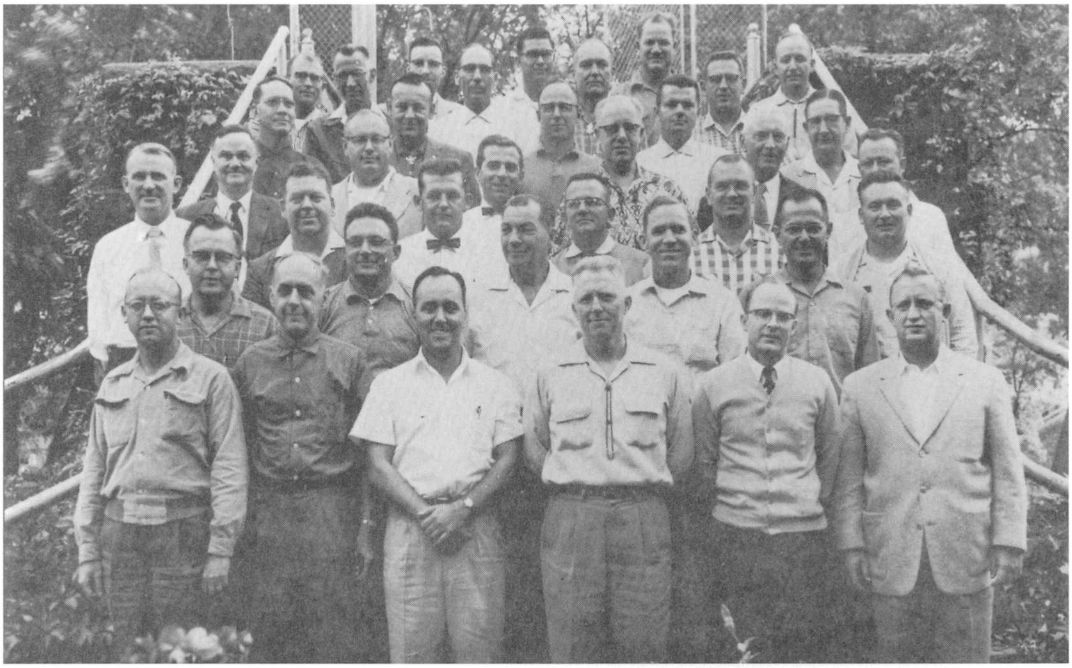
Figure VI-3. Attendees at GWB short course, Baton Rouge, La., February 16 to March 1, 1958.

FIFTEENTH GROUND WATER BRANCH SHORT COURSE, UNIVERSITY OF OKLAHOMA
NORMAN, OKLAHOMA
APRIL 6–19, 1958
UNITED STATES GEOLOGICAL SURVEY

Lockwood Bennett May Southwood Shaw Bader Peace Lohman Goode Nyman Hicks Thomas Berry
Ray Stephens Speer Merritt Sandberg
K. Johnson Price
Shuter Albin B. Myers McConaghy Phoenix Janzer
R. Meyers Wassen Smith Hollowell Niehaus Coffin Watt Randall Plebuch Burton
Floyd Gill Horr Morse Hansen Foster F. Meyer Rogers
A. Johnson Cressler Croft Emmett Mason Garza Nelson Grogin Davis

Figure VI-4. Attendees at GWB short course, Norman, Okla., April 6–19, 1958.

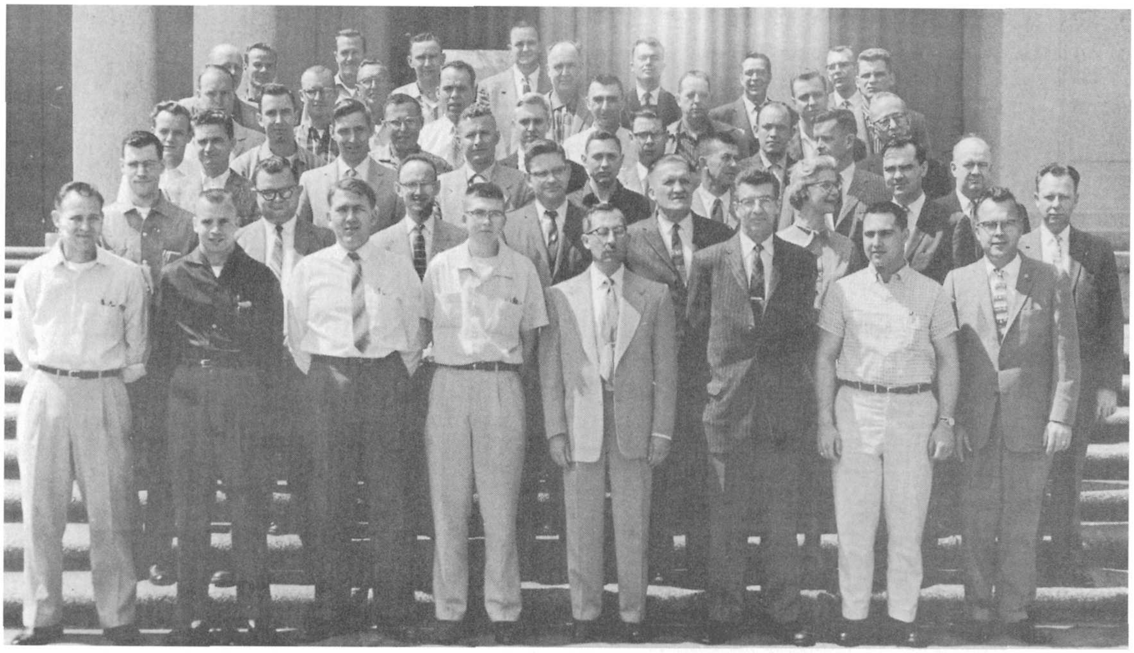
SIXTEENTH GROUND WATER BRANCH SHORT COURSE (THIRD ADVANCED COURSE)
HOTEL COLORADO, GLENWOOD SPRINGS, COLORADO
OCTOBER 5-18, 1958
UNITED STATES GEOLOGICAL SURVEY



Chase Leonard Stallman Skibitzke Bennett
Davis Hoy Lohman Cooper
McLaughlin J. Powell LaMoreaux Sniegocki Gordon
Barksdale Newport Rima Thomas Taylor Berry
Lusczynski Siple Moulder Metzger Trauger Rhodehamel
Johnson Meyer Nace Thomasson Schneider
W. Powell Ferris DaCosta Drescher Jones Turcan

Figure VI-5. Attendees at GWB short course, Glenwood Springs, Colo., October 5–18, 1958.

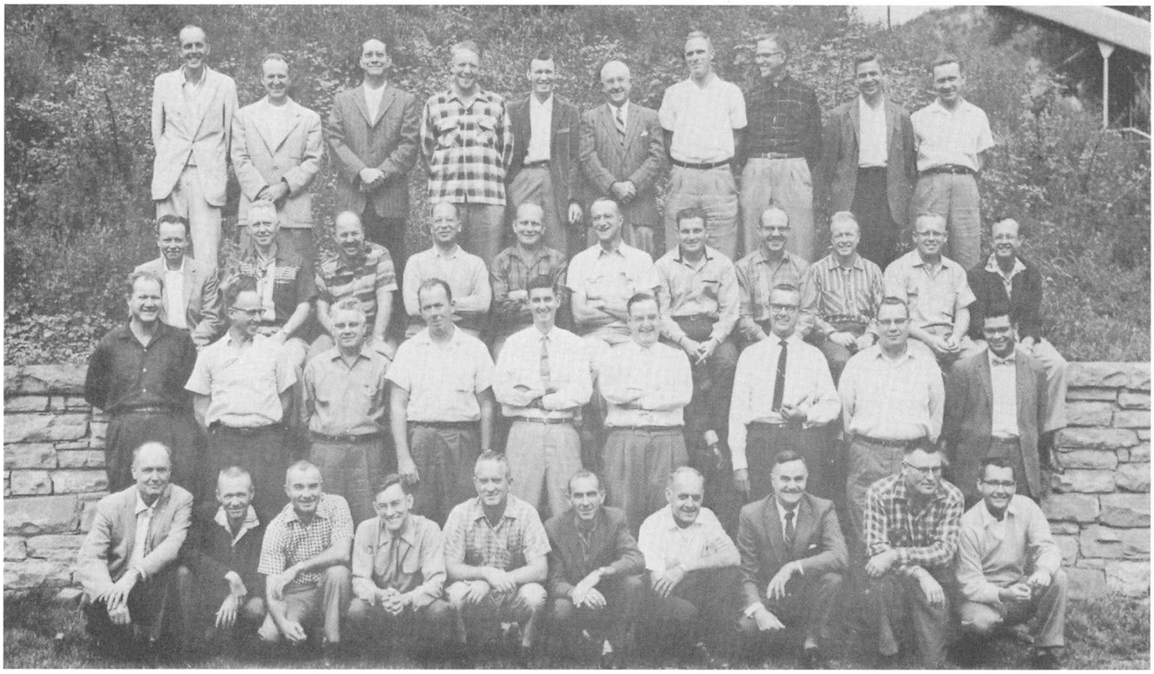
SEVENTEENTH GROUND WATER BRANCH SHORT COURSE, LOUISIANA STATE UNIVERSITY
BATON ROUGE, LOUISIANA
MARCH 15-28, 1959
UNITED STATES GEOLOGICAL SURVEY



Davidson Miller Jeffery Bull Sumsion Woods Marsh
Meyer Busch Lohman Bayne Appel Jablonski
McClymonds Ash Franks Rodis
Moston Baker Leve Meisler Grolier Dale Williams
Clark Sever Dodson Sammel Robinson Brandon Eisenlohr
Hunn Alverson Schneider McMillion Martin C. Hubbard H. Hubbard Berry
Gabrysch Hart Meneley Hampton Rozanski Hardman Vecchioli Johnson

Figure VI-6. Attendees at GWB short course, Baton Rouge, La., March 15–28, 1959.

EIGHTEENTH GROUND WATER BRANCH SHORT COURSE (FOURTH ADVANCED COURSE)
HOTEL COLORADO, GLENWOOD SPRINGS, COLORADO
SEPTEMBER 13-26, 1959
UNITED STATES GEOLOGICAL SURVEY



Vanlier  Rosenau  McLaughlin  Goode  Peek  Fiedler  Prescott  Allen  Harvey  R. Brown

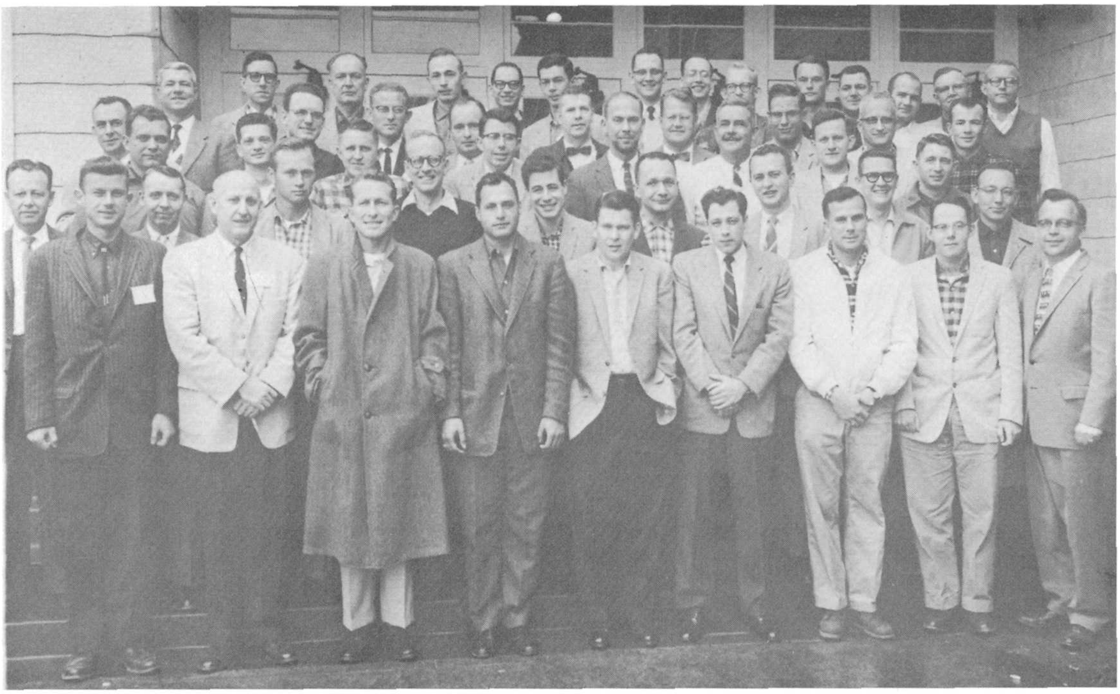
Berry  Drescher  Heindl  Walker  Counts  Swenson  Ryling  Kunkel  Worts  Clebsch  Winslow

Skibitzke  LaMoreaux  Fishel  P. Brown  Newcome  Garrett  Voegeli  Keech  Stallman

Lohman  Knowles  Heath  Price  Barclay  Klein  Ferris  Barksdale  Babcock  Bermes

Figure VI-7. Attendees at GWB short course, Glenwood Springs, Colo., September 13–26, 1959.

NINETEENTH GROUND WATER BRANCH SHORT COURSE, UNIVERSITY OF OKLAHOMA
NORMAN, OKLAHOMA
MARCH 6-19, 1960
UNITED STATES GEOLOGICAL SURVEY



Broom McClelland Lohman Wahl Rau Huxel Jones Rosene Dyer Lowry Savini Reeves Holland Boettcher
Cyphers Hamilton McCoy Laughlin Newcomb Waananen Weeks Matthai Penley
Isbister Havens Hallenstein Page McMasters Ballance Koch Stewart
Berry Marvin Pashley Meade Tannenbaum Warman Toth Carpenter Walker
Duryea Jackson McNellis Gutentag Klausing Cordova Cherry Salvas Johnson

Figure VI-8. Attendees at GWB short course, Norman, Okla., March 6–19, 1960.

Lubke Chun Dixon Williams Kennon T. Robison Lytle Keys Winner
Reed J. Robison H. Johnston Gates Rush Rooney Whiteside Thordarson
Lohman Causey Kimrey Howells Welborne Taylor Burtis Hyde
McGreevy Gregg McCollum Fortier French Dyer Purtyman Zdenek
Conover Young Bearden Wise Bingham R. Johnston Moore Schneider Soren
Berry Robinove Eddy Hirashima Dinwiddie Yanchosek Voegtle Wilder Johnson

Figure VI-9. Attendees at GWB short course, Baton Rouge, La., March 5–18, 1961.

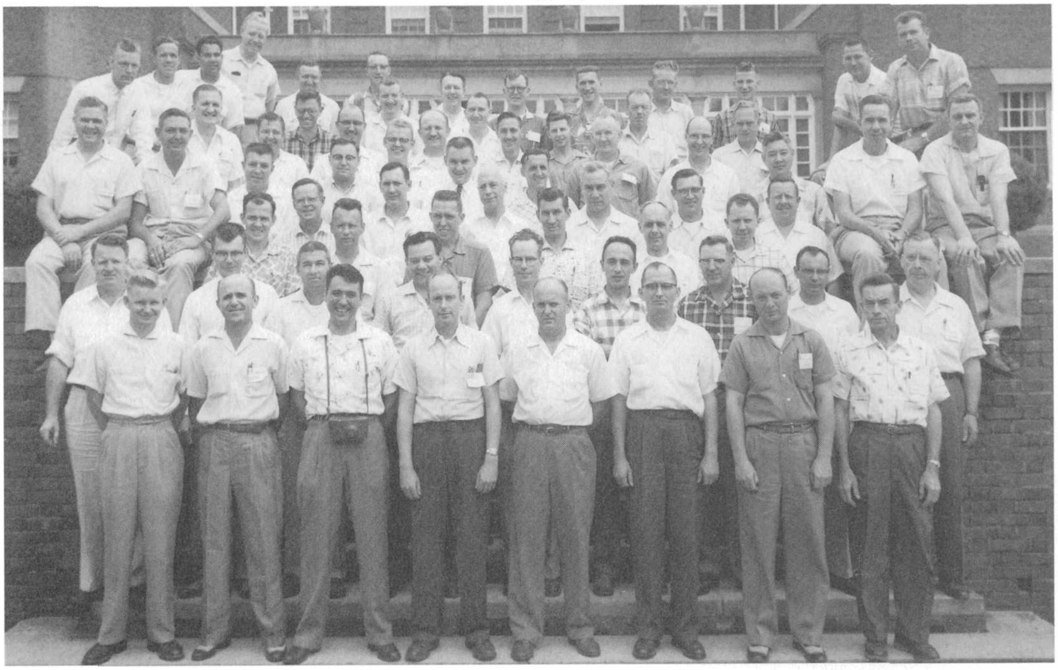
FOURTH SURFACE WATER BRANCH SHORT COURSE
LOWER COLORADO RIVER AUTHORITY AUDITORIUM
AUSTIN, TEXAS
FEBRUARY 4-15, 1957
UNITED STATES GEOLOGICAL SURVEY

Moore Horton Moulder Petitt Anderson, F. Anderson, D. Todd Mehrhoff Burns McDowell Nations Baltzer
Wells Hale Welborn Dosch Harris Leppanen Newcomb Goddard Ham Dunn Rostvedt Richardson
Hinson Furness Swanson Pendleton Davey Ericson Myers, B. Culler McCabe Curtis, A. Musgrove Lamke
Kennedy Bogart Flynn Schaefer Carter, F. Myers, R. Sullivan Hedges Avrett Eagle Allen Smith Dennis Odell Curtis, R.
De Paulo Lendo Evett Ligner Larimer Grozier Hall Vaudrey Schneider Calandro Pearce Dalrymple

Figure VI-10. Attendees at SWB short course, Austin, Tex., February 4–15, 1957.

The SWB held 20 short courses between February 1957 and February 1961 of which six were termed "advanced" and 14, "basic." The last advanced short course was in September 1960 and was the ninth of that series which began in 1956. The first basic SWB short courses was in April 1957. The fourteenth, and last, was in February 1961. Roy E. Oltman, who headed the SWB Training Section from its creation in 1956, organized and led the early advanced short courses until he moved to the Division in 1957. Following Oltman, James J. Ligner, as Chief of the Section, was responsible for arranging the short courses until 1960 when Medford T. Thomson became Section Chief. Group photographs of the attendees and instructors showing locations and dates of the courses follow as figures VI–10 to VI–29.

FIFTH SURFACE WATER BRANCH SHORT COURSE, ALLERTON PARK
CHAMPAIGNE, ILLINOIS
JUNE, 3-14, 1957
UNITED STATES GEOLOGICAL SURVEY



Oltman Holm
Whitaker Hines Robles Randolph Scott Lingham Vickers Busby Cragwall Knutilla Dove
Beall Martin Pluhowski Longfield Benson Yarger Holland Wilson Reid
Bowie Perkins Lind Burti Hartwell Wertepny
Walker Patterson Dougherty
*Guetzkow* *Borghese* Weeks Koks Ogata
Bunch Wollin Morgan Montgomery Ramsvick Minehan
Guy Lamson Ruggles Bartells Ferris Fogarty
Lawrence Godfrey Rabon Barton Edelen Lara Johnson Nady McCreery
Werho Mathews Ligner Stackpole Rukkila Carns Koberg Hickenlooper
Attended, but not in picture — Lokke; Harris; Hoggatt; Savini.

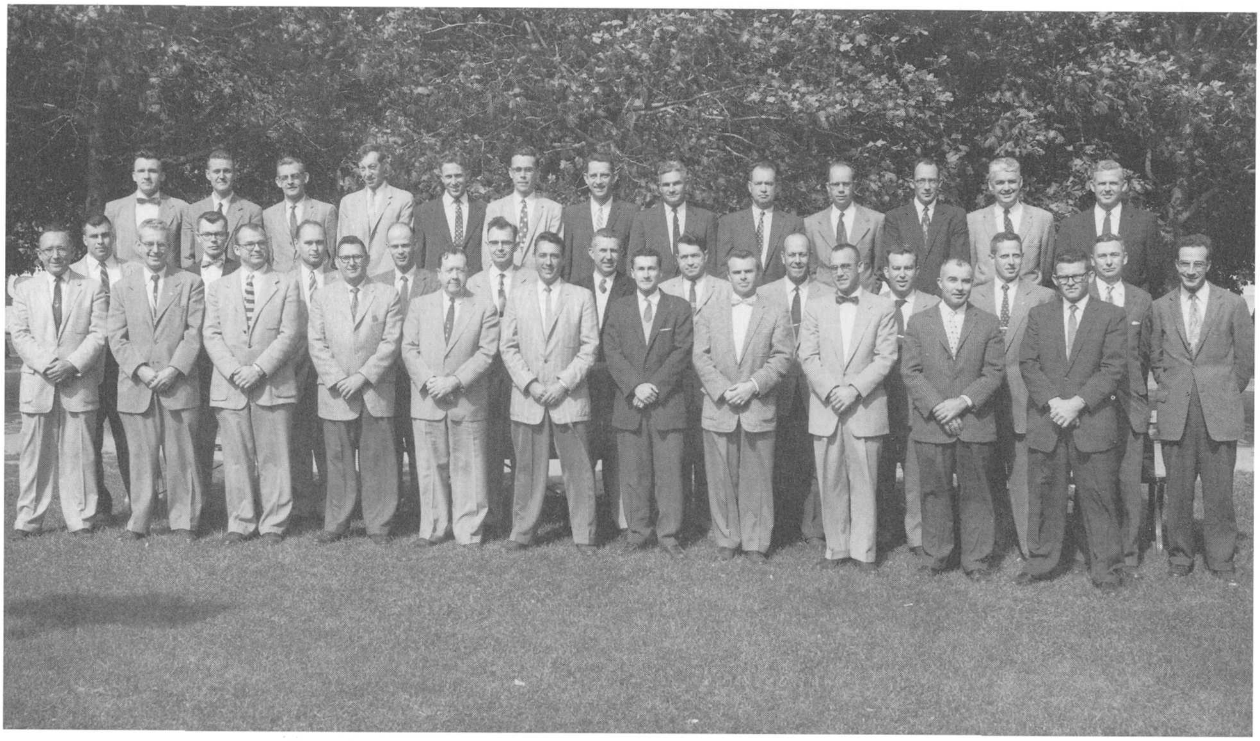
Figure VI-11. Attendees at SWB short course, Champaign, Ill., June 3–14, 1957.

SIXTH SURFACE WATER BRANCH SHORT COURSE
DENVER, COLORADO
MARCH, 3-14, 1958
UNITED STATES GEOLOGICAL SURVEY


Petsch Golden West Moore Carter Lawrence Rossow Mullnix Osborne Thomas Whiteman
Perry Hodges Sollid Murphy Miller Aldridge Shell Buchanan Cook Strilaeff Ellis Conger
Burgess Westfall Jamison Wiitala Childers Rennick Johnson Warren Ozga Kennon Davidian Lusby
Hassler
Swecker Mitchell Buswell Philipsen Jenkins Hopper Eissler Brownlie Valenciano Mills McKillop Matthai
Pettengill Ligner Stearns Snipes Crosby Myrick Likes Gwinn Jordan Goshorn

Figure VI-12. Attendees at SWB short course, Denver, Colo., March 3–14, 1958.

Surface Water Branch Short Course
Albany, New York
October 6–17, 1958
United States Geological Survey



Pfannebecker Moyle Hayes Searles Reeder Wark Cosner Smith Gilstrap Miller Tate Steacy Richard Heath

Hetling Godfrey Stichling O'Sullivan Bresee Craig Johnson Charnley Bettendrof Schiavo Wood Barnum

Trotter Wagar Koloseus Lang Mitchell Ligner Huberman Darling Winget Ralph Heath Sauer

Figure VI-13. Attendees at SWB short course, Albany, N.Y., October 6–17, 1958.

SURFACE WATER BRANCH SHORT COURSE
SALT LAKE CITY, UTAH
OCTOBER 26,–NOVEMBER 6, 1959
UNITED STATES GEOLOGICAL SURVEY

E. G. Miller A. Johnson Stenstadvold
Swift D. O. Moore McQueen Swing Larson Kilpatrick McCollam Smith Hardt Pike Saboe Davis

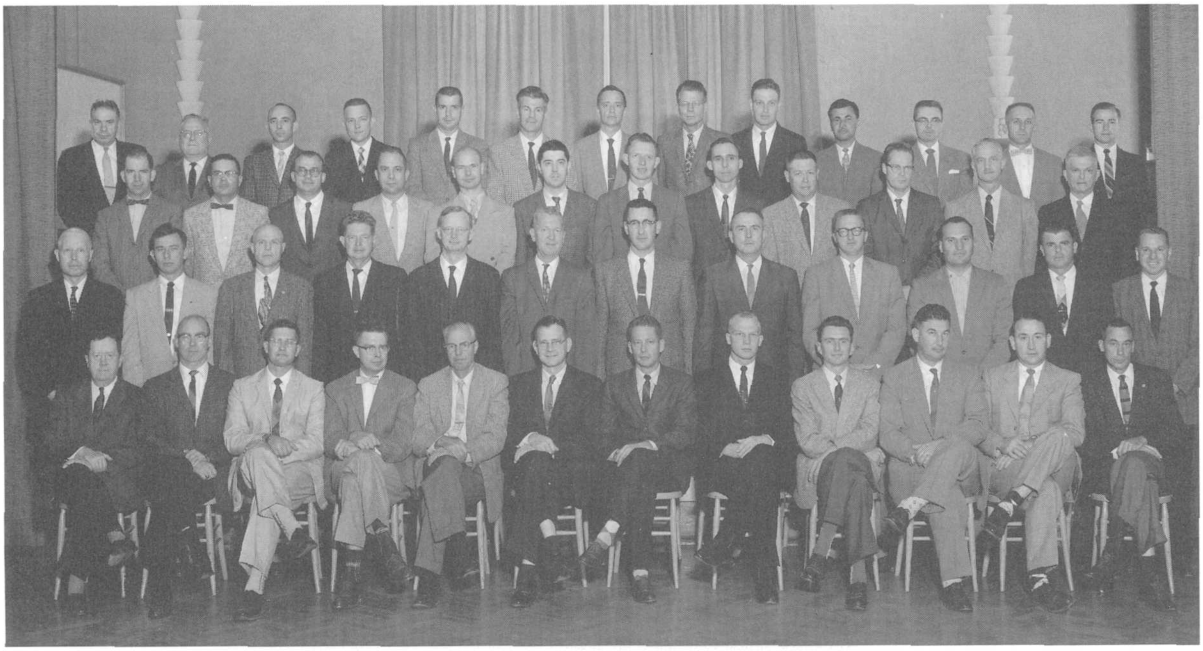
B. A. Anderson
J. B. Miller Hoffard McDonald Morby Cahill Cerny Roeske Carstens Knox Koloseus Noehre Sloss Kallio Reiland Veatch

Cummings Humphreys
Abrams Ferris Ogilvie Cummans Hulme Showen Thompson May Peterson Jones Mitchell Spiers Ebling Crippen T. O. Miller Iqbal Ligner

Burkham Bailey Rickher Sieber Monis Diaz Carlson Hurtgen G. Andersen R. W. Moor E. B. Johnson Cadaoas Christensen

Figure VI-14. Attendees at SWB short course, Salt Lake City, Utah, October 26 to November 6, 1959.

NINTH SURFACE WATER BRANCH SHORT COURSE
ST. PAUL, MINNESOTA
SEPTEMBER 19–30, 1960
UNITED STATES GEOLOGICAL SURVEY



Pederson Mussey Scott Hutchison Martens Heckmiller Anderson Oeltjen Meyer Juruf Feeney Havelka Van Lewen

Campbell Weiss Koloseus Frye Jansen George Hedman Mohler Chase Conn Joerns Busch

Oltman Keller Saltnass Murphy Meppen Smith Godwin Alexander Norvitch Giacomini Camp Abrams

Mitchell Kinnison Comegys Dein Prior Sawyer Stallings Ficke Hood Amoroso Beckers Hess

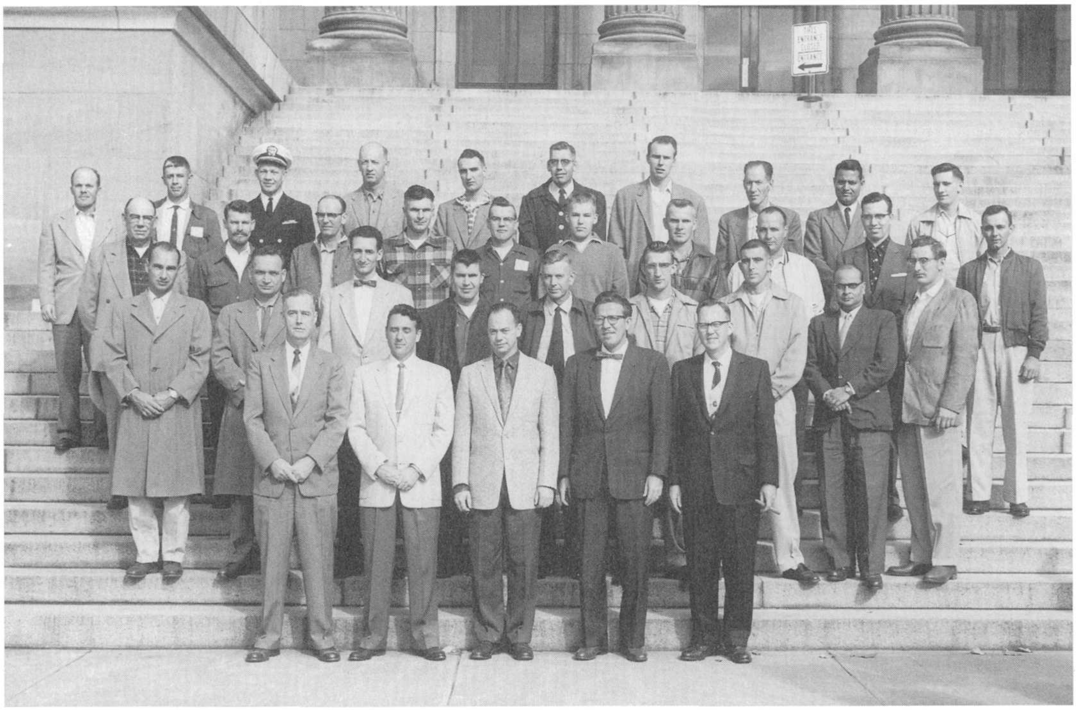
Figure VI-15. Attendees at SWB short course, St. Paul, Minn., September 19–30, 1960.

SURFACE WATER BRANCH BASIC SHORT COURSE
ATLANTA, GEORGIA
APRIL 22–26, 1957
UNITED STATES GEOLOGICAL SURVEY

Ligner Condrey Ming Bell Marshall Cunningham Carlson
Johnson Boyd
Oltman Hall Elkins Creasman Norris Utter Bloxham
Speer Bogart Counts
Bodhaine Bradley Woods McWilliams Humphreys Lowe

Figure VI-16. Attendees at SWB basic short course, Atlanta, Ga., April 22–26, 1957.

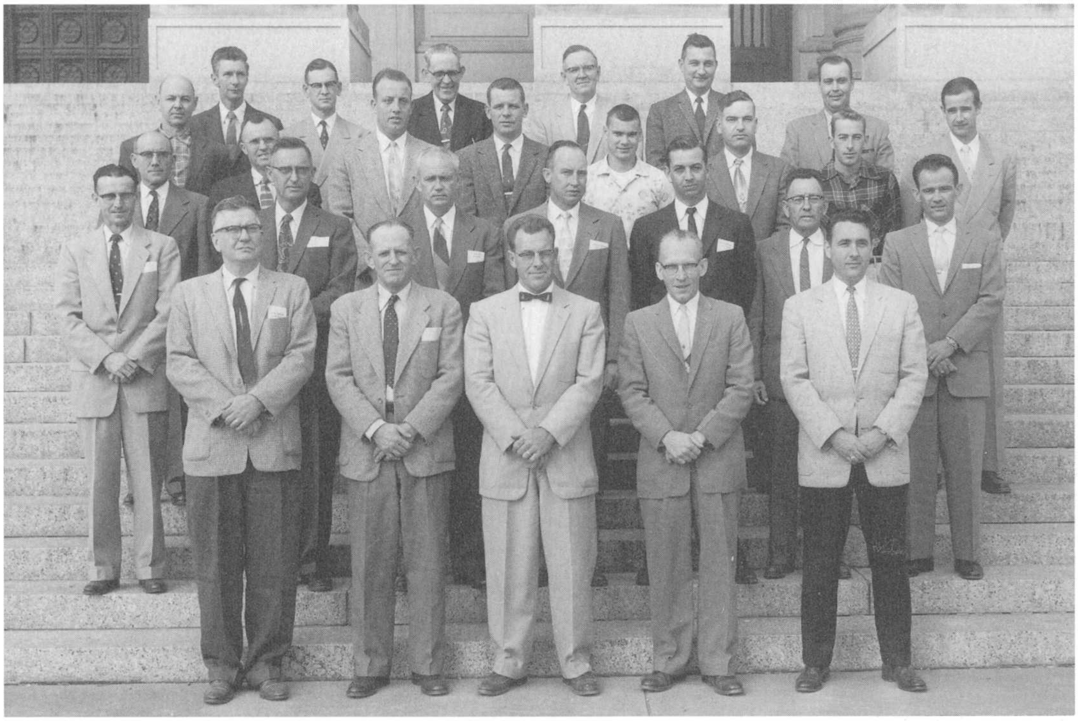
SURFACE WATER BRANCH BASIC SHORT COURSE
BOISE, IDAHO
OCT. 28–NOV. 1, 1957



Seldal; Malesky; Miller; Johnston; Obenchain; Hartley; Edmund; Kennedy; Pathak; Teske
Eastman; Pedley; Darden; Brannan; Gutenberger; Higgins; Brostrom; LaRue; Granstra; Hettick
Anderson; Hull; Baldrica; Cordes; Koski; Weinberg; Blank; Roy; Oster
Griffin; Ligner; Bodhaine; Hofmann; Hulsing

Figure VI-17. Attendees at SWB basic short course, Boise, Idaho, October 28 to November 1, 1957.

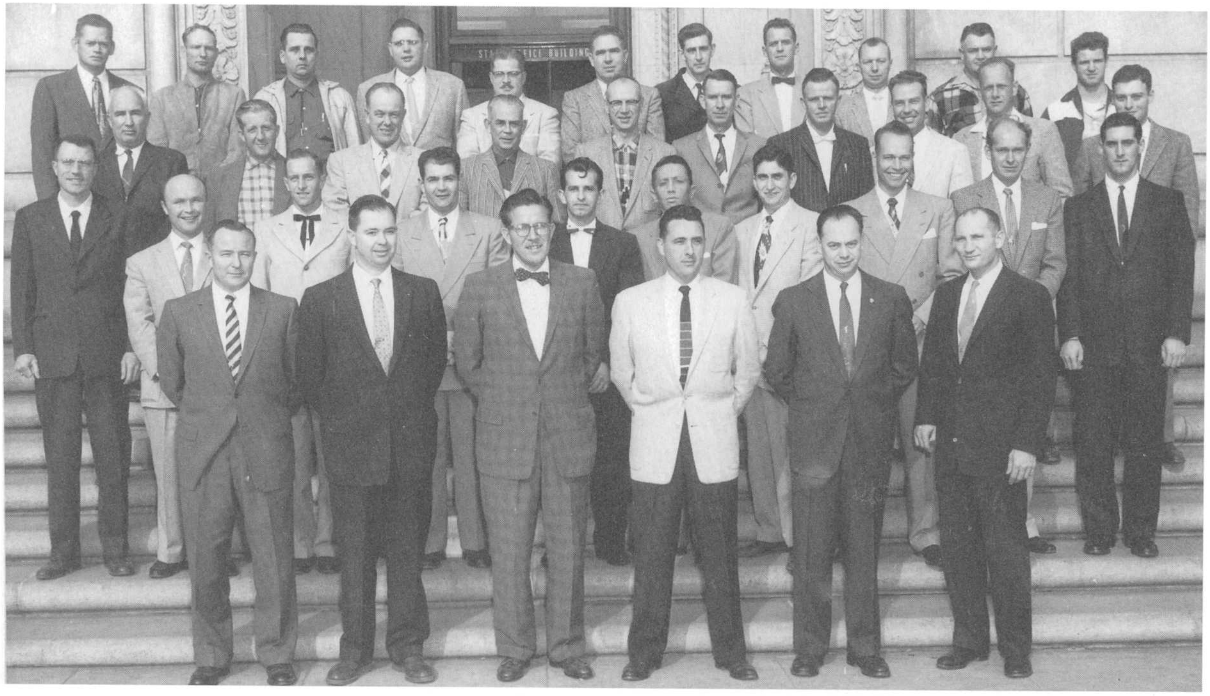
SURFACE WATER BRANCH BASIC SHORT COURSE
OKLAHOMA CITY, OKLAHOMA
NOVEMBER 18-22, 1957
UNITED STATES GEOLOGICAL SURVEY



Dolman Spence Murphy Parham Holland Hampton Martin
Albert Ollar Bergman Mitchell Curtis Bohner Thomas Schröer
Hart Rose Reid Kennedy Walker Dodd Kaminski
Speer Pearce Haddock Ayer Ligner
Attended, but not in picture were: Moore, Bell, Gilbert, Laine, Sullivan.

Figure VI-18. Attendees at SWB basic short course, Oklahoma City, Okla., November 18–22, 1957.

Surface Water Branch Basic Short Course
San Francisco, California
January 13-17, 1958
United States Geological Survey



Rickard Freestone Pehrson LaCornu Harms Duensing Quinlan Thoreson Edington Watkins Lesher
McGraw Stanton McConKie Carter Garff Hodges Clendenon Keliher VanderBurg Meyer
Lopp Frisbie Trenck Whitman Krueger Peck Piro Peterson Crosby Schoeller
Harris Hains Hofmann Ligner Bodhaine Rantz

Figure VI-19. Attendees at SWB basic short course, San Francisco, Calif., January 13–17, 1958.

Surface Water Branch Basic Short Course
Columbus, Ohio
May 19–23, 1958
United States Geological Survey

Crawford Nell Carrico Gallman Hammond Speer Jackson Raney

Hough Ensminger Robertson Allen Noehre Workmaster Brigham Kaupanger

Wall Moore Saboe Gamble Robison Palmer Bartoo Ligner

Riddle Failing Sieger Bagley Atkinson Leonard Wagner Ayer

Figure VI-20. Attendees at SWB basic short course, Columbus, Ohio, May 19–23, 1958.

SURFACE WATER BRANCH BASIC SHORT COURSE
HONOLULU, HAWAII
SEPT. 8–12, 1958
UNITED STATES GEOLOGICAL SURVEY

S. Wong J. Lee R. Lau C. Wyse J. Grance R. Young W. Ling L. Wong N. Kojiri
S. Sumida J. Cheong G. Gohara Ligner Hofmann Bodhaine P. Patacsil R. Nakahara
H. Miyake H. Matuura H. Kanno R. Takaesu H. Nakagawa K. Takumi

Figure VI-21. Attendees at SWB basic short course, Honolulu, Hawaii, September 8–12, 1958.

SURFACE WATER BRANCH BASIC SHORT COURSE
SPOKANE, WASHINGTON
OCTOBER 27–31, 1958
UNITED STATES GEOLOGICAL SURVEY

Hickson French Fowler Ebling Taylor Sydiongco Roberts O'Neill Folsom Schuller
Diamond Merrill Eicher Potter Colson Janssen Lovely
McCall Bodhaine Ligner Hofmann Frederick Williams Craig

Figure VI-22. Attendees at SWB basic short course, Spokane, Wash., October 27–31, 1958.

SURFACE WATER BRANCH BASIC SHORT COURSE
BATON ROUGE, LOUISIANA
DECEMBER 8-12, 1958
UNITED STATES GEOLOGICAL SURVEY

Chenault Speer Stullken King Dorminey Clemence Williams Camp Whetstone Senseman

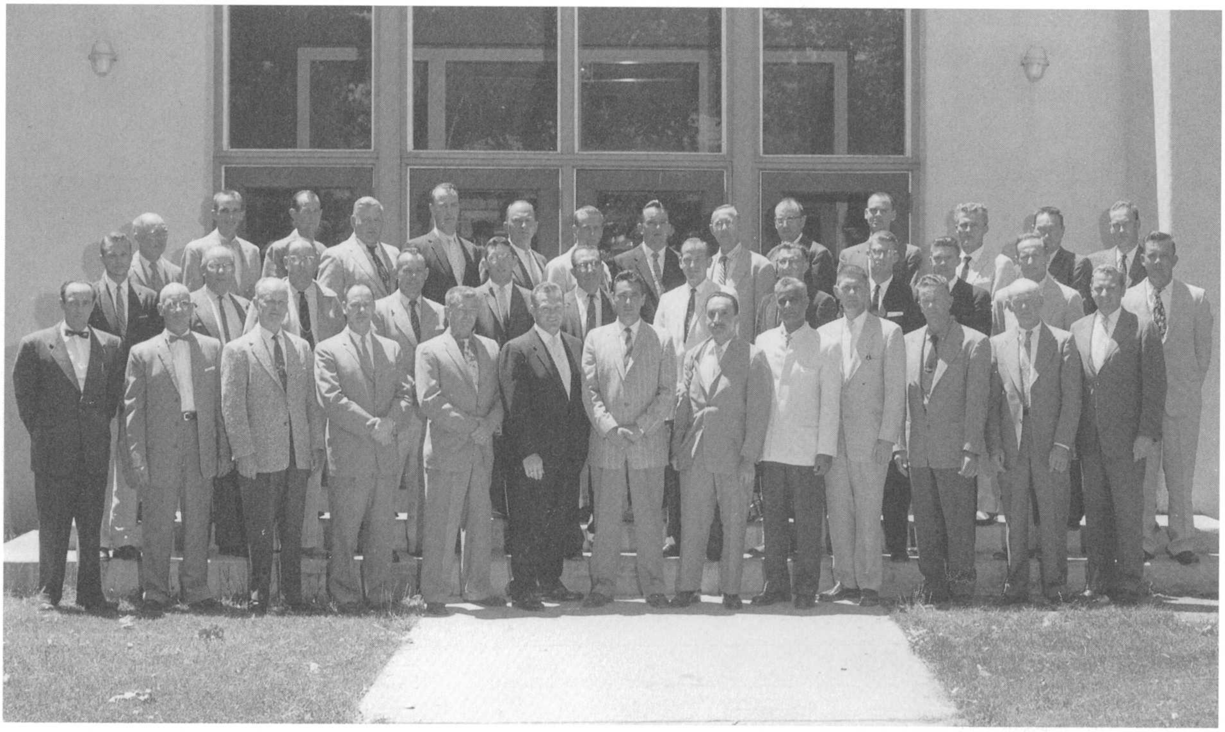
Ligner Robbins Bonnet Finley Carnes Nelson Sedberry Cariaga Hathcock Simmons Fountain Ayer Bird

Couvillion McCollum Miller J. G. Alexander Buckner J. M. Alexander Edwards Skelton

Attended, but not in picture: W. O. Holloway

Figure VI-23. Attendees at SWB basic short course, Baton Rouge, La., December 8–12, 1958.

SURFACE WATER BRANCH BASIC SHORT COURSE
SANTA FE, NEW MEXICO
JUNE 8–12, 1959
UNITED STATES GEOLOGICAL SURVEY



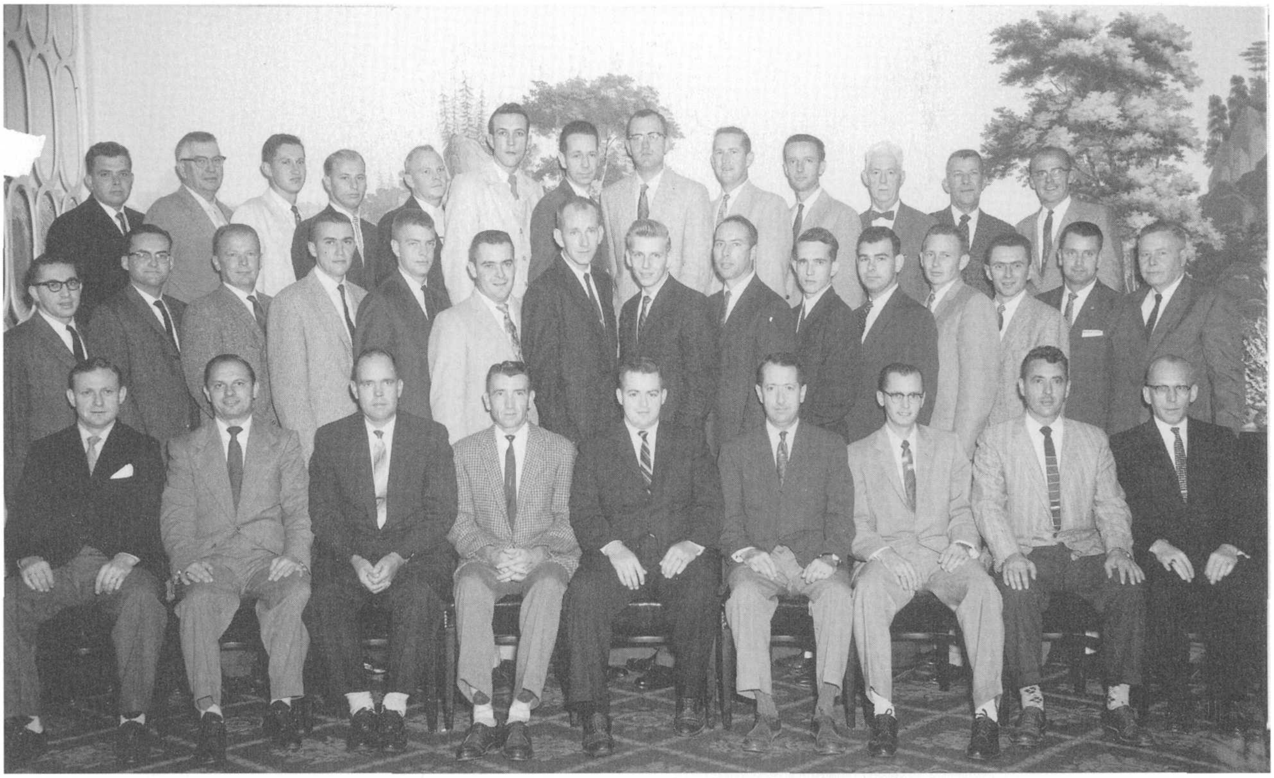
Kamm Delaney DeWees Pierce Ragsdale Goraj Cranston Pangburn Ewing Burch Buell D. A. Reynolds, Jr. Yates Compton

Dinwiddie Riebeek McCoy Wheatley Borland Baca Click Gerhart Perkins Sarasua Miklas Cooper

Hogue Rathbunn Hungate Bodhaine Deans Nalder Ligner Salazar Awasthi Foulk D. A. Reynolds, Sr. Hobbs Abrams

Figure VI-24. Attendees at SWB basic short course, Santa Fe, N. Mex., June 8–12, 1959.

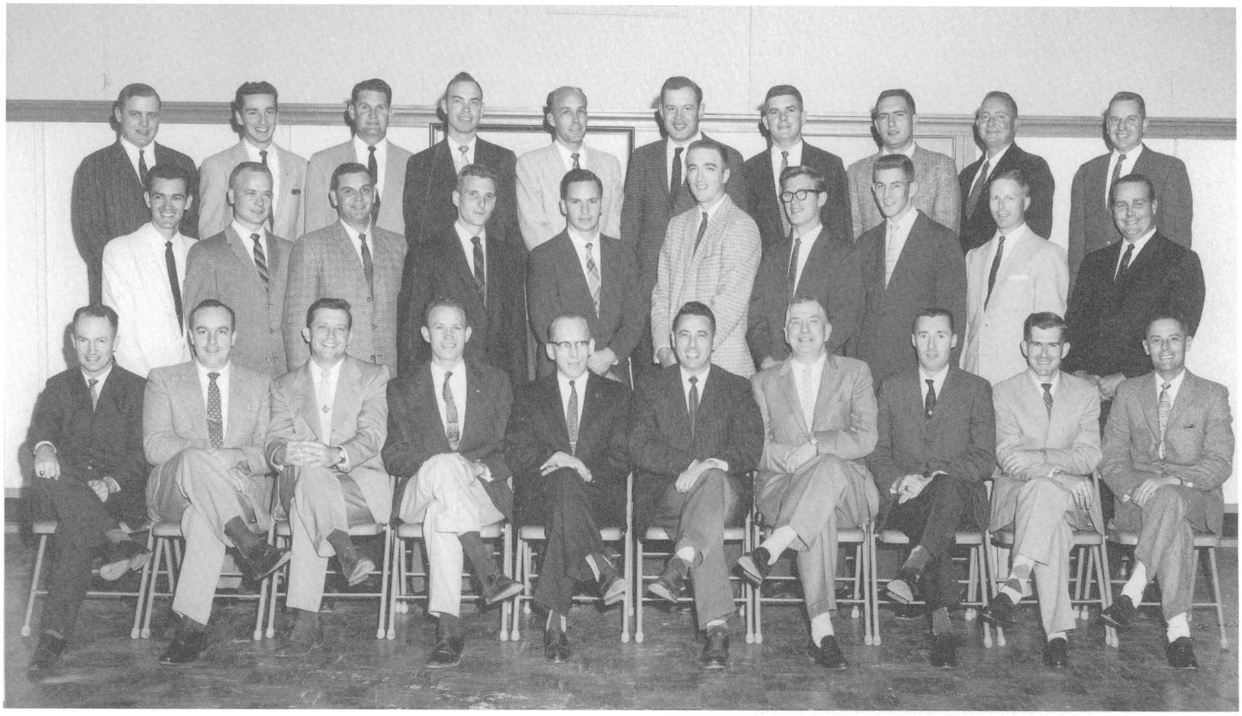
Surface Water Branch Basic Short Course
Harrisburg, Pennsylvania
September 28,–October 2, 1959
UNITED STATES GEOLOGICAL SURVEY



Wilson Speer Meyer Kauffman Burkey Oberg Taylor Herreid Linney Washington Ludlow Huffer Francis
Weiss Harding Graff Ardner Gilbert Philbrick Tangborn Kollar Spotts Dowd Cole Lindstrom Hood Bailey Wallace
Bird Hladio Spillman Oglesby Plantz Roth Curtis Ligner Ayer

Figure VI-25. Attendees at SWB basic short course, Harrisburg, Pa., September 28 to October 2, 1959.

SURFACE WATER BRANCH BASIC SHORT COURSE
MONTGOMERY, ALABAMA
MARCH 21–25, 1960
UNITED STATES GEOLOGICAL SURVEY



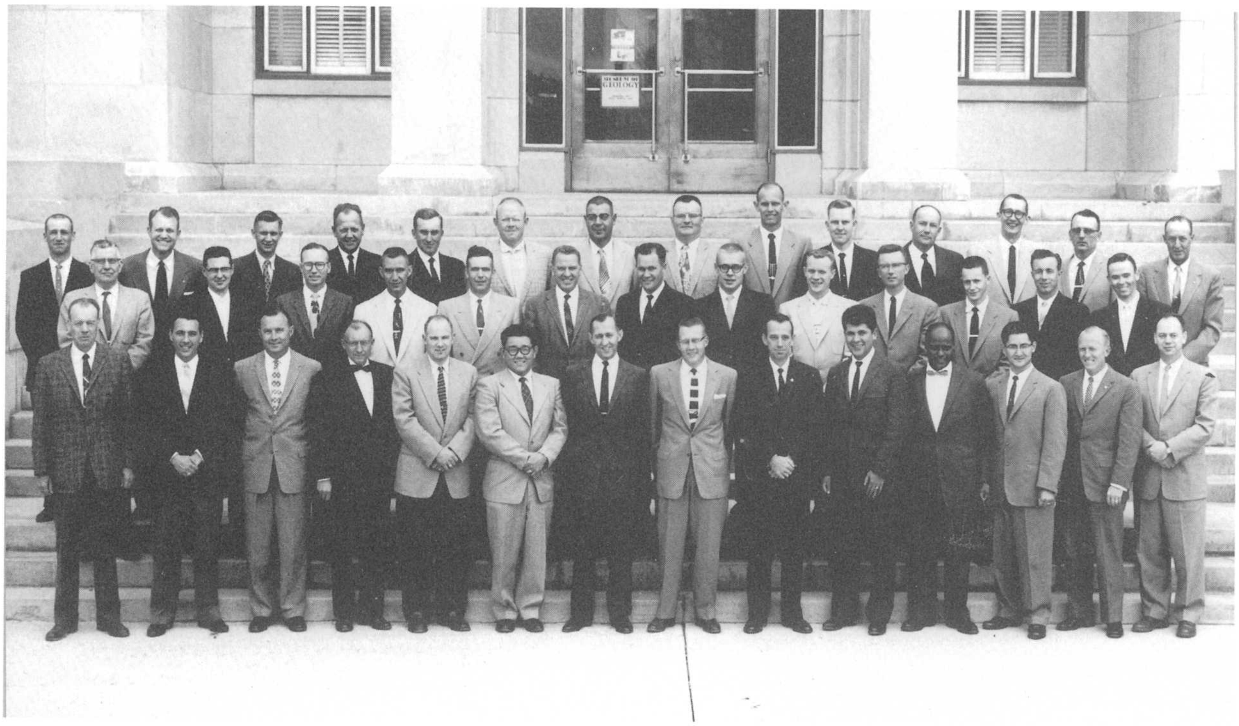
LeGwin McCabe Hudson Wetmore Edmiston Sparks Dantin Lambert Dark Abrams

Cole Hendricks Williams Joslin Adamek Terry Lamar Colson Rosenquest Rathbun

Baker Flint Ray Neely Ayer Ligner Speer Mize Duvall Different

Figure VI-26. Attendees at SWB basic short course, Montgomery, Ala., March 21–25, 1960.

SURFACE WATER BRANCH BASIC SHORT COURSE
RAPID CITY, SOUTH DAKOTA
APRIL 25—29, 1960
UNITED STATES GEOLOGICAL SURVEY



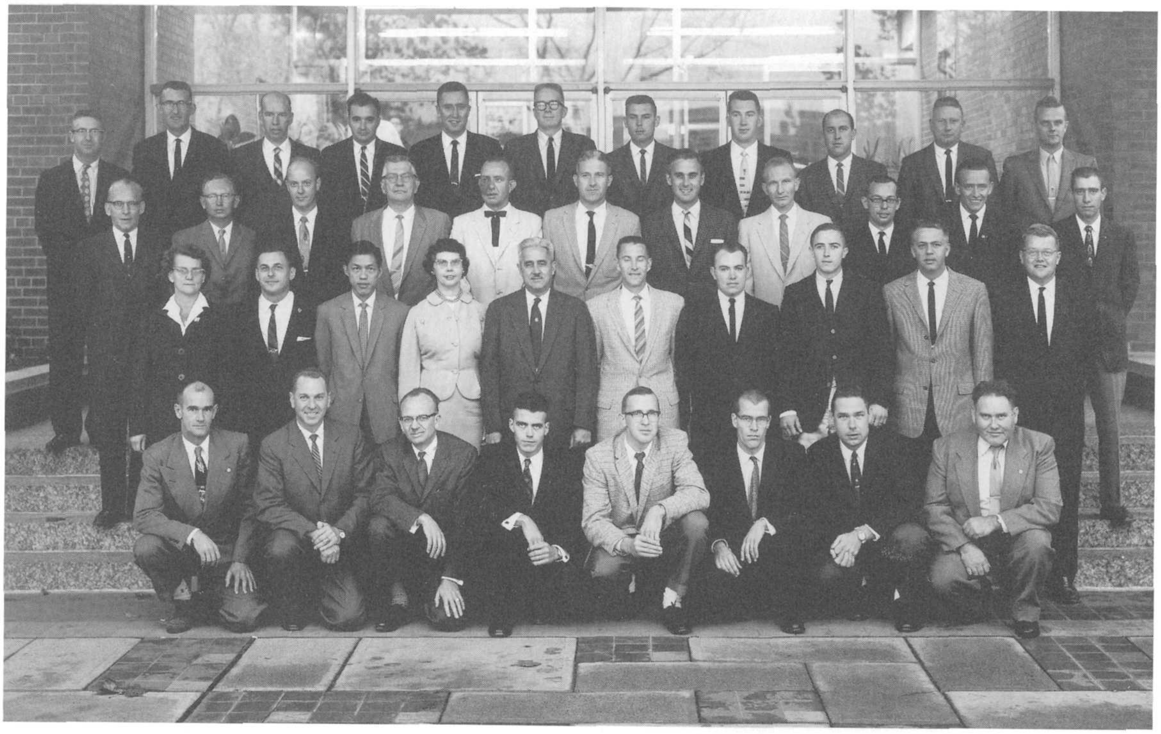
Ellenbecker Pitts Felsbeim Mack Kubicek Kelly Chaparro Thompson Dixson Polinoski Custis Eade Liggett Singleton

Speer Hanson Hicks Mapes Steele Abrams Nelson Toumi Kraus Cornelius Menke Finn Stewart

Yarger Ligner Myers Heinrich Blodgett Hattori Heyd Page Cox Gonzalez Shimelis Chinn Thomsen Bodhaine

Figure VI-27. Attendees at SWB basic short course, Rapid City, S. Dak., April 25–29, 1960.

SURFACE WATER BRANCH BASIC SHORT COURSE
LANSING, MICHIGAN
OCT 31–NOV. 4, 1960
UNITED STATES GEOLOGICAL SURVEY



Bent Wagner Evans Phillips Shipley Stenson Gockel O'Donnell Cherry Marks Jansma

Ayer Brooks Blackey Speer Miles Ganster Lipscomb Beck Gardner McAlexander Failing

Drilleau Weiss Romasanta Romine Ash Siler Gillen Kutil Stahl Bruck

Thompson Abrams Egan Comer Hulpert Zirbel Hare Bartoo

Figure VI-28. Attendees at SWB basic short course, Lansing, Mich., October 31 to November 4, 1960.

SURFACE WATER BRANCH BASIC SHORT COURSE
JACKSON, MISSISSIPPI
FEBRUARY 13–17, 1961
UNITED STATES GEOLOGICAL SURVEY

Adey Hauth Higer Clark Everett Nave Blue Brown Mathis Isherwood Shell Thomson

Walsworth Kimball Lee Klingler Lites Bridges Jones Gaines Simmons Largent Reed Moore

Butler Supianoski Speer Rimes Hilker Boyd Craig Corp Stahl Giles

Ayer Abrams Robinson Hastings Berry

Figure VI-29. Attendees at SWB basic short course, Jackson, Miss., February 13–17, 1961.

THIRD QUALITY OF WATER BRANCH TECHNIQUE TRAINING SCHOOL
RALEIGH, N.C., JUNE 2–14, 1958

UNITED STATES GEOLOGICAL SURVEY

McCartney; Haffty; Jenkins; Geurin; Reeder; Magin; Mallory; Anderson; Weeks; Hastings
McCarthy; Cummings; Hood; Guy; Irclan; Swenson; Martin; Wahlberg; Menke; Schupp
Harris; Adamson; Barker; Langbein; Hem; Simons; Wark; Back; Sui; Haushild; Billings
Robertson; Woodard; Clark; Rainwater; Brown; Ringen; Flint; Jordan; Tanaki

Figure VI-30. Attendees at QWB technical training school, Raleigh, N.C., June 2–14, 1958.

The QWB organizational chart provided for a training section during the early years of this period of history but it was never activated. Two Branch training schools during this period, the third and fourth of the series, were organized by Warren W. Hastings and Herbert A. Swenson. They were held in Raleigh, N.C., June 2–14, 1958, and in Austin, Tex., January, 1960. The group photograph of the Raleigh training school attendees and instructors is figure VI–30. No photograph of the attendees at the Austin school was found nor were the exact dates recovered.

### *Correspondence Courses*

Correspondence courses in statistics and fluid mechanics became available in 1959. Both were developed in SWB; however, the courses were available to all members of the Division.

Henry C. Riggs prepared the correspondence course, Elementary Statistics in Hydrology, to encourage the use and understanding of statistics in hydrologic studies. By 1973, when the course was discontinued because the original edition of the key textbook was no longer available, about 450 employees had completed the course.

The correspondence course in fluid mechanics was started by Roy Oltman when he was Chief, Training Section, SWB, in 1957 and 1958. Oltman worked with Maurice L. Albertson, member of the engineering faculty at Colorado State University and part-time Survey employee in the QWB Research Section at Fort Collins, Colo., to develop the course. Its title was "The Mechanics of Fluids" and it was designed for the graduate level of difficulty. The last five chapters of the course were completed by A. Ray Chamberlain, also a member of the engineering faculty and part-time Survey employee in the University-based Research Section. After Oltman moved to the Division to head the Career Development Section, James J. Ligner and Raymond O. Abrams, principal members of the SWB Training Section, managed the course. Approximately 150 Branch personnel enrolled; however, only about 20 completed the difficult course.

#### *Division Short Courses*

Except for the correspondence courses, there was a break in intramural training between 1961, when Branch training programs were discontinued, and 1963, when Division training programs began.

After a year or more of planning and negotiating with staff of the University of Arizona, a contract was signed in 1962 for a series of 7-week hydrology short courses on the University campus in Tucson. The first began in January 1963. Through the end of this period and beyond, one to three courses were held each year. The courses were designed and conducted for new and intermediate-level employees. Between 25 and 30 students were enrolled in each course, including one or more employees of a State cooperating agency or a Federal agency or students from a foreign country.

The 30 to 40 instructors for the short courses were about equally divided between University faculty members and WRD employees. Among those from WRD who served regularly as instructors were John G. Ferris, Herbert E. Skibitzke, Jose da Costa, Nicolas C. Matalas, David R. Dawdy, and Alfonso Wilson. Many other project leaders and members of research activities instructed less frequently. Eugene S. Simpson, a University faculty member and former employee of WRD, was a regular instructor.

The informal "dean" of the hydrology short courses was Raymond O. Abrams, Chief of the WRD Training Section as the hydrology short courses began and principal Division representative during negotiations with the University. Among Abrams' primary University contacts was John W. Harshbarger, head of the Geology Department and formerly District Geologist, Arizona District, GWB.

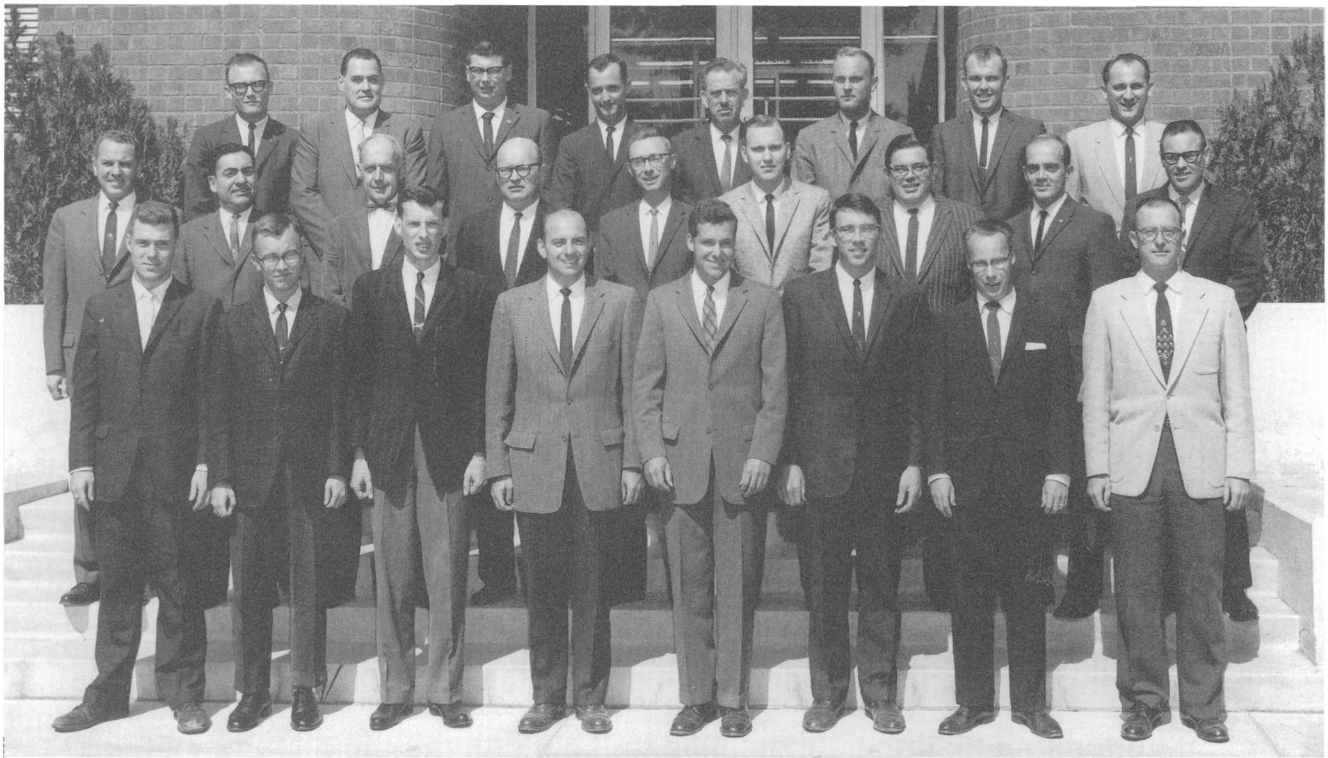
By mid-June 1966, eight courses had been held. Group photographs of the attendees, instructors, and others associated with each course follow as figures VI–31 to 38.

#### *Training Newly Employed Professionals*

In early 1964, the CSC (Civil Service Commission, now the Office of Personnel Management) approved a proposal by WRD to place all newly employed professional employees in an 18-month training program. Highlights of the program were as follows:

> All new, professional employees, grades GS–5, 7, and 9, entered the training program at entrance on duty, effective July 1, 1964.
>
> The 18-month training program was divided into two phases. Phase I was 6 months of classroom training and Phase II, 12 months of hands-on experience.
>
> During Phase I, the new employee was assigned to Denver where the training facility was located, initially in the Hydrologic Laboratory. A. Ivan Johnson, Chief of the Laboratory, organized and managed this phase. In 1966, the training facility was moved to space adjacent to the Office of the Regional Hydrologist.
>
> During Phase II, the trainee was assigned to an operational unit of the Division, typically to a Branch or WRD District.
>
> The program guaranteed or assured promotion on completion of each phase, subject to certain limited provisions. Because of this element of the program, CSC approval was required.
>
> Trainee salaries and expenses were partially paid from Federal funds.
>
> A training manual was prepared by Johnson and others, and copies were provided to all professional employees of the Division.

WATER RESOURCES DIVISION HYDROLOGY SHORT COURSE
UNIVERSITY OF ARIZONA, TUCSON, ARIZONA
JANUARY 14—MARCH 2, 1963
UNITED STATES GEOLOGICAL SURVEY



Stangland Harshbarger Obr Tharpe Maddock Anderson Gillespie Broussard

Abrams Wilson Ferris Wyerman Doyle Jennings Marcher Jeffs John

Olmstead Shope Leibbrand Knochenmus Schmidt Cawood Robison Dial

Figure VI-31. Attendees at WRD hydrology short course, Tucson, Ariz., January 14 to March 2, 1963.

WATER RESOURCES DIVISION HYDROLOGY SHORT COURSE
UNIVERSITY OF ARIZONA, TUCSON, ARIZONA
APRIL 1—MAY 17, 1963
UNITED STATES GEOLOGICAL SURVEY

Harshbarger Chang Boucher

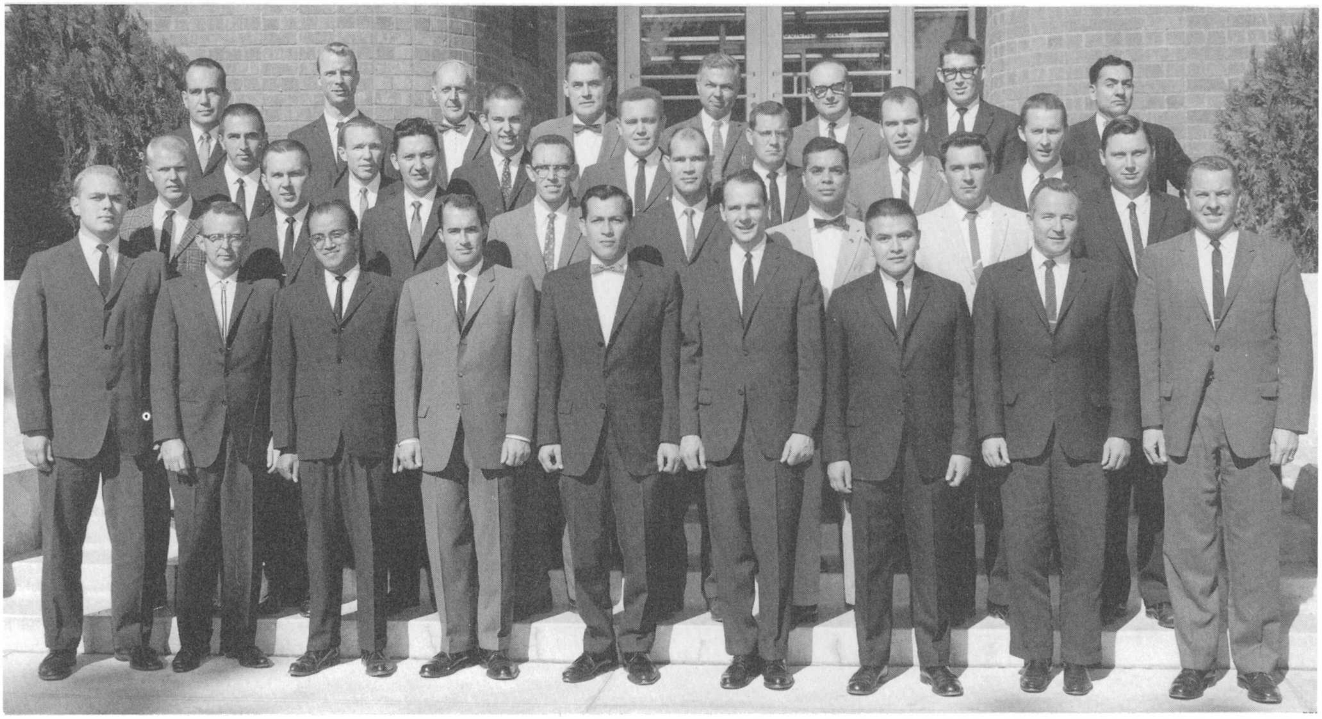
Edwards Robinson Ducret C. A. Wilson Abrams Skibitzke

Casseaux Waddell Becher Ferris Hjalmarson Lee Irelan

A. Wilson Kister Melvin Emery Coble Harkleroad Thompson Taylor

Figure VI-32. Attendees at WRD hydrology short course, Tucson, Ariz., April 1 to May 17, 1963.

WATER RESOURCES DIVISION HYDROLOGY SHORT COURSE
UNIVERSITY OF ARIZONA, TUCSON, ARIZONA
OCTOBER 7—NOVEMBER 22, 1963
UNITED STATES GEOLOGICAL SURVEY



Lustig Carpenter Ferris Harshbarger Simpson Handy Plummer Wilson

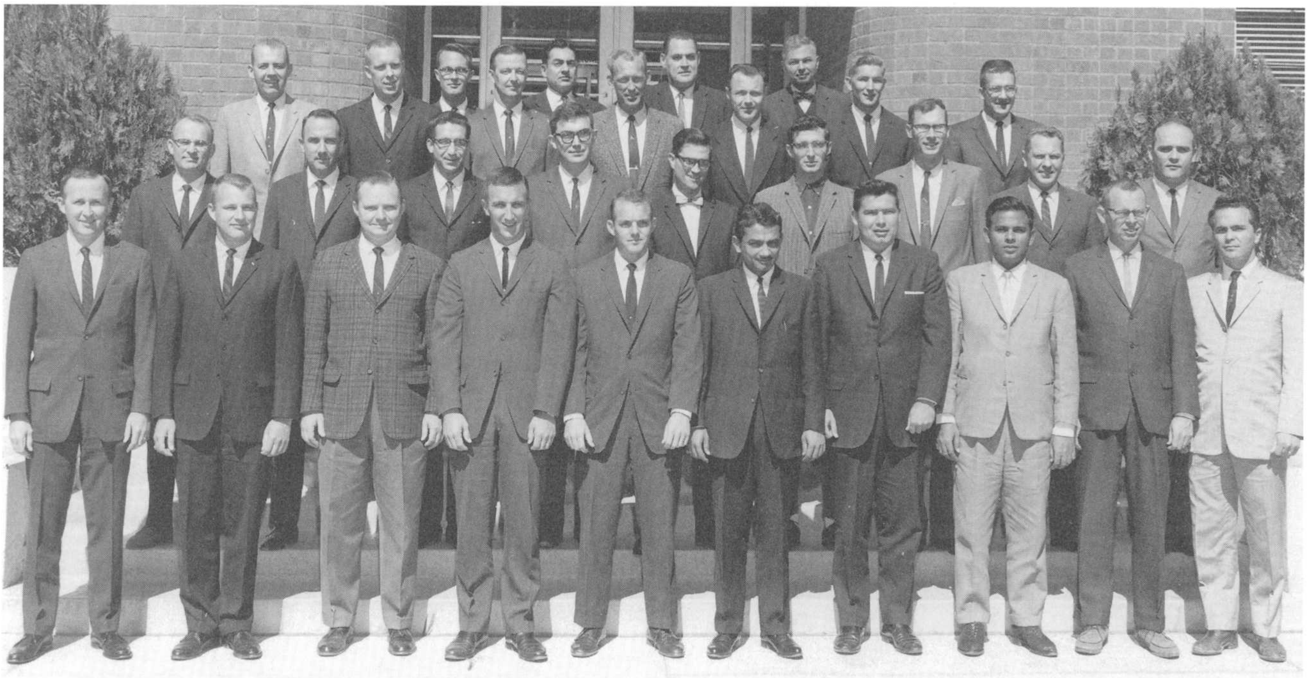
Medina Jones Shampine Trapp Crist Crain Cox

Hauth Gaydos Runner Sanford Cahal Marrei Glancy O'Neill

Biesecker Kister Amatya Luzier CondesDeLaTorre Lloyd Shorty Harris Abrams

Figure VI-33. Attendees at WRD hydrology short course, Tucson, Ariz., October 7 to November 22, 1963.

WATER RESOURCES DIVISION HYDROLOGY SHORT COURSE
UNIVERSITY OF ARIZONA, TUCSON, ARIZONA
JANUARY 13—FEBRUARY 28, 1964
UNITED STATES GEOLOGICAL SURVEY



Moss Wilson Harshbarger Simpson

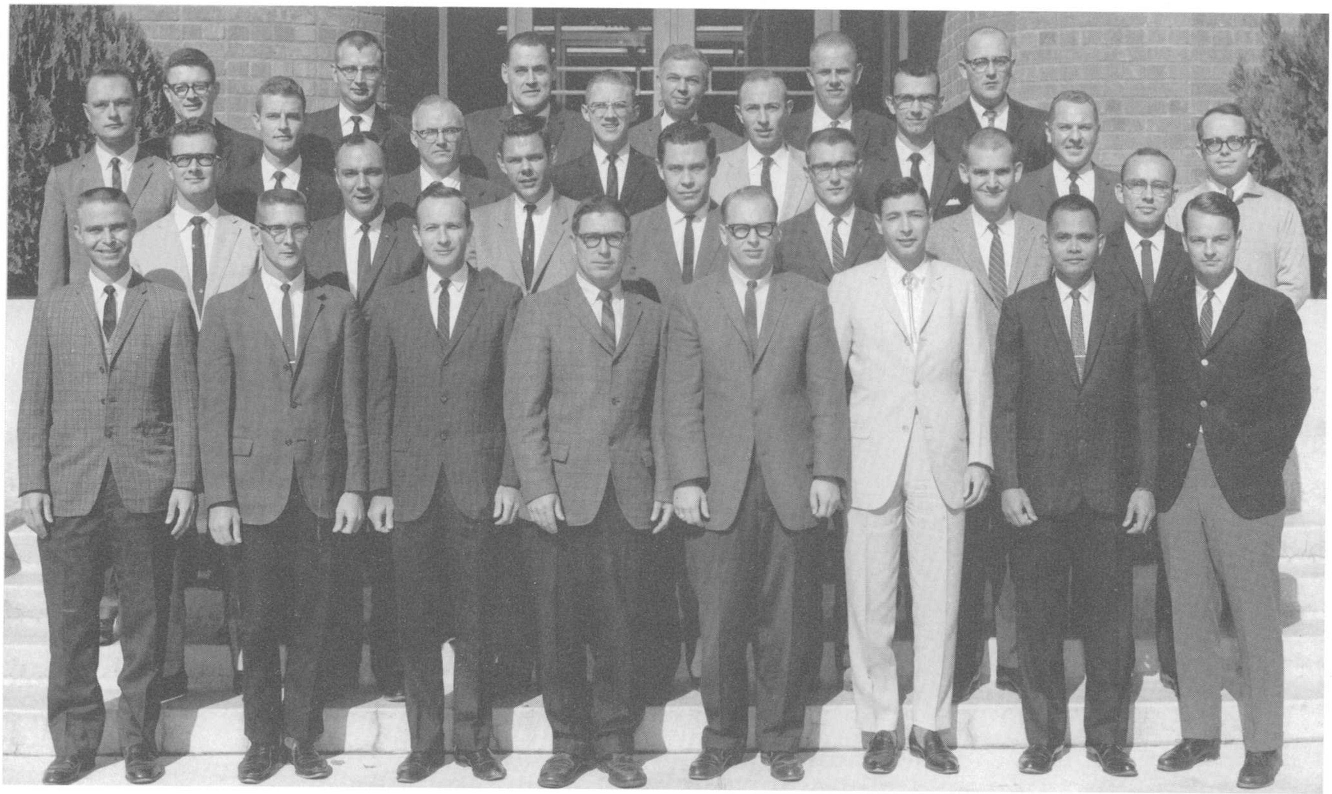
Lipscomb James Malmberg Rohne Starr Colson Whatley

Welder Wilson Gravlee Molnau Jenne LaFreniere Beck Abrams Wood

Feltis Bair Haney Hedges Kelley Kazmi O'Connell Kamal Faust Robinson

Figure VI-34. Attendees at WRD hydrology short course, Tucson, Ariz., January 13 to February 28, 1964.

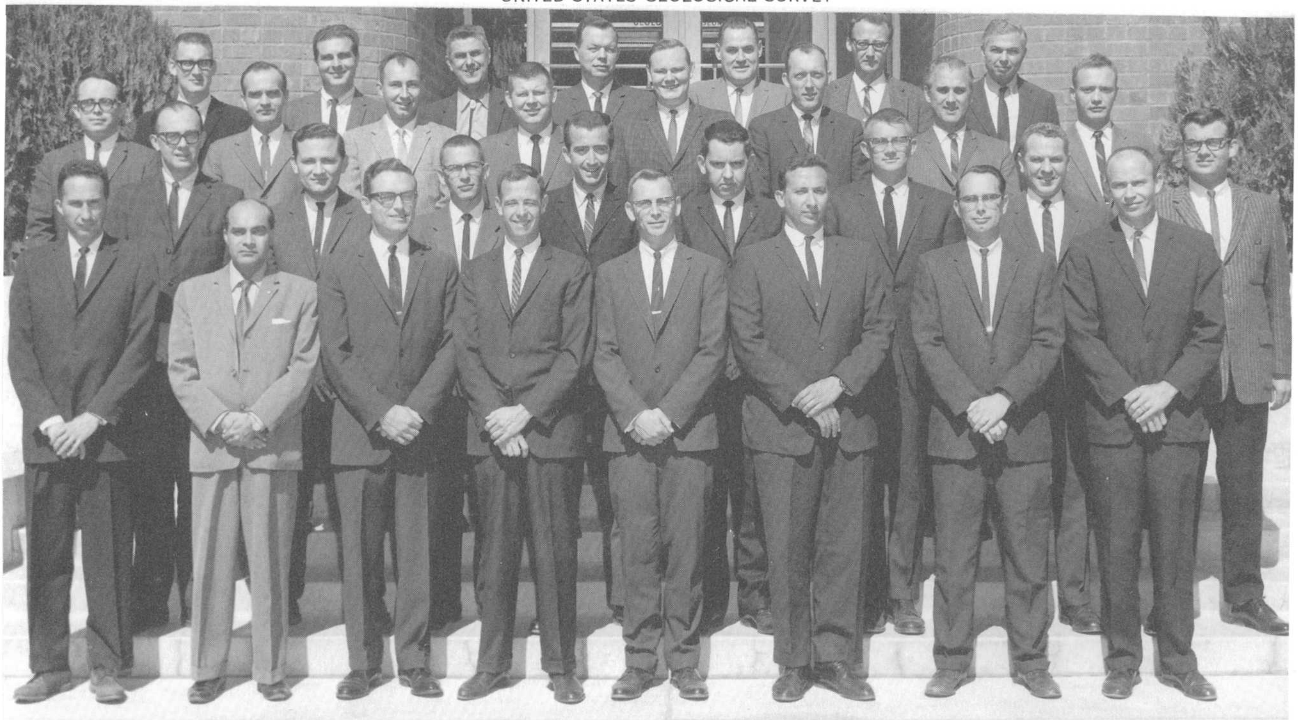
WATER RESOURCES DIVISION HYDROLOGY SHORT COURSE
UNIVERSITY OF ARIZONA, TUCSON, ARIZONA
OCTOBER 5—NOVEMBER 20, 1964
UNITED STATES GEOLOGICAL SURVEY



Hutchinson Blakey Harshbarger Simpson Williams Herreid
Lowry Stephens Jefferson Johnson Wahl Hahl Abrams Riley
Hanke Toler Fields Baltz Williams Whitman Flippo
Layton Wilder Humphreys McCullough Kauffman Kaufman Rivera Oakes

Figure VI-35. Attendees at WRD hydrology short course, Tucson, Ariz., October 5 to November 20, 1964.

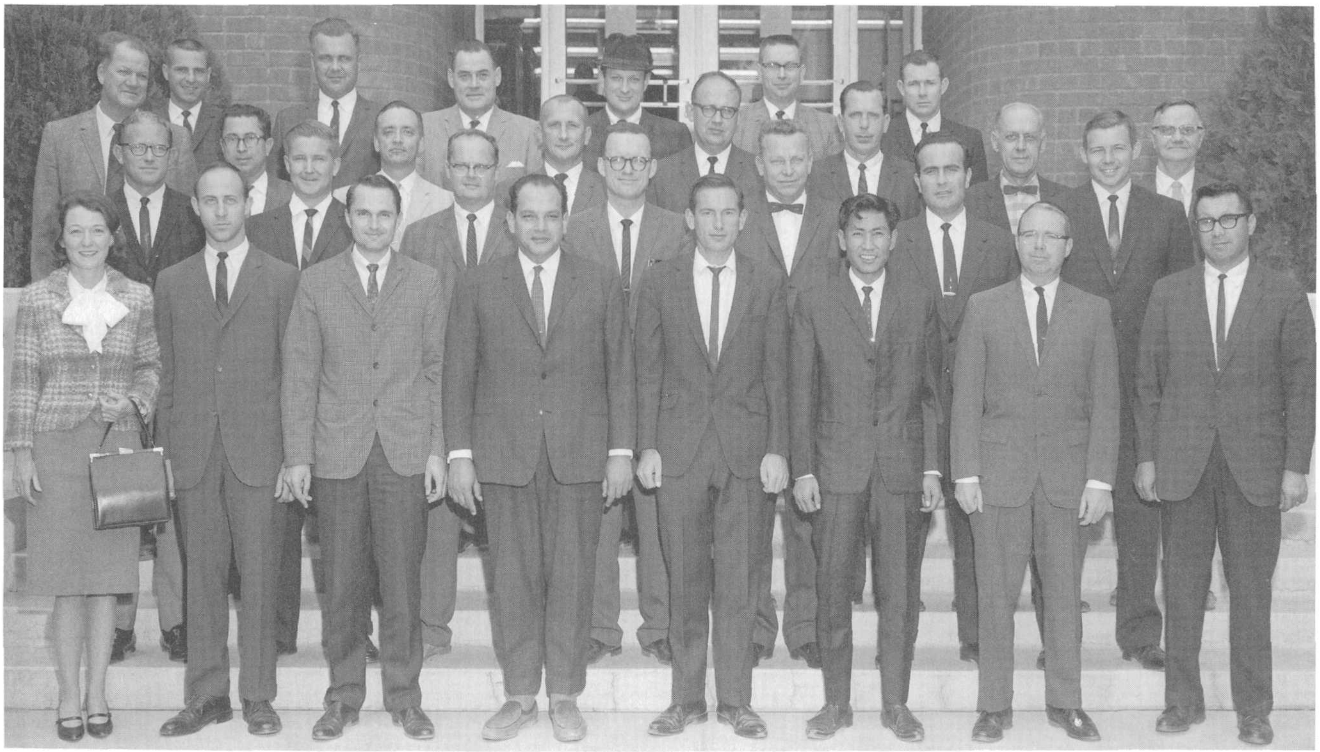
WATER RESOURCES DIVISION HYDROLOGY SHORT COURSE
UNIVERSITY OF ARIZONA, TUCSON, ARIZONA
JANUARY 11—FEBRUARY 26, 1965
UNITED STATES GEOLOGICAL SURVEY



Druse Donsky Feulner Ericson Harshbarger Lubke Simpson
Riley McCain McGavock Thomas Hansen Everett Lipscomb Perry
Pettyjohn Spinello Winter Lescinsky Collins Souders Abrams Sauer
Angelo Shamsi Heinetz Bain George Feder French Neely

Figure VI-36. Attendees at WRD hydrology short course, Tucson, Ariz., January 11 to February 26, 1965.

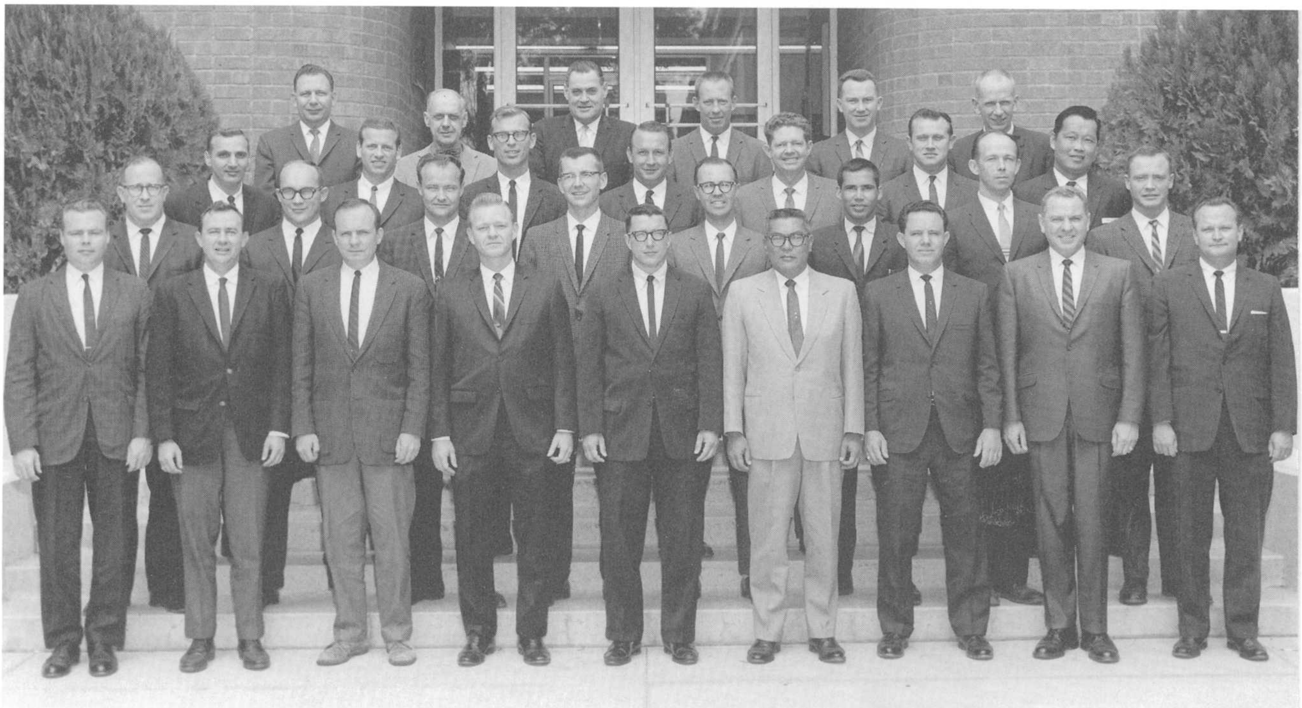
WATER RESOURCES DIVISION HYDROLOGY SHORT COURSE
UNIVERSITY OF ARIZONA, TUCSON, ARIZONA
OCTOBER 5—NOVEMBER 19, 1965
UNITED STATES GEOLOGICAL SURVEY



Scott Whiteman Harshbarger Wershaw Anderson Meckel
Skibitzke Hurr Anderson Reed Vaupel Raketich Ferris Barksdale
McCoy Noehre Emmett Hamilton Remington Nassar Barnett
Robinson Murphey Hollowell El-Shafie Caddie Gauchion Alter Garza

Figure VI-37. Attendees at WRD hydrology short course, Tucson, Ariz., October 5 to November 19, 1965.

WATER RESOURCES DIVISION HYDROLOGY SHORT COURSE
UNIVERSITY OF ARIZONA, TUCSON, ARIZONA
JANUARY 17—MARCH 4, 1966
UNITED STATES GEOLOGICAL SURVEY



Boner Ferris Harshbarger Carswell O'Donnell Tangborn
Tilstra Ferrall Sain K. R. Taylor Murphy Geiger Jay
Ellis Gann McGreevy LeVeen Schoen Karki Hansen Perry
Cotton Farr Johnston Rawson R. E. Taylor Takasaki May Abrams Dempster

Figure VI-38. Attendees at WRD hydrology short course, Tucson, Ariz., January 17 to March 4, 1966.

#### *Training Foreign Hydrologists*

For several years prior to 1963, hydrologists from other countries came to the Hydrologic Laboratory, in Denver for training in "Laboratory in and field methods for hydrologic studies." They came singly or in groups and for differing periods of time. In 1963, Ivan Johnson, then Chief of the Laboratory, was granted approval to systematize the training by arranging for groups of foreign trainees for 4 weeks each and at specified times in order to reduce its interference with laboratory operations. Seven training sessions were held from 1963 through mid-June 1966 for hydrologists from Ceylon, Jordan, Pakistan, the Philippines, Sudan, Turkey, Egypt, Indonesia, Libya, Afghanistan, Zaire, Thailand, Argentina, India, Nepal, and Ghana.

### Extramural

#### *Graduate School Training*

Luna Leopold held strongly to his goal of increasing the numbers of WRD employees with advanced degrees. At the beginning of his tenure as Division Chief, the legislative authority for financing graduate study at government expense did not exist. Financial support for those wishing to pursue graduate work included the following sources:

Part-time tours of duty while in school became an option in late 1957 when the Division relaxed its earlier policy of prohibiting such arrangements. Approval became possible for 1 year at a time and with the stipulation that the employee have a regular work schedule of 20 or more hours per week.

Financial support of graduate students whose theses were of direct interest to the Division. A fund of $18,000 was reserved in FY 1958 to support such students, each of whom was placed on the rolls of GHB.

National Science Foundation Fellowships were available that paid annual stipends of $1,600 to $10,000 to selected graduate, postdoctoral, and senior postdoctoral students.

Rockefeller Public Service Awards included grants to mature, career government employees for study at an American or foreign university.

The Fullbright Act provided funds for graduate training or advanced research at a foreign university.

Conservation and Water Resources Fellowships provided stipends to those selected for training at Harvard University.

Despite limited opportunities, progress was made in increasing the number of employees holding advanced degrees. The GWB reported that the percentage of its staff with advanced degrees increased from 25 percent in 1956 to 46 percent in 1960. Several, however, were new hires who entered on duty with one or more advanced degrees.

The greatest impetus to graduate training came with passage of Public Law 85–507, the Government Employees Training Act, on July 7, 1958. For the first time, WRD employees could be granted a full year of study at government expense. The costs of paying a year's salary, tuition, and family relocation, however, did not permit full implementation of the Act until funds could be budgeted. The first group of WRD graduate-school students was enrolled for the 1962–63 academic year. During the 3-or-so years WRD was marshalling its resources and getting the administrative machinery underway to take full advantage of the Training Act, several senior employees were selected for graduate school. The first person selected, and indeed the first from the DOI, was Hilton H. Cooper from Tallahassee, Fla. Cooper attended Columbia University during the 1959–60 school year, studied math and hydraulics, and was graduated with the M.S. degree. He was soon followed at Columbia by Raymond L. Nace, who earned the Ph.D. degree under the Training Act in 1960.

The Training Act did not permit attainment of an advanced degree to be its objective; however, earning masters' and doctors' degrees was encouraged by the Division.

By 1962, the Division's process for soliciting applications and selecting candidates for graduate school was operating and funds were budgeted to support about a dozen students. Intense competition developed between Districts, Regions, and Branches to acquire those employees after graduate school.

Table VI–1 lists the WRD employees who received graduate training under the Act by academic year, university attended, and degree attained if earned as a direct benefit of the Training Act.

## Establishing Degree Programs in Hydrology

(Much of the following information was provided *by* Raymond O. Abrams *and* Eugene S. Simpson.)

An external goal of Luna Leopold was to increase the supply of trained hydrologists from undergraduate and graduate-degree programs at universities. The universities that were encouraged to develop such programs included Iowa State University; Colorado State University; Georgia Institute of Technology; the Universities of Arizona, California, Michigan, Illinois, Wisconsin, and New Mexico; California Institute of

Table VI–1. WRD Graduate School Students, 1962 to 1966

| NAME | UNIVERSITY | DEGREE |
|---|---|---|
| 1962–63 | | |
| Carey, Charles L. | California Institute of Technology | -- |
| Coffin, Donald L. | University of Arizona | -- |
| Ficke, John F. | University of Pittsburgh | M.S. |
| Harbeck, G. Earl, Jr. | University of Arizona | * |
| Jordan, Paul R. | Stanford University | M.S. |
| Kohout, Francis A. | University of Miami | -- |
| Lamke, Robert D. | Stanford University | M.S. |
| Meade, Robert M. | University of California | -- |
| Pashley, Emil F., Jr. | University of California | -- |
| Richardson, Everett V. | Colorado State University | -- |
| Roberson, Charles E. | Scripps Institute of Oceanography | -- |
| Thomsen, Bert W. | University of Arizona | -- |
| 1963–64 | | |
| Boning, Charles W. | Colorado State University | -- |
| Hanson, Ronald L. | Stanford University | M.S. |
| Haynes, George L. | Stanford University | -- |
| Kilgore, Carroll M. | University of Arizona | -- |
| Laney, Robert L. | University of Arizona | -- |
| Pendleton, Alvin F. | University of Arizona | * |
| Richardson, Everett V. | Colorado State University | Ph.D. |
| Rosenshein, Joseph S. | University of Illinois | Ph.D. |
| Sammel, Edward A. | Princeton University | -- |
| Scott, Cloyd H. | Colorado State University | -- |
| Weist, William G. | University of Arizona | -- |
| Wright, Robert R. | Georgia Institute of Technology | -- |
| *Courses completed for Ph.D. | | |
| 1964–65 | | |
| Burmeister, Ivan L. | Iowa State University | M.S. |
| Childers, Joseph M. | University of Arizona | -- |
| Emmett, William W. | Johns Hopkins University | -- |
| James, Ivan C. | University of Kansas | -- |
| Jones, Paul H. | Louisiana State University | Ph.D. |
| Lichty, Robert W. | University of Arizona | M.S. |
| Pluhowski, Edward J. | Johns Hopkins University | M.S. |
| Price, William E. | University of Arizona | -- |
| Stangland, Herbert G. | University of Wisconsin | M.S. |
| Taylor, O. James | University of Arizona | -- |
| Wiesnet, Donald R. | University of Arizona | -- |
| 1965–66 | | |
| Barnes, Harry H. | Johns Hopkins University | -- |
| Blodgett, James C. | University of Washington | -- |
| Carpenter, Philip J | University of Kansas | M.S. |
| Carrigan, P. Hadley | Colorado State University | -- |
| Emmett, William W. | Johns Hopkins University | -- |
| Jennings, Marshall E. | Colorado State University | -- |
| McNellis, Jesse M. | Stanford University | -- |
| Moss, Marshall E. | University of Arizona | M.S. |
| Nordin, Carl F. | Colorado State University | -- |
| Robertson, John B. | University of Arizona | M.S. |
| Waller, Roger M. | University of Arizona | M.S. |

Technology; Johns Hopkins University; Harvard University; and Stanford University.

Contacts with the universities were made at about the time negotiations were underway with CSC to create the "hydrologist" category of Federal employment. (See "Establishing the hydrologist series.") The contacts were also made after the Senate Select Committee on National Water Resources provided the initiative for passage of the Water Resources Research Act of 1964 and the Water Resources Planning Act of 1965. In its deliberations, the Select Committee acknowledged that more trained hydrologists were needed.

While the Division continued its encouragement of universities to establish degree programs in hydrology, it chose a far more active role at the University of Arizona. The selection of Arizona as its centerpiece effort was strongly influenced by the presence of John W. Harshbarger, formerly District Geologist, GWB, Tucson, as head of the Geology Department and Eugene S. Simpson, also formerly of the GWB, as a faculty member. The selection of Arizona to receive active support was also quite likely influenced by Thomas Maddock, Jr., an Arizona alumnus and advisor to Leopold.

Eugene Simpson recalled in Volume 1, No. 1, April 1986, Alumni Newsletter, Department of Hydrology and Water Resources, that "the planting of the seed that grew to be the Department of Hydrology and Water Resources [was] at a bar in the Denver airport."

"It was at that bar that Professors John W. Harshbarger (Big John as he was affectionately referred to by his students), then chairman of the Geology Department, and T.L. Smiley, then director of the Laboratory of Geochronology, sat with several colleagues from the U.S. Geological Survey, waiting for a plane. The USGS colleagues included, among others, Luna Leopold, then Chief Hydrologist of the Water Resources Division, and Walter Langbein and Nick Matalas, research hydrologists. History does not record what they drank nor where they were going, but we do know what they discussed (here freely paraphrased). 'This country needs,' said one of the Survey men, 'a university program in hydrology that will teach ground water and surface water as an integrated discipline, and the University of Arizona is the place to do it.' 'I agree,' John replied, 'but we'll need the cooperation of the Survey.' 'You got it,' said Luna. Then and there a tentative program was outlined (probably on the back of an envelope taken from one of John's pockets)."

"Following that fateful meeting in Denver, little time was lost. In the fall of 1961, the University of Arizona established the first comprehensive curricula leading to the degree of Bachelor of Science in Hydrology, and the Master of Science, and Doctor of Philosophy degree with a major in Hydrology. In the beginning, the undergraduate program was administered by the Department of Geology, then part of the former College of Mines, whereas the graduate program was placed under the direction of an interdisciplinary committee composed of representatives from departments having an interest in water and operating under the aegis of the dean of the Graduate College (in later years under the University vice-president for research). The first hydrology committee consisted of Professors J.W. Harshbarger (Geology), chairman; A.R. Kassander (Meteorology); E.M. Laursen (Civil Engineering); M.M. Kelso (Agricultural Chemistry and Soils); S.D. Resnick (Institute of Water Utilization); and J.G. Ferris (Hydrology). Jay Lehr, who was to become the first recipient of the Ph.D. degree in hydrology, was employed as an instructor, and Herb Skibitzke of the USGS was loaned to the program as a lecturer. Herb, by the way, commuted between Phoenix and Tucson in his private plane. John Ferris, who was with the USGS was given temporary faculty status to teach aquifer mechanics and to organize short courses for USGS (more on this later). Other Survey personnel that did part-time teaching during the first few years included Alfonso Wilson (surface water), Nick Matalas (Statistical Hydrology), Jose da Costa (who filled in when Herb couldn't make it), and Tom Maddock, Jr."

The hydrology degree program became a reality despite jurisdictional rivalry between the engineering and geology departments which shared the hydrology curriculum. The University of Arizona became the first university in the Nation to offer the B.S. degree in hydrology and later offered degrees at the M.S. and Ph.D. levels. Within a few years, other universities were also granting B.S., M.S., and Ph.D. degrees in hydrology.

## Recruiting Professional Employees

Policies, procedures, and standards applicable to recruiting new professional employees for the Division were thoroughly changed during the period 1957 to 1966. Early in this period of history, recruiting was a headquarters activity aimed at engineers, geologists, and chemists and hampered by the delays and red tape inherent in the several CSC registers that were involved. Decentralization followed, first to Council Chairmen and members, then to special recruiters selected largely from District staffs. Later, there was complete decentralization of recruiting with headquarters serving as coordinator; with the recruiting effort aimed at a single discipline—hydrology; and with recruiters armed with CSC authority to make on-the-spot job offers.

In the late 1950's, formal contacts with universities were largely by headquarters staff. Roy E. Oltman, as Chief of the Career Development Section, headed and participated in the recruiting effort. He and his associates visited campuses equipped with lists of current and anticipated vacancies that were compiled from monthly reports of personnel needs supplied by each field office. Emphasis was on hiring hydraulic engineers, who were in short supply and were competitively sought by industry and other government agencies and who, at the time, made up less than 15 percent of WRD's staff in GS grades 5 and 7. The problem of successfully recruiting engineers was worsened by the maintenance, outside the Survey, of a national register of engineers, thus adding to the time required to process applications and to the uncertainty of selecting applicants from the register.

By early 1960, Division headquarters took a positive step toward more productive recruiting by more actively involving Districts. Also, in January 1960, the CSC authorized the Survey to establish and maintain a central register of eligible hydraulic engineers in grades GS–5 to 15 for appointments throughout the United States and its territories. This improvement was accompanied by authority from the Commission to make appointments outside the register subject to certain limitations if no suitable eligibles were available from the register. The Survey had maintained the register of qualified geologists for many years. These changes produced near-immediate results. By June 1960, 113 applications had been received, of which about 100 were the result of WRD recruiting activities; 71 were eligible at grades GS–5 and 7 and 25 at grade GS–9. Although 32 appointments were made, the shortage of engineers persisted.

Leopold had long deplored a lack of selection standards that would assure WRD vacancies being filled by the cream of the crop. Put simply, no Federal agency was permitted to apply qualifying criteria that overrode the standards established by the CSC.

In late 1960, Leopold commissioned an Ad Hoc Committee on Recruitment Standards. The Committee completed its assignment and made recommendations to the Chief Hydraulic Engineer in a memorandum dated February 20, 1961. Of the Committee's several recommendations, one in particular caught Leopold's attention. It was that attention be given to selecting candidates who had high academic standing in their basic science courses and in those courses applicable to hydrology. The recommendations contained a rather oblique reference to advice from Willard McCormack, Chief of the Personnel Branch, Administration Division (AD), that "it might be possible to construct a new rating standard to incorporate all or most of the quality provisions and to factor in the crediting of additional points for stronger course work in the basic sciences. The result would be a higher score for such candidates, making their appointment more likely."

Staffing problems were even more acute by October 1961 when the Division identified expected needs for new professionals by June 1962 as 105 geologists, 180 hydraulic engineers, and 40 chemists. Leopold asked all council chairmen to make immediate arrangements with universities for midwinter recruiting dates. Meanwhile, Headquarters was developing recruiting guides, brochures, and a system to coordinate the large recruiting process, including procedures for screening, rating, and placing.

Leopold continued to emphasize the need for quality graduates, but objective measures of quality were still lacking. Grades were to be considered, but no specific numerical procedure for analyzing grades in courses applicable to a successful career in hydrology was yet available. His advice to Council Chairmen was to seek "men of good quality to perform different kinds of work for WRD and our estimation of their quality will depend largely on how they rate on the following factors: degree; courses in the basic sciences and hydrology; grades; graduate study and degrees; level and type of experience; recency of education and experience; special accomplishments; personal interviews; and recommendations of superiors and associates."

Personnel specialists of the AD suggested a seminar to better inform the field recruiters of details of the coming recruiting effort. Subsequently, the first recruiting seminar was held in Washington on December 18 and 19, 1961. WRD at headquarters was represented by Elwood R. Leeson, John H. Adamson, Delmar W. Berry, Russell L. McAvoy, John J. Molloy, and Roy B. Sanderson. Branch of Personnel, AD, brought in all four of its regional personnel officers and had four of its Headquarters staff participate.

Willard McCormack's suggestion that it might be possible to construct a rating scale to assure high-quality recruits had apparently fallen on fertile ground. By early 1962 a procedure was developed by Eugene Kaiser of the AD that was based on a numerical score for academic achievement and a more subjective score for such accomplishments as academic honors, graduate work, publications, and so forth. The general standard was that an applicant was a good candidate for WRD employment if his combined score was plus 15, of which at least plus 5 was in the academic factor.

But then, in January 1962, the Division took a giant step backward by forming a staffing committee to screen all applications. All matters relative to recruiting and staffing were directed to the committee and all appointments, conversions, and reinstatements of all professional personnel, with limited exceptions, required committee approval. The committee, by its charter, created a bureaucratic bottleneck that obviated some of the best efforts and intentions of the field recruiters. The time required for committee approval discouraged some applicants who preferred faster responses than employment with WRD. The committee was abolished a year later.

After the staffing committee was abolished in 1963, the recruiting coordination function was assigned to the Training Section and its name changed to the Recruiting and Training Section. Concurrently, the Manpower Utilization Section was abolished and its two-person staff was integrated into the Recruiting and Training Section. The Recruiting and Training Section, with Raymond O. Abrams as its chief, coordinated the Division's recruiting programs for the remainder of this period of WRD history.

In 1963, Headquarters approved recruiting at field level. A pilot recruiting program was organized by Harry D. Wilson, Regional Hydrologist, MCA. WRD personnel who assisted were James W. Geurin, John P. Monis, James H. Criner, William H. Robinson, Mack R. Stewart, John J. Molloy, Russell L. McAvoy, Theron R. Dosch, Raymond O. Abrams, Richard T. Sniegocki, Harry R. Page, Thomas J. Buchanan, Malcolm D. Hale, Marion S. Hines, Frank A. Watkins, and A. Ivan Johnson. Bosco Eudaly and Robert Smith of the AD also assisted.

Two events occurred in 1964 that greatly helped the recruiting program. The CSC granted authority (referred to as 775 authority) to the Survey to make on-the-spot job offers to qualified candidates. Now, for the first time, recruiters could discuss details of specific vacancies location, and general nature of the work. The Hydrologist Series was established with its register of applicants maintained by the Survey. The combination of these changes assured the continuing success of the recruiting program.

Also beneficial to the recruiting program was the continuation of recruiting seminars. The forerunner of the regional recruiting seminars was that organized and conducted by A. Ivan Johnson for RMA recruiters and invitees from other areas in Denver on October 12 and 13, 1964. Participants included university, CSC, and other-agency personnel specialists, WRD members from other areas and from Headquarters, and the recruiting specialists of RMA. Such seminars, organized on a regional or multiregional basis were conducted in other cities and became a fixture of the recruiting program during the remainder of this period of history.

In a memorandum to the Chief Hydrologist on September 8, 1966, S. Keith Jackson, Regional Hydrologist, RMR, said "I feel certain that the 20 professionals entered on duty as a result of last year's effort in our Region represent the most highly qualified group of college graduates ever employed in the Rocky Mountain Region."

### Establishing the Hydrologist Series

In a memorandum to District Chiefs and staff officials on March 23, 1963, Associate Chief Hendricks announced that the title of the chief of the Division had been changed to Chief Hydrologist. Hendricks pointed out in his memorandum, "The broadening scope of Division activities has placed greater emphasis on hydrology as an interdisciplinary science containing many skills, including engineering, geology, chemistry, and others. The change in Mr. Leopold's title has been made as a natural consequence of this emphasis on hydrology."

The change in Leopold's title from Chief Hydraulic Engineer to Chief Hydrologist occurred during the period of several months when representatives of WRD, led by Tyrus B. Dover, were negotiating with the CSC for the recognition of hydrology as a distinct and separate discipline in the field of science and for the establishment of the hydrologist series as a professional job category within the Federal service.

Dover later recalled (written communication to Hudson, June 12, 1988) that at the time the request was formally made to CSC to establish the hydrologist series, WRD was the only Federal agency to express interest in the proposed new series. According to Dover, lack of interest outside WRD may have been a factor in CSC giving WRD virtually a free hand in writing the qualification requirements and the grade-level standards.

The hydrologist series was established by CSC effective October 1, 1964, and vested responsibility for maintaining its register of applicants in the Geological Survey. In the announcement of the new series, CSC defined hydrology as "the study of interrelationships and reactions between water and its environment in the hydrologic cycle." The qualifications required the completion of the bachelor or higher degree with a course of study that included a year of physics, a year of chemistry, math through differential and integral calculus, and 12 semester hours in at least three of the following groups: geology; botany; hydraulics, fluid dynamics or fluid mechanics; and climatology or meteorology. The qualifications opened the door for agricultural and geological engineers, soil scientists, watershed management majors, and other graduates with water-resources options to enter Federal service as hydrologists.

An additional bonus to WRD was CSC's permission to place hydrologists in the same shortage category as engineers and chemists and to pay moving expenses for new hires to report to their jobs. Being placed in the shortage category meant higher starting salaries for recruits at typical entrance levels. The higher pay was also vital to Division plans to reclassify its professional employees as hydrologists. Reclassification would therefore give automatic pay increases to geologists in the lower grades who were not considered as being in short supply and would assure no pay reduction for other WRD professionals.

As soon as practicable after CSC approval of the hydrologist series, the Division began reclassifying most of its professional staff. It was a large task made up of hundreds of individual personnel actions, and progress was slow. Leopold's job classification was changed from engineer to hydrologist effective May 23, 1965, more than 2 years after his title was changed to Chief Hydrologist. By January 1, 1966, few hydrologists were on the rolls; most were still engineers, geologists, and chemists. However, by July 1, 1967, reclassification was essentially complete. The Division's professional staff was made up almost entirely of hydrologists. A few senior members of the Division remained classified according to their chosen professions. Not surprisingly in an organization of individualists and free thinkers, there remained a few engineers, geologists, and chemists who chose not to be identified as hydrologists.

# PART VII—MANAGEMENT AND OPERATIONS

Reviewed *by* George E. Ferguson *and* Warren S. Daniels

## Administrative Issues

Condensed from material provided *by* Frank Barrick, Jr.

### Fund Control and Cost Distribution

The period from May 1957 through June 1966 saw continued expansion of programs and increased funding with greater emphasis on proper allocation of operating costs and better utilization of manpower. During this period, a new accounting system for fund control and cost distribution was installed using direct-labor hours as the basis for charging direct and indirect costs to the projects. The Bureau computer provided the detailed information required.

### Washington Office Technical Support Charge (WOTSC)

The WOTSC against cooperative-program, transfer, and repay funds from other Federal agencies, including permittees and licensees of the Federal Power Commission, was increased from 7.5 percent to 9 percent and standardized effective July 1, 1962. The increase strengthened technical support of cooperative and collaborative projects and equalized charges for technical support against all sources of funds (see Part V, "Budget and Appropriations").

The increase in the assessment on cooperative programs raised questions from cooperators regarding the use of assessment funds. The cooperative agreement provided that the field and office work pertaining to the investigation be under the direction of an authorized representative of the Geological Survey; however, it was the Survey's position that equal recognition be given expenditures by either party in planning and conducting the investigations. Accordingly, upon request by a cooperator, the Survey gave full consideration for credit as direct expenditures of the costs to cooperators for such activities as may be reasonably comparable with Division activities financed by the Technical Support Charge. As it turned out, however, few cooperators sought credit for their technical support costs.

### Centralizing Administrative Functions

During the period of Volume VI, greater emphasis was placed on consolidating and centralizing administrative functions. Districts were encouraged to put administrative activities in a single unit responsible to the Council Chairman (see table III–1, "Organization"). In the Bureau, centralizing administrative services continued. For example, equipment and supplies stocked by the Equipment Development Laboratory, Columbus, Ohio, were transferred to the Property Maintenance Section of the AD, effective July 1, 1959. Field offices were instructed to place orders directly with that Section. The relatively new General Services Administration (GSA) continued to expand its programs nationwide for leasing office and storage space and for providing motor vehicles from pools at convenient locations for Federal-agency use by all government agencies.

At first, District supervisors were unhappy with the GSA motor pools, fearing loss of control of vehicles, many of which were modified to carry special equipment. After discussions with pool managers, however, satisfactory arrangements were made permitting the Districts to maintain control of specialized vehicles and to use pool vehicles for other purposes.

### Congressional Investigation

In June 1960, staff of the House Appropriations Subcommittee began reviewing the operations of several DOI bureaus including those of the Geological Survey. The major concerns of the Subcommittee were (1) the proportion of appropriated funds available for direct work on programs for which funds were appropriated, (2) the cost of administering and managing programs, and (3) the numbers and grades of personnel in Headquarters and Area offices and in field offices.

Satisfactory answers were provided the investigators. However, during the investigation, questions were asked by the investigators about the organization of the Division and about consolidating activities within a State under the direction of a single supervisor reporting directly to an Area or Regional Hydrologist.

### Federal Telecommunications System (FTS)

The FTS, providing relatively cheap long-distance telephone service, was established in 1963 and drastically changed communication methods within WRD.

### Function and Influence of the Computer in WRD

#### *In Administration and Management*

(Based on information provided *by* Frank Barrick, Jr., *and* James J. Snyder)

Although a "punch-card" machine had been used by the Survey since 1948 (Volume V, p. 237), the first digital computer was installed in the Geological Survey in the late 1950's. At first, it was used mostly for general-ledger accounting, payroll preparation, and personnel records; then project allotment accounting was added. The computer also made possible the use of an accounting system using direct-labor hours as the basis for distributing costs to projects.

As overseers of the Surveywide accounting system, only the Branch of Budget and Finance of AD was authorized to input accounting transactions into the computer. Account cards were punched and regularly updated by the Fiscal Management Unit of WRD for all formally established projects using the Summary of Program as the input document. The Monthly Statement of Account (the A–16) was the most widely used document produced by the accounting system.

#### *In Program Operations*

*By* Charles R. Showen *and* Solomon M. Lang

The digital computer's capacity to do repetitive computations with great speed and accuracy made it possible to process many times the volume of data as could be done by hand. The computer also made it possible to apply new methods which were infeasible by manual computations, and use of the computer opened areas of research that previously had been virtually impossible. Use of the digital computer was also justified on basis of cost savings. For example, automatic processing of streamflow data was estimated to save $300,000 per year. Although dollar savings were important, a computer processing system could be fully justified for other reasons—namely, the system provided greater flexibility in the type, form, and extent of analysis of published data; the time interval between collecting and releasing data was shortened; personnel were relieved of a tremendous volume of routine work; and the Survey avoided possible deterioration of scientific stature if timely and innovative applications of this powerful technological tool to the earth sciences were not made.

The purchase of analog-to-digital recorders (ADR) for gaging-station use started in 1964 with federally appropriated funds and continued in 1965 and 1966 at a rate of 1,000 recorders per year. The recorders were rented to District and project offices for $40 per year and the income was used to buy more recorders. About $125,000 per year, budgeted for data processing and analysis, was used primarily to purchase equipment (translators and plotters) and to develop new computer applications. The cost of developing new computer-application programs was not charged directly to projects but was covered by technical-support funds.

A set of programs was prepared to store and retrieve the data rapidly and to present the data as tables, graphs, and maps. The maps were valuable in planning and directing hydrologic projects because they showed specifically where data were available. The maps also indicated the density of available field data and were used to allocate resources for the collection of further information on the geology and water resources within project areas.

The computer programs developed through the years helped in interpreting hydrologic conditions and trends including rising or falling water tables, increasing or decreasing chemical-quality constituents, and changing volumes and areal variations in water use. Programs were developed for contouring hydrologic and geologic data and determining formation presence and continuity, aquifer permeability and hydraulic-boundary impacts, and water-quality constituent concentrations in an aquifer.

Computer applications in program operations greatly enhanced productivity and information products of the Division by the close of this period of WRD history.

## Personnel Issues

### Equal Employment Opportunity

*by* Frank Barrick, Jr.

On March 25, 1965, the President read a policy statement on Equal Employment Opportunity within the Federal Government to the Cabinet. Responsibility for carrying out the policy was delegated to the CSC by Executive Order 11246, dated September 24, 1965. In February 1966, the CSC issued guidelines for Federal agencies in establishing programs for equal opportunity in employment and in personnel operations. The guidelines were sent to Division field offices by the Chief Hydrologist on July 18, 1966, with a memorandum requesting heads of major field offices to personally assume leadership in equal employment activities. A monthly report was required on equal opportunity in recruiting, appointing, and separating employees.

### Employment Ceilings

Employment ceilings became a way of life in the early 1960's. Each fiscal year, the BOB imposed strict limits on the number of full- and part-time employees in each bureau. Within the Survey, the ceiling was allocated to each Division by the Director on the basis of recommendations of the Survey's Budget and Finance Committee.

The WRD gave top priority to hiring full-time professional employees. Full-time nonprofessional employees were hired only if ceiling limitations permitted. The full-time employee ceiling was effective throughout the fiscal year, but the part-time ceiling usually was applicable only to year-end employment as reported for the month of June. The Division Administrative Officer and the manpower representatives of the regional offices managed the employment ceilings on a day-to-day basis.

### Employee Benefits

#### Pay Rates

Basic beginning annual pay rates in effect in May 1957 and in June 1966 for various GS grades were as follows:

| | 1957 | 1966 |
|---|---|---|
| GS–1 | $ 2,690 | $ 3,507 |
| 3 | 3,175 | 4,149 |
| 5 | 3,670 | 5,181 |
| 7 | 4,525 | 6,269 |
| 9 | 5,440 | 7,479 |
| 11 | 6,390 | 8,961 |
| 13 | 8,990 | 12,510 |
| 15 | 11,610 | 17,055 |
| 18 | 16,000 | 25,382 |

Effective March 20, 1960, the cost-of-living allowance for employees headquartered in Hawaii was reduced from 20 percent to 17.5 percent; in Puerto Rico from 17.1 percent to 12.5 percent; and in the Virgin Islands from 25 percent to 17.5 percent.

#### Health Benefits

The Federal Employees Health Benefits Act of 1959, Public Law 86–382, became effective July 1, 1960, and provided for Government contributions to the cost of prepaid health benefits plans for Federal employees. It authorized deductions from the salaries of employees to meet the remainder of the cost.

#### Life Insurance

Public Law 86–377, enacted September 23, 1959, amended the Federal Employees Group Life Insurance Act of 1954 by discontinuing the reduction in the amount of insurance available to employees over 65. It also reduced from 15 to 12 the number of years of creditable service required for title to group life insurance during nondisability retirement.

#### Retirement

The Federal Employees Salary Act of 1966 stated that employees can retire with no reduction in annuity at age 55 with 30 years of service, at age 60 with 20 years of service, and at 62 with 5 years of service. The percentage of pay withheld as a deduction for retirement remained at 6.5 percent through June 30, 1966, and beyond.

## Health and Safety

(Many of the details of this section were provided by Roy C. Gilstrap, Ivan L. Burmeister, Wayne H. Hammond, Russell H. Langford, Ernest L. Ray, Malcolm D. Hale, and Donald W. Spencer.)

Although the nature of its work places WRD employees, especially field employees, at risk of injury or death, the Division maintained a commendable safety record during this period of history. The only job-related fatalities for which records are available involved stream gagers, with two exceptions.

In 1958, DeWayne L. Miller drowned in Applegate River near Cooper, Oreg., while attempting to wade the river. Also in 1958, Leslie L. Finley was fatally injured in a fall from a cable car at Little River near Mt. Carmel, S.C. In 1960, Kenneth W. Walker was fatally overcome by fumes from a gasoline-driven pump while cleaning a stilling well on the Arkansas River at Little Rock, Ark. In 1964, Richard H. Thompson drowned in the Missouri River at Sioux City, Iowa, while making a discharge measurement, complicated by shore ice, from a boat. In 1966, Robert S. Hammond died at Bloomington Reservoir in Indiana. Although he fell from the control structure into the lake, the immediate cause of Hammond's death was said to have been a heart attack.

The only other fatalities for which documentation is available were those of W. Baird Nelson and John P. Miller. Nelson, a GWB engineer in Utah, was killed in an automobile accident while on duty June 15, 1959, and Miller, a professor at Harvard and WAE employee, died of bubonic plague after returning to Boston from field work in New Mexico during the summer of 1961.

In the summer of 1961, five Survey employees drowned in two separate accidents, both of which occurred on the same day and both in Alaska. Three of the victims were Conservation Division employees, one of whom was the son of John Savini of the Tacoma District, SWB. The other two were Geologic Division employees. Although none of the victims was a WRD employee, the accidents were widely publicized within the Survey and led to increased emphasis on the need to use extreme care in the field, particularly when working around water. Soon after these fatalities occurred, wearing life preservers became mandatory for all Survey employees aboard watercraft less than 26 feet in length. The December 1961 issue of the WRD Bulletin was a special issue devoted to safety.

A drilling accident cost Willis K. Kulp an arm in November 1959. Kulp, an engineer with the Hydrologic Laboratory in Denver, was on a test-drilling job in Nevada when his hand, then his lower arm, became caught in the auger. Kulp returned to school, obtained a law degree, and later became a county judge in Weld County, Colo.

Records of injuries to WRD employees are not available except for 1959 and 1960. The table below was compiled from material provided by Russell H. Langford for 1959 and 1960 when he was Bureau Safety Officer and by Ernest L. Ray, AD, who became Bureau Safety Officer in the mid-1960's. The table offers a limited account of WRD-employee injuries and a limited comparison of injuries within WRD to those in the Survey.

The Geological Survey had no full-time safety officer until 1962, when Heinz Wilms was hired, assigned to the AD, and stationed in Denver. Before

Table VII–1. Reported accidents, 1957–66

| | Accident experiences | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
| **Fatalities** | | | | | | | | | | |
| Survey except WRD | 2 | 2 | 3 | 1 | 6 | 3 | 0 | 1 | 5 | 0 |
| WRD | - | 2 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 |
| Total | 2 | 4 | 4 | 2 | 7 | 3 | 0 | 2 | 5 | 0 |
| **Injuries** | | | | | | | | | | |
| Survey | 427 | 380 | 412 | 366 | - | - | - | - | - | - |
| WRD | - | - | 149 | 162 | - | - | - | - | - | - |
| Total | - | - | 561 | 528 | - | - | - | - | - | - |

Note: Figures are not available where no numbers are shown.

Wilms, the Bureau Safety Officer was the WRD employee temporarily assigned to assist Assistant Director Lyddan. They were John Horton, Russell H. Langford, and Hugh H. Hudson. Lawrence E. Newcomb, John H. Adamson, and Hallard B. Kinnison were WRD Headquarters contacts with the Director's Office in safety matters. There were no designated safety specialists in field offices of the Division before June 1966.

Job-related automobile accidents led to courses in defensive driving in which WRD employees participated and to the mandatory installation of seat belts in vehicles maintained by GSA in 1963.

Films that were publicized and made available to WRD offices during this period of WRD history included "Falls are no fun" and "Rescue breathing." Advisories were also distributed to employees on such general or local field hazards as poisonous snakes, tetanus, schistosomiasis, Rocky Mountain spotted fever, and poison ivy.

## Supervisory Training

Condensed from information provided by Raymond O. Abrams

The Division recognized the need for supervisory and management training and used the well-established training programs of the CSC to meet many of those training needs. In some cases, the CSC contracted to provide training designed to meet local needs at district and regional offices. Training was also offered at CSC regional offices and at the Executive Seminar Centers at Kings Point, N.Y., Oak Ridge, Tenn., and Berkeley, Calif. Many of the Executive Seminar lecturers were executives from government, business, and universities. Usually at least four WRD employees attended each seminar each fiscal year. Details of supervisory training including names of attendees from WRD are not available.

Temporary assignment of field personnel to Headquarters offices also provided on-the-job management training and was used extensively.

## Awards

[The compilation of awards would not have been possible without the assistance of Beverly A. Pittarelli of WRD's Branch of Manpower, Jane H. Wallace of the Director's Office, and retirees Robert M. Beall, Theron R. Dosch, and A. Ivan Johnson. Ray Abrams' review of this part of volume VI is also gratefully acknowledged. Jane Wallace's "The Honor Awards Program of the U.S. Department of the Interior," May 1988, provided a history of the program and its several types of awards and gave statistical summaries of the awards and recipients.]

WRD employees recieved numerous awards during the years from 1957 through 1966 from the DOI, the Geological Survey, and from technical societies and service organizations.

***The Distinguished Service Award***

According to Wallace, the Secretary of the Interior granted 1,702 Distinguished Service Awards from April 1948, when the Honors Awards program began, through December 31, 1987. The Geological Survey was by far the most active bureau with 344 of the honorees. From 1957 through 1966, 26 percent of the Geological Survey honorees were from WRD. Employees of WRD who received the award, the year of their award, and their headquarters were as follows:

Recipients of Distinguished Service Awards

| Name | Headquarters at year of award |
|---|---|
| **1957** | |
| John Mangan | Harrisburg, Pa. |
| Carl G. Paulsen | Washington, D.C. |
| Harold C. Troxell | Los Angeles, Calif. |
| **1958** | |
| Henry C. Beckman | Rolla, Mo. |
| Lynn Crandall | Idaho Falls, Idaho |
| John G. Ferris | Washington, D.C. |
| Joseph S. Gatewood | Tuscon, Ariz. |
| Arthur W. Harrington | Albany, N.Y. |
| Charles S. Heidel | Helena, Mont. |
| Charles S. Howard | (Retired) |
| Walter B. Langbein | Washington, D.C. |
| Luna B. Leopold | Washington, D.C. |
| Thomas Newell | Boise, Idaho |
| Barney J. Peterson | Arlington, Va. |
| Charles V. Theis | Albuquerque, N. Mex. |
| **1959** | |
| Harvey B. Kinnison | Menlo Park, Calif. |
| Raymond L. Nace | Washington, D.C. |
| A. Nelson Sayre | Washington, D.C. |
| **1960** | |
| Eugene H. Herrick (Post.) | Okinawa |
| **1961** | |
| Albert G. Fiedler | Washington, D.C. |
| Joseph V.B. Wells | Washington, D.C. |

Recipients of Distinguished Service Awards --Continued

| Name | Headquarters at year of award |
|---|---|
| **1962** | |
| Lawrence C. Crawford | Columbus, Ohio |
| S. Kenneth Love | Washington, D.C. |
| George H. Taylor | (Retired) |
| **1963** | |
| G. Earl Harbeck | Denver, Colo. |
| Ernest L. Hendricks | Washington, D.C. |
| **1964** | |
| Irving E. Anderson | Washington, D.C. |
| **1965** | |
| Tate Dalrymple | Arlington, Va. |
| Harold V. Peterson | (Retired) |
| Arthur M. Piper | Menlo Park, Calif. |
| **1966** | |
| Robert R. Bennett | Arlington, Va. |

## Valor Awards

The Department gave Valor Awards to those who risked their lives to save the lives of others.

Recipients of Valor Awards

| Name | Headquarters at year of award |
|---|---|
| **1958** | |
| Robert H. Simmons | Charleston, W. Va. |
| **1963** | |
| Bernard C. Massey | Austin, Tex. |
| Elmer E. Schroeder | Austin, Tex. |

## The Meritorious Service Award

The Meritorious Service Award also dates back to April 1948. Through December 31, 1987, 6,216 Meritorious Service Awards were presented and again, the Geological Survey led the nominating bureaus with 1,161 of its members represented. During the years from 1957 through 1966, 21 percent of those in the Survey who received the Meritorious Service Award were from WRD.

## Recipients of Meritorious Service Awards

Recipients of Meritorious Service Awards

| Name | Headquarters at year of award |
|---|---|
| **1957** | |
| Revoe C. Briggs | San Francisco, Calif. |
| John H. Gardiner | Tucson, Ariz. |
| Berkeley Johnson | Santa Fe, N. Mex. |
| Oliver W. Hartwell | Trenton, N.J. |
| Miner R. Stackpole | Augusta, Maine |
| Harlowe M. Stafford | Sacramento, Calif. |
| Vincent J. Stermitz | Helena, Mont. |
| **1958** | |
| Karl Jetter | Arlington, Va. |
| William G. Bratschi* | Albuquerque, N. Mex. |
| Jack M. Terry * | Denver, Colo. |
| Meta H. Wendels | Mineola, N.Y. |
| **1959** | |
| John A. Baumgartner* | Tehran, Iran |
| Arthur H. Frazier | Columbus, Ohio |
| Dewayne L. Miller* | Medford, Oreg. |
| J. Holloway Morgan | Champaign, Ill. |
| **1960** | |
| Burke L. Bigwood | Hartford, Conn. |
| Seth D. Breeding | Austin, Tex. |
| Donald S. Wallace | Arlington, Va. |
| John D. Goshorn | Helena, Mont. |
| **1961** | |
| Joseph W. Brookhart | Grand Forks, N. Dak. |
| Holbert W. Fear | Albany, N.Y. |
| John L. Lamson | Raleigh, N.C. |
| Edwin W. Lohr | Washington, D.C. |
| Carl C. Yonker | Ankara, Turkey |
| **1962** | |
| Warwick L. Doll* | Charleston, W. Va. |
| Howard S. Leak | Honolulu, Hawaii |
| Orville D. Mussey | Arlington, Va. |
| John L. Saunders | Ft. Smith, Ark. |
| Robert D. Schmickle | Pittsburgh, Pa. |
| **1963** | |
| Harry C. Bolon | Rolla, Mo. |
| Albert B. Goodwin* | Portland, Oreg. |
| Orison H. Jeffers | Columbus, Ohio |
| Hugh C. McCreery | Bismarck, N. Dak. |
| Kenneth N. Phillips | Portland, Oreg. |
| Leon R. Sawyer | St. Paul, Minn. |

Recipients of Meritorious Service Awards --Continued

| Name | Headquarters at year of award |
|---|---|
| **1964** | |
| Douglas D. Lewis | Tucson, Ariz. |
| Norbert J. Lusczynski* | Mineola, N.Y. |
| Charles W. Reck | Arlington, Va. |
| Paul R. Speer | Chattanooga, Tenn. |
| **1965** | |
| Robert H. Brigham | Lashgar, Pakistan |
| Vernal Bennion | Iowa City, Iowa |
| Bruce R. Colby | Lincoln, Nebr. |
| Fay N. Hansen | Baton Rouge, La. |
| Paul M. Johnston | Garden Grove, Calif. |
| Carroll M. Kilgore | Arlington, Va. |
| Edith D. McLean | Washington, D.C. |
| Archibald O. Patterson | Ocala, Fla. |
| Raymond L. Sunstrom | Cairo, Egypt |
| Fred M. Veatch | Tacoma, Wash. |
| Frederick W. Wagener* | Columbia, S.C. |
| **1966** | |
| Edgar G. Barron | Columbus, Ohio |
| Roy E. Cabell | Salt Lake City, Utah |
| Byrnon C. Colby | Minneapolis, Minn. |
| Donald F. Dougherty | Albany, N.Y. |
| Vinton C. Fishel | Denver, Colo. |
| William V. Iorns | Salt Lake City, Utah |
| Albert E. Johnson | Columbia, S.C. |
| Frank Kennon | Austin, Tex. |
| Ralph E. Marsh | Juneau, Ark. |
| Godfrey L. Oakland | Albuquerque, N. Mex. |
| Charles H. Prior | St. Paul, Minn. |
| Frank Stermitz | Helena, Mont. |
| May E. Thiesen | Washington, D.C. |
| J. Robert Throckmorton | Tacoma, Wash. |
| Adrian H. Williams | Washington, D.C. |
| Milton T. Wilson | Salt Lake City, Utah |

* Awarded posthumously.

### *Length of Service Awards*

Administrative Digest No. 150, April 1, 1960, carried the following summary of the Survey's length-of-service awards:

> During January and February, length of service awards were presented to 46 Survey employees whose length of service ranges from 30 to 50 years. Since distribution of length of service awards by the Survey began in December 1957, 377 employees have received 30-year awards, 64 have been recognized for 40 years of service, and 13 have been honored for 50 years of service. All of these awards have been presented personally by the Director or by the Associate or Assistant Directors. The relatively small size of the Survey personnel force at the time the awardees entered on duty 30, 40, and 50 years ago (less than 1,000 employees during the years from 1909 to 1929) indicated that an extremely large proportion of Survey employees have devoted essentially their entire career to Government service.

According to Digest No. 150, in January and February 1960, 30-year emblems and certificates were presented to Irving E. Anderson, Edgar G. Barron, Paul C. Benedict, Harry C. Bolon, Harold E. Cox, Earl H. Curtis, Vinton C. Fishel, Lawton W. Furness, A. Rice Green, Floyd F. LeFever, Edith D. McLean, Roy H. Monroe, Eva M. Patton, A. Nelson Sayre, Floyd F. Schrader, and Joseph V.B. Wells. Albert Fiedler, Henry C. Beckman, and Jacob B. Spiegel were presented 40-year scrolls.

Administrative Digest No. 167, December 7, 1960, listed 9 WRD personnel who recently received 30-year emblems and certificates. They were Elmer Butler, Fay N. Hansen, George A. LaRocque, Stanley W. Lohman, R. Stanley Lord, Robert O.R. Martin, Lucy M. Miller, Godfrey L. Oakland, and George L. Whitaker. A 40-year scroll was presented to J. Holloway Morgan.

Administrative Digest No. 277, September 25, 1964, listed nine WRD employees who received recognition for 30 years of service. They were Henry C. Barksdale, Bruce R. Colby, Tate Dalrymple, Albert E. Harris, Rodney Hart, Thomas Johnson, Jr., Leo L. Laine, Lois Randall, and Raymond B. Vice. Albert E. Johnson and Milton T. Wilson were awarded 40-year scrolls.

Administrative Digest No. 322, November 5, 1965, listed 18 WRD employees who had been awarded 30-year emblems and certificates during the past fiscal year. They were Samuel G. Anderson, Frank Barrick, Jr., Dean B. Bogart, Oscar C. Dale, Warren S. Daniels, Donald C. Hurtgen, Dorothy M. Ireland, Paul M. Johnston, Frank W. Kennon, Martha L. Keith, Norma E. Lathrop, Thomas Maddock, Jr., Wilson McConkie, Laurence B. Pierce, Tinnie C. Schmitt, Leonard J. Snell, J. Robert Throckmorton, and Herbert A. Waite. The 40-year scroll was awarded to Fred M. Veatch.

Administrative Digest No. 356, October 28, 1966, listed 26 members of WRD who had received 30-year emblems and certificates during the past fiscal year. They were Benita V. Beldon, Lawrence E. Birdwell, Walter A. Blenkarn, Milton F. Cook, Richard C. Culler, Donald F. Dougherty, Henry C. Eagle, James W. Gambrell, Clayton H. Hardison, Ernest L. Hendricks, James D. Hungate, Oliver P. Hunt, Albert E. Johnson, Walter B. Langbein, Kenneth A. MacKichan, Evelyn M. Ogden, Agnes P. Ranlett, Elmer A. Roemer, Merle E. Schroeder, Marvin J. Slaughter, William O. Smith, Wilbur T. Stuart, Laura R. Teres, Mendall P. Thomas, Horace G. Thomasson, and Lenord B. Yarger. Scrolls representing 40 years of service were given Henry C. Pritchett and Trigg Twichell.

***Other Department of the Interior Awards***

The Unit Award for Excellence, according to Administrative Digest No. 322, November 5, 1965, was given to the Basic Records Unit, SWB, Iowa City, Iowa, and to the SWB District, Baton Rouge, La.

The DOI Safety Council Award of Merit was presented to Holbert W. Fear of the Albany, N.Y., SWB District in 1960 and to A. Ivan Johnson, Hydrologic Laboratory, Denver, Colo., in 1965.

***Technical Society and Public Service Awards***

The following list of WRD members honored by technical societies and other organizations may be incomplete. A WRD-maintained record of such awards evidently does not exist. The names and awards were compiled from numerous sources such as monthly reports from the Division to the Director and honorees' biographies, as available. Kathy Miller, American Water Works Association, June Forstrom, Geological Society of America and Grazia Tramontana, ASCE, provided information on technical-society awards from their files.

Mark Meier won the Sigma Xi Award in 1957.

In 1958, Albert G. Fiedler was presented the George Fuller Award of the American Water Works Association; Walter B. Langbein and Stanley A. Schum shared the Robert E. Horton Award of the American Geophysical Union; Luna B. Leopold and Thomas Maddock, Jr., shared the Kirk Bryan Award of the Geological Society of America; and a Rockefeller Public Service Award was given to Joseph E. Upson.

In 1960, Rolland W. Carter and Carl E. Kinsvater were awarded the Norman Medal of ASCE and Robert W. Stallman won an award from the National Science Foundation.

In 1961, Francis A. Kohout won the Robert E. Horton Award of the American Geophysical Union.

In 1963, Walter B. Langbein and Thomas Maddock, Jr., shared the J.C. Stevens Award of ASCE, and Luna B. Leopold was awarded the Veth Medal of the Royal Netherlands Geographical Society.

In 1964, Daryl B. Simons and Maurice L. Albertson shared the James R. Croes Medal of ASCE, and S. Kenneth Love was given the George Fuller Award of the American Water Works Association.

In 1966, Luna B. Leopold was awarded the Medal of the University of Liege, Belgium; Charles L. McGuinness won the O.E. Meinzer Award of the Geological Society of America; and William W. Sayre was granted the Walter L. Huber Civil Engineering Research Prize of ASCE.

## Management Support

### Program Planning and Project Management

As recounted in other parts of this volume and in Volume V (p. 19), Division leadership sought a better depiction and redirection of program to:

1. Improve program balance by conducting more analytical and interpretive studies, built upon the large existing data base, and more research in support of the overall hydrologic mission.
2. Make program content more responsive to water resources and environmental management needs.
3. Achieve better understanding of hydrologic systems and man's interactions with those systems.
4. Improve the quality and timeliness of reports.

To achieve these ends, much effort during the period was devoted to improving program and project planning and execution through stronger leadership direction, coordination, and control at all management levels—Headquarters, Areas, and Districts.

District supervisors were directed to prioritize and integrate, through their District councils, long-range and project planning and to maintain strict vigilance over project execution and report preparation.

Division Hydrologists, with their Area Committees of Branch Area Chiefs, were progressively delegated more responsibility to oversee District-level planning, programming, allocation of funds, project execution, and report acceptability. (See Part III, "Offices of the Division.")

The Branches increased their technical support to the field by providing improved and enlarged techniques manuals, technical training opportunities for personnel, and corps of specialists to serve as consultants for planning and executing projects. Through operations research (see Part IV, "Operations Research"), the Branches improved techniques for data collection, processing, and publication, and their procedures for tracking project progress to assure completion in accordance with plans. (See Part III, "Ground Water Branch.")

Division headquarters retained authority to approve programs and projects and allocation of resources to fund them.

Before this period of stronger supervisory management and control of programming, the Division, through its former Program Control Branch (1951–56) under the leadership of George E. Ferguson assisted by Kenneth B. Young, began to develop a systematic and coherent process of program design, documentation, and control (Volume V, p. 18–19). As an early effort, Young prepared a draft of the Division's first manual on programming procedures.

Central to the management process was a documentation system basically in place by 1957 when Young assumed leadership of the new Division Planning Section. The system employed a standardized set of related program, project, and fiscal forms. These, integrated into a manual of policy and instructions, became the so-called "Proposed Division Supplement" to the program series of the Survey Manual. It became a working program manual with its transmittal to District Chiefs and Staff Officials by memorandum of February 20, 1959, signed by the Chief Hydraulic Engineer. The policy and procedures stipulated therein were followed, with minor refinements from time to time, for the remainder of the period and beyond, but for reasons unknown, the Division never submitted the document for final approval by the Director and inclusion in the Survey Manual.

This program manual was quite comprehensive and thorough, containing 30 pages, plus appendices, and divided into five chapters:

1. Program objectives and policies,
2. Program formulation,
3. Long-range program plans,
4. Short-range program plans, and
5. Planning procedures.

Chapter 5 detailed the program-documentation process, the forms to be used, and instructions for their use. Four formats provided a management framework for program proposals, project design, annual project execution, and funding authorization.

Project Description.—Used to describe a project, for the life of the project but not more than 3 years. The format provided for statement of the problem(s), scope of work proposed, manpower and costs by years and branches, major activities, leadership and staffing, and proposed form of publication.

Yearly Work Plan.—An annual supplement for each project description that described the work to be performed on that project for that year.

Summary of Program.—The display of all work (all projects) by an office (usually District) funded by a particular cooperator (fund source).

Fiscal Analysis of Cooperative Agreement.—Served as an accounting document for a particular cooperative fund source. It initiated an estimated account authorization, modified it as necessary later to reflect firm authorization, and provided information for other fiscal planning and control purposes.

An expanded summary of program document, a Consolidated Work Plan (not specified in the program manual), was developed by Ferguson for use in ACA early in the period, FY 1958. It used two displays, a projected summary and a water-records schedule. Its purpose was to summarize all program activity in a State (Council Districts) by Branches and sources of funding for the current and upcoming fiscal year. Not only did this plan aggregate the total State program in a convenient format for the Division Hydrologist, but it also served to stimulate program awareness and dispel any "hidden agendas" among the Branch members of a Council. Ferguson felt strongly that it served as a useful, team-building exercise for the Division line organization that was to come. The consolidated work plan of same or similar format soon followed in the other Areas.

This program documentation process served several purposes in program management. It enabled all levels of management, District, Area, and Headquarters, to prioritize, in advance of the upcoming year, for problem relevancy, program balance, and resource allocation. It enabled a systematic area and national aggregation of program activity and costs as a necessary base for planning and budgeting ahead at the Federal level. It tracked program accomplishment. It provided a means for evaluating program effectiveness at the several levels of management. But perhaps most important of all, the process stimulated an increased awareness of total program activity and needs throughout the Division in preparation for moving to a Division line organization.

The process was managed throughout the period by the Division Planning Section, headed by Young until September 1960, when he moved to Madison, Wis., to become District Engineer, SWB. He was followed successively by Irving E. Anderson and Lawrence E. Newcomb. Near the close of the period, Warren S. Daniels became Section Chief and continued in the position for many years.

Division leadership similarly pressed for better and more timely reports as program end products. Those efforts are recounted in some detail in Parts III, IV, and IX of this volume.

### Major Conferences

The conferences held during this period, 1957–66, were convened to exchange or impart technical, operational, or management and policy information. They were sponsored at all organizational levels within WRD—District, Regional, and National. WRD personnel, in increasing numbers, attended and participated in outside conferences, hosted by professional societies, technical groups, and other public agencies—State, Federal, and International.

Many Districts, especially those with Subdistrict and field offices, found it beneficial to schedule District conferences from time to time, primarily for training of and information exchange among all personnel. Some of the larger Districts scheduled them annually, organizing rather formal technical agendas, as for example the New York SWB District's annual "Convocation." As Branch Districts became Division Districts during the final years of the period, such gatherings were especially useful for orientation, training, and team-building for their new "one-water" organizations.

Onward from early in this period the Branch Area Chiefs regularly convened Area conferences of District Chiefs, mostly on a Branch basis before District-level reorganization, to guide and oversee program planning and project execution. These conferences served as forums for imparting leadership policies, goals, and priorities, and for group exchanges on new and different District programs and on operational problems of common interest. Some conferences involved Districts of adjacent areas to ensure against regional parochialism and to broaden awareness among the District Chiefs. Other gatherings were initiated by Regional groups of District Chiefs having similar program interests. One such self-proclaimed group, SEDEC (Southeastern District Engineers Conferences) met annually before and through most of this period. They were noted for showing no reluctance to petition or challenge Headquarter's leadership for changes in policies and priorities deemed beneficial to getting their jobs done. Their feedback "up the hierarchy" helped to forge new directions for WRD or "to drag the anchor," as thought appropriate.

Unfortunately, lack of records about the regional and specialty conferences prevents a listing of all, but group photographs of a number of SWB conferences (figs. VII-1 through VII-6) will recall fond memories to those who attended.

National conferences of the period were sponsored by individual Branches before reorganization. There was none in the QWB. One Divisionwide National conference was convened in late 1965.

The General Hydrology Branch convened its first and only national conference in Denver, Colo., February 24–27, 1958. Nearly all professional personnel of the Branch participated (fig. VII-7). Other attendees included a few staff members of the Division and other Branches. Having been created in mid-1956 from the former Technical Coordination Branch, the program was organized to review the work in progress in hydrologic effects of land use, evaporation, and transpiration; geomorphic processes; soils and soil moisture; specialized hydrologic problems; instrumentation and equipment development; and comprehensive water-resources investigations. (See also Part III, "General Hydrology Branch.")

The SWB held a national conference in Dallas, Tex., December 12–14, 1960 (fig. VII-8). In addition to the full contingent of SWB officials, key staff members, and District Engineers, Assistant Director Lyddan and Assistant Division Chief Nace attended and addressed the group on status and plans of the Bureau and Division. The 2 days of Branch sessions focused on operations research, reports, special programs, current technical studies, equipment development, training, and administrative and personnel matters. These highly participative sessions involved virtually all of the registrants, either as speakers, session chairmen, or discussion leaders. The main conference was preceded by a meeting of the Branch Area Chiefs on December 10, followed by closing concurrent sessions of district engineers from the four Areas on December 14. This conference was the last of a series of 5-year national gatherings of the SWB.

The GWB held two national conferences of its district supervisors during the period—the first in New Orleans, La., February 12–14, 1962, and the second, in Atlanta, Ga., April 1–3, 1964 (figs. VII-9 and VII-10). Though no written records of agendas or minutes were found, O. Milton Hackett, then the Branch Chief (oral commun.), recalls that the major emphasis at Atlanta concerned the status of and outlook on computer use in ground-water programs. Sessions there dealt with automatic data processing and future applications of the digital computer in ground-water modeling. Hackett recalls there were strong feelings and heated discussions, pro and con, about the viability of computers for ground-water investigations and research. Earlier in the period, May 19–24, 1958, the GWB had convened a thematic national meeting in Boise, Idaho, on the hydrology of volcanics, attended by senior Branch personnel (fig. VII-11).

The first of a yet-to-follow series of postreorganization, national Division conferences was convened at Dayton, Ohio, November 2–3, 1965 (fig. VII-12). All Districts were represented by WRD District Chiefs or WRD Council Chairmen. Headquarters and Area officials and some of their assistants rounded out the attendance. At that time only about half of the Districts had been designated "Division-level," and Headquarters offices and units were yet to be restructured.

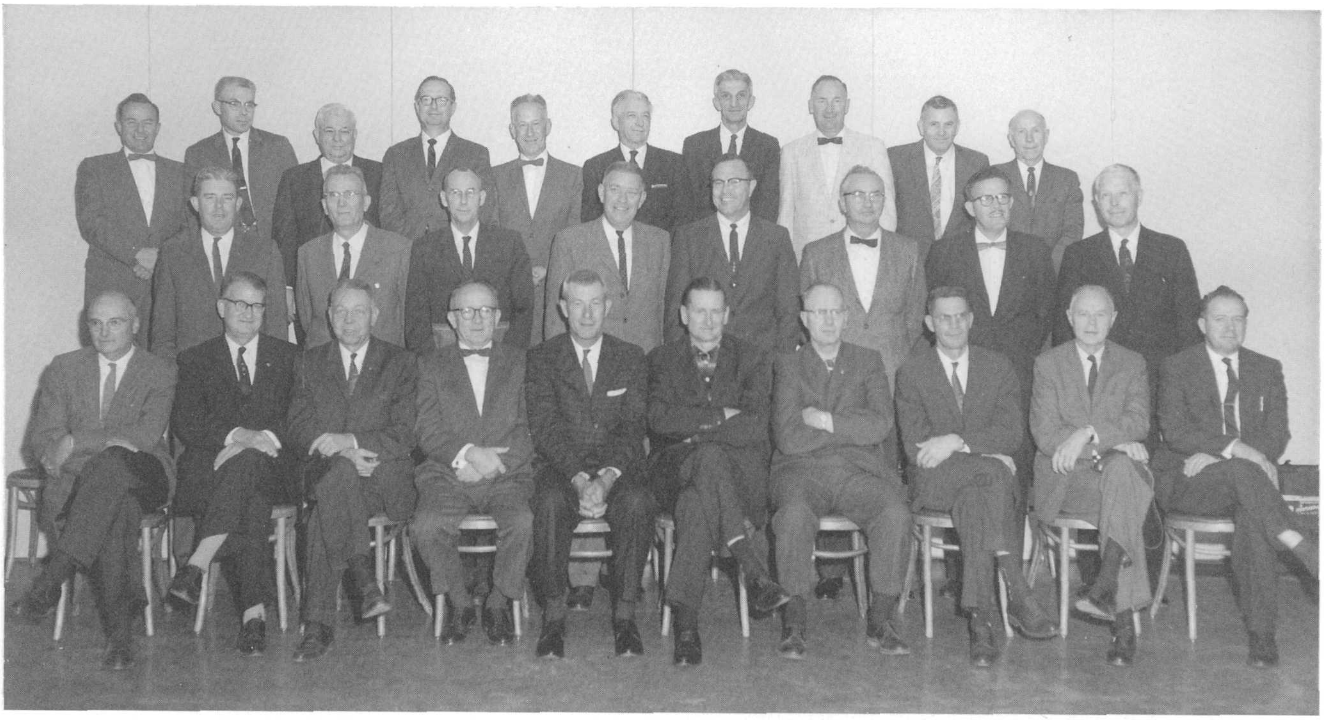
The date and location of this meeting had been selected to recognize the 50th anniversary of the Miami Conservancy District (MCD) and the long-term cooperation with that pioneer river-basin water-management agency. Lawrence C. Crawford, former District Engineer (SWB) for Ohio who retired in 1962 and was now affiliated with MCD, was instrumental in initiating and arranging for the conference site and joint plenary luncheon and dinner programs. At those events, participated in by officials of both agencies, Lyddan, Nace, and Hendricks officiated for the Survey.

The first day of 2 days of Division sessions focused on Circular A–67 plans and activities of the new Office of Water Data Coordination, the Water Resources Research Act of 1964, and the newly legislated Water Resources Planning Act of 1965. The second day involved status and plans of the Division, revolving in large part around completing the reorganization of WRD.

This conference is remembered by those in attendance as not being a very enjoyable event. Anxiety permeated the group, many yet facing reorganization of their District or Branch offices. Understandably, morale was not very high at the time. Chief Hydrologist Leopold put in but a brief appearance to address the group and departed just before the main dinner event with MCD. As now viewed, this meeting signaled a "passing of the old order" and much concern about what the future would bring. No minutes or proceedings were ever prepared and no copy of an agenda could be found in Division records. As one former Division officer put it, "It's best forgotten."

Throughout the period the Division maintained a high degree of involvement in a number of international programs and related conferences. These are recounted in Part IV, "International Programs." The most ambitious perhaps of all such conferences was the International Water for Peace Conference, held in Washington, D.C., in May 1967. It required extensive and detailed advanced planning in which WRD became deeply involved (onward from October 1965) on behalf of the Departments of State and Interior. Among those from WRD who planned and managed the conference were Thomas E. Eakin, George C. Taylor, Jr., Herbert A. Swenson, William J. Schneider, and Leopold A. Heindl.

CONFERENCE OF DISTRICT ENGINEERS (RMA AND PCA) AND STAFF OFFICIALS
SURFACE WATER BRANCH
SALT LAKE CITY, UTAH
OCTOBER 16-18, 1961
UNITED STATES GEOLOGICAL SURVEY



Harris Travis Twichell Kennedy Wiard Wilson Stermitz Anderson Leak Tripp

Erskine Phillips Williams Lewis Sanderson Le Fever Hofmann Oltman

Heckler Thomson Bell Lord Fischback Hendricks Marsh Iorns Veatch Jibson

Figure VII-1. Attendees at conference of SWB district engineers, RMA and PCA, Salt Lake City, Utah, October 16–18, 1961.

CONFERENCE OF DISTRICT ENGINEERS AND STAFF OFFICIALS
ATLANTIC-COAST AND MID-CONTINENT AREAS
SURFACE WATER BRANCH
LOUISVILLE, KENTUCKY
OCTOBER 19–21, 1961

Figure VII-2. Attendees at conference of SWB district engineers, ACA and MCA, Louisville, Ky., October 19–21, 1961.

| | Left to Right in Photo | | |
|---|---|---|---|
| **No.** | **First Row** | **Second Row** | **Third Row** |
| 1. | McCall | Meyers | Molloy |
| 2. | Hayes | M.R. Williams | Cragwall |
| 3. | Schaefer | Dougherty | Patterson |
| 4. | Hendricks | Thomson | Robinson |
| 5. | Sawyer | Ash | Carroon |
| 6. | Young | Schrader | Gambrell |
| 7. | Hale | Bennion | Bolon |
| 8. | Cameron | Johnson | Horton |
| 9. | Odell | Hansen | Saunders |
| 10. | | Knox | Rice |
| 11. | | Mitchell | Eaton |
| 12. | | | Bogart |
| 13. | | | A.H. Williams |
| 14. | | | Crawford |
| 15. | | | Doll |

SOUTHEASTERN DISTRICT ENGINEERS CONFERENCE, WITH STAFF OFFICIALS, SWB, ATLANTA, GEORGIA, JUNE 12–13, 1962

Figure VII-3. Attendees at conference of SWB district engineers, Southeastern States, Atlanta, Ga., June 12–13, 1962.

Seated, left to right: Carroon (Alabama), Schaefer (ACA), Leeson (WRD, Washington), Eaton (MCA), Johnson (South Carolina), Rice (North Carolina)

Standing, left to right: Hanson (Louisiana), Williams (SWB, Washington), Robinson (Mississippi), Cameron (Georgia), Patterson (Florida), Cragwall (Tennessee)

CONFERENCE OF DISTRICT CHIEFS AND STAFF OFFICIALS
ATLANTIC COAST AND EASTERN MID-CONTINENT AREAS
SURFACE WATER BRANCH
Grove Park Inn, Asheville, North Carolina
October 17–18, 1963

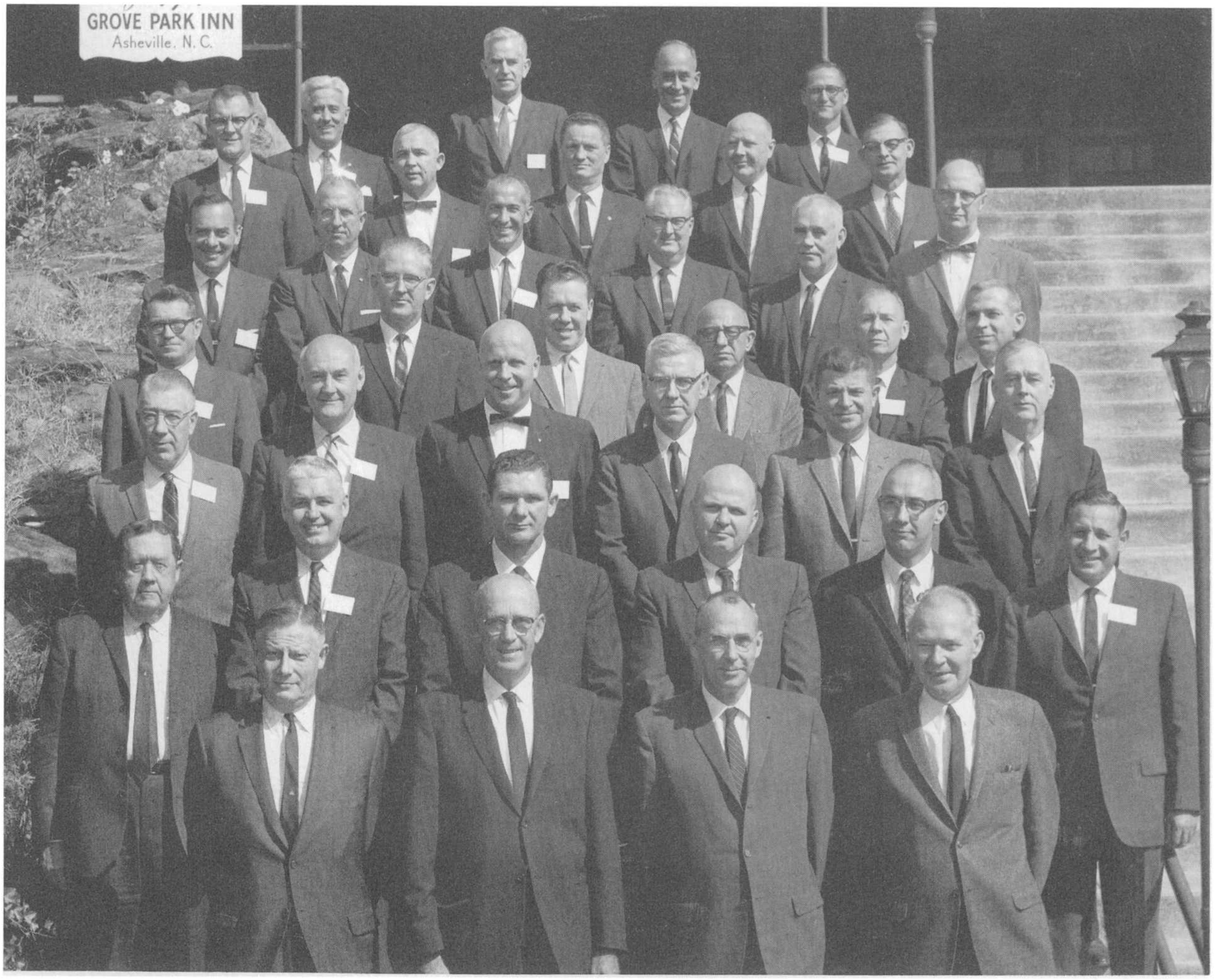



Figure VII-4. Attendees at conference of SWB district engineers, ACA and eastern MCA, Asheville, N.C., October 17–18, 1963.

Ash; Knox; Bogart; Lopez
Malloy; Cameron; McCall; Carter; Hayes
Kilpatrick; Patterson; Jackson; Rice; Schrader; Dougherty
Johnson, T.G.; Cragwall; Flynn; Johnson, A.E.; Ferguson; Rima
Miller; Williams, A.H.; Forrest; Gambrell; Horton; Griffin
Mitchell; Steacy; Hale; Robinson; Carroon; Deutsch
Schaefer; Eaton; Williams, M.R.; Wells

CONFERENCE OF DISTRICT ENGINEERS, PCA AND RMA, WITH STAFF OFFICIALS, SWB AND WRD, LAS VEGAS, NEVADA, OCTOBER 30 TO NOVEMBER 1, 1963

Figure VII-5. Attendees at conference of SWB district engineers, PCA and RMA, Las Vegas, Nev., October 30 to November 1, 1963

Standing, left to right: Lord (SWB, PCA); Marsh (Alaska); W. Miller (SWB, Washington, DC); Stermitz (Montana); Worts (WRD, Nevada); Travis (Idaho); Harris (WRD, Nevada); Eaton (SWB, MCA); Jackson (WRD, RMA); Lewis (Arizona); Bell (SWB, RMA); Carter (SWB, Washington, DC); Flynn (SWB, Washington, DC); Wiard (Wyoming); Wells (SWB, Washington, DC); Odell (Colorado)

Kneeling, left to right: M. Williams (SWB, Washington, DC); Heckler (New Mexico); Hofman (California); M. Miller (Hawaii); Sanderson (Oregon); Wilson (Utah)

Photo by Fred Veatch (Washington)

Attendees missing from photo: Veatch (Washington); Leopold (WRD, Washington, DC); A. Williams (SWB, Washington, DC); Hastings (WRD, PCA); Schaefer (SWB, ACA)

CONFERENCE OF DISTRICT ENGINEERS, SWB, PCA, AND
STAFF OFFICIALS, MENLO PARK, CALIFORNIA JUNE 4–7, 1963

Figure VII-6. Attendees at conference of SWB district engineers, PCA, Menlo Park, Calif., June 4–7, 1963.

Back row, left to right: Veatch, Leak, Bailey, Travis, Marsh, Moore, Lewis, Phillips
Hofmann, Peterson, Milliken, Littlefield, Hendricks, Throckmorton

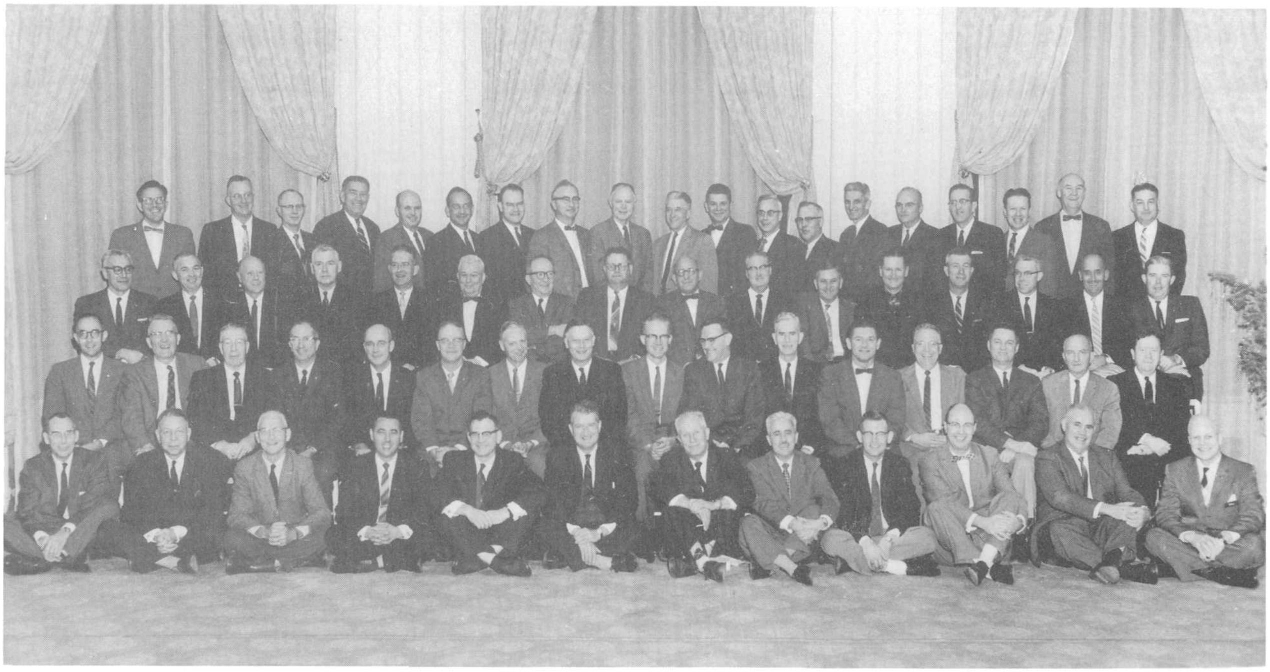
Front row, left to right: Miller, Carstens, Lord, Orem, Rantz, Piper, Williams;
Bill Dean attended, not in picture.

GENERAL HYDROLOGY BRANCH CONFERENCE
DENVER, COLORADO
FEBRUARY 24–27, 1958


Figure VII-7. Attendees at GHB conference, Denver, Colo., February 24–27, 1958.

Koberg; Hendricks; Peterson; Hadley; Melin; Benedict; Burkham; Schumm; Leppanen
Smith; King; McQueen; Brush, Jr.; Wolman; Oakland; Young; Kammerer; Magin, Jr.
Snyder; Coffay; Meier; Culler; Lichty; Kennon; Ferguson; Harbeck, Jr.; Daum; Savini
Sumsion; Parker; Van Lewen; MacKichan; McDonald; Cox; Hely; Waananen; Essex
Simons; Iorns; Olmsted; Lusby; Van Hylckama; Sigafoos; Miller; Branson

CONFERENCE OF DISTRICT ENGINEERS AND STAFF OFFICIALS
SURFACE WATER BRANCH
DALLAS, TEXAS
DECEMBER 12-14, 1960
UNITED STATES GEOLOGICAL SURVEY



Hofmann Yost Marsh Lewis Robinson Young Barrick LeFever Veatch Wilson Horton Hardison Crawford Stermitz Heckler Leeson Flynn A. Williams Dalrymple
Montgomery Cameron Carter Gambrell Cragwall Twitchell Lord Bolon Johnson Rice Leak Hendricks Fischback Travis Bogart Erskine
Carroon Phillips Miller Patterson Eaton Hansen Barron Schaefer Isherwood Molloy Knox Hale Bennion McCall Odell Mitchell
M. Williams Bell Saunders Ligner Sawyer Thomson Anderson Ash Hayes Dougherty Schrader Doll

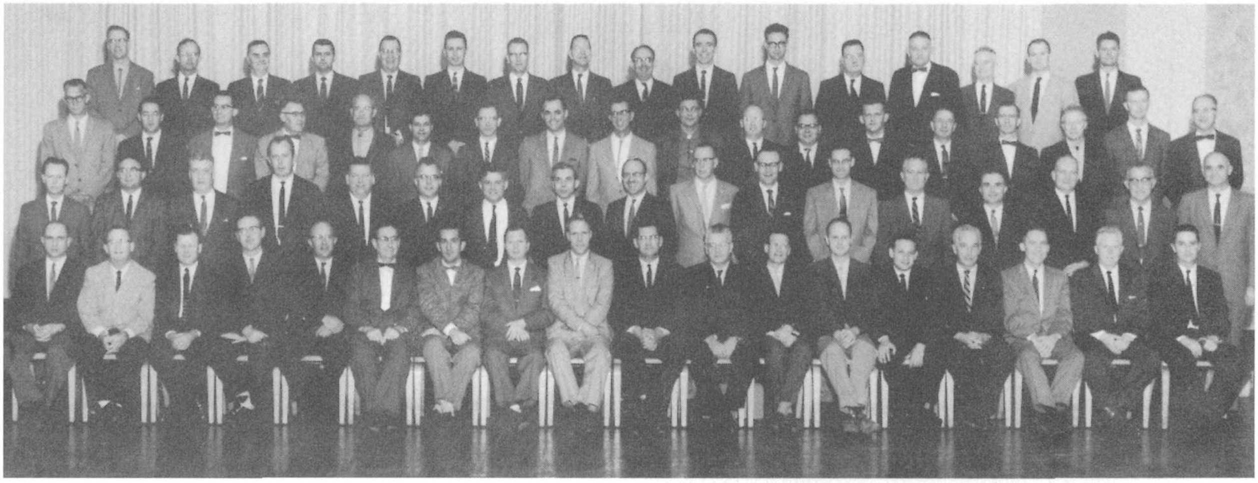
*Figure VII-8. Attendees at conference of SWB district engineers, Dallas, Tex., December 12–14, 1960.*

**CONFERENCE OF DISTRICT CHIEFS, GROUND WATER BRANCH**

**WATER RESOURCES DIVISION — U. S. GEOLOGICAL SURVEY**

NEW ORLEANS, LOUISIANA

February 12-14, 1962



Fourth row (left to right): Allen, Winslow, Barksdale, Sniegocki, Keech, Poole, Cushing, McLaughlin, De Buchananne, Callahan, Brown, R., Garrett, Reed, Lang, Baker and Weigle.

Third row (left to right): Davis, Ward, Conover, Babcock, McDonald, Foxworthy, Norris, Schneider, West, Stallman, Powell, W., Steinhilber, Moulder, Roberts, Hackett, Worts, Malmberg and Otton.

Second row (left to right): Berry, Meyer, G., Stuart, Brown, P., Siple, Johnson, Taylor, Rima, Kunkel, Snyder, Powell, J., Cushman, Barclay, Heath, Counts, La Rocque and Mundorff.

First row (left to right): Peterson, Turcan, Wilson, Holt, Meyer, R., Gordon, Arnow, King, Prescott, Lane, Fishel, Bradley, Waller, Deutsch, Payne, Thomasson, Drescher and Sinnott.

Missing from picture: Dennis, Leonard, Leopold, Upson.

Figure VII-9. Attendees at conference of GWB district chiefs, New Orleans, La., February 12–14, 1962.

CONFERENCE OF DISTRICT CHIEFS, GROUND WATER BRANCH

WATER RESOURCES DIVISION — U. S. GEOLOGICAL SURVEY

ATLANTA, GEORGIA

April 1 – 3, 1964

Figure VII-10. Attendees at conference of GWB district chiefs, Atlanta, Ga., April 1–3, 1964.

CONFERENCE OF GROUND WATER BRANCH ON THE HYDROLOGY OF VOLCANICS
BOISE, IDAHO
MAY 19–24, 1958

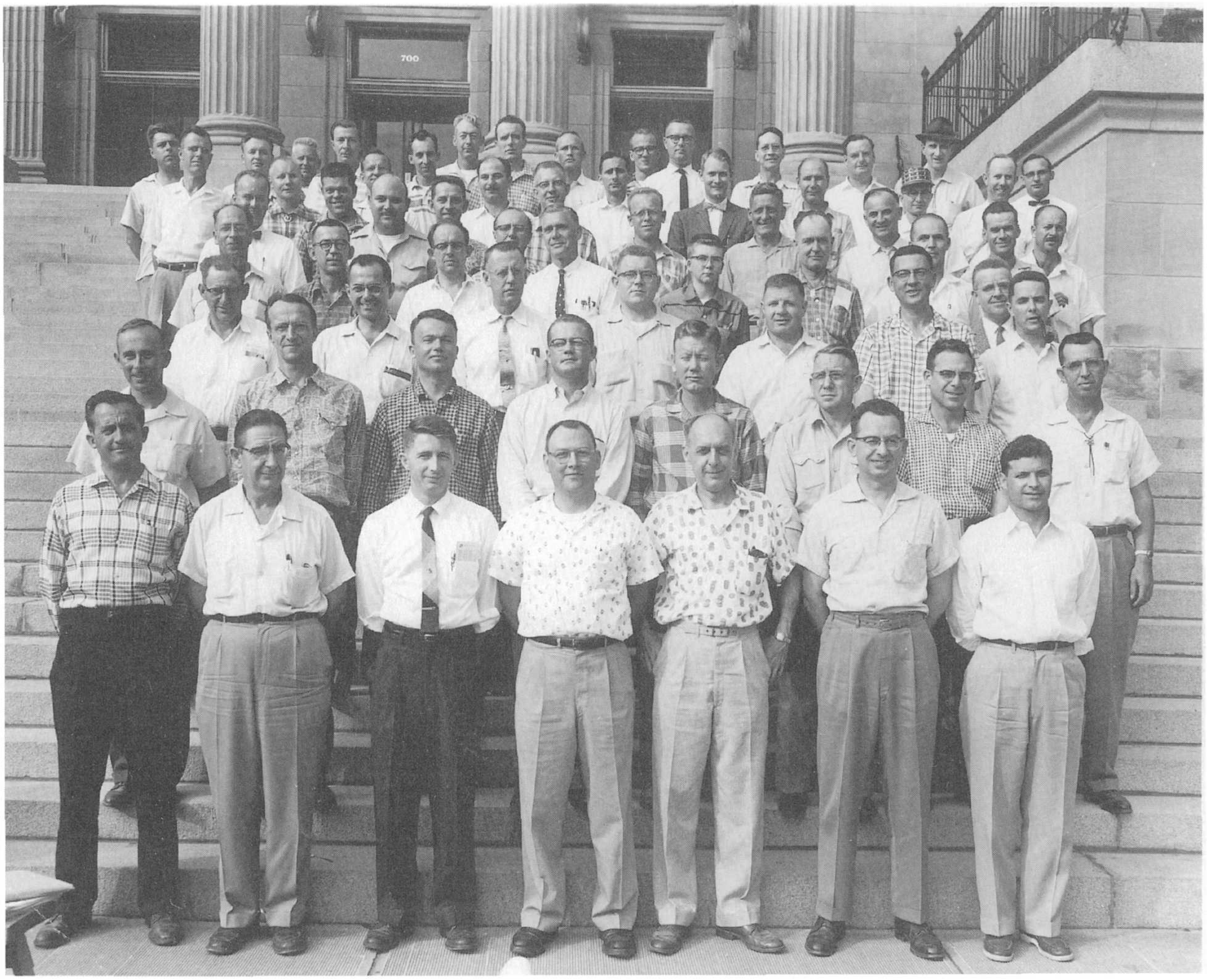
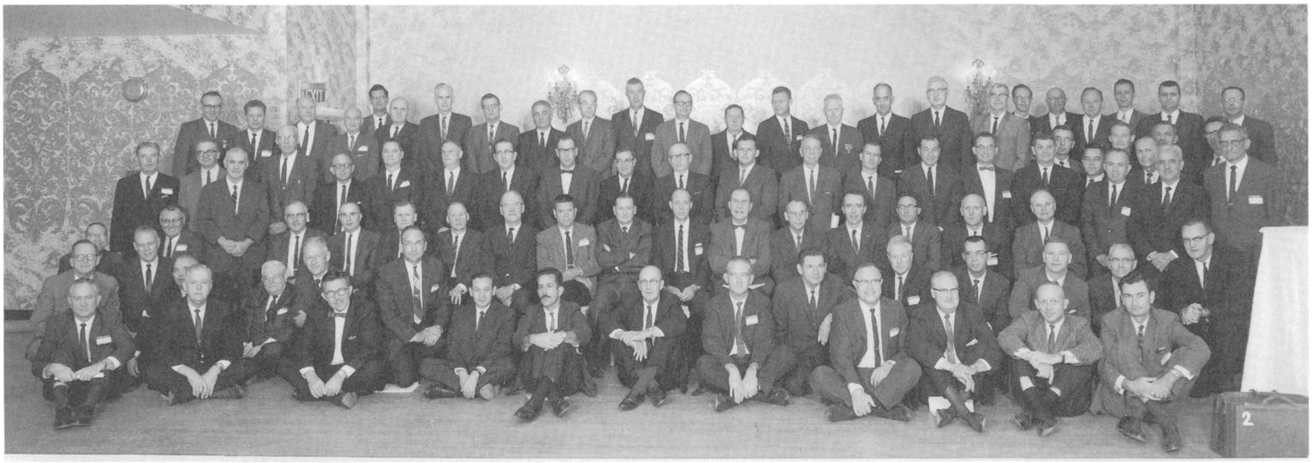


Figure VII-11. Attendees at GWB conference on hydrology of volcanics, Boise, Idaho, May 19–24, 1958.

Frank; Rhodehamel; Gale; Loeltz; Sceva; Crosthwaite; Callahan; Houston; Price; Voegeli; McLaughlin; Garrett; Carlston
Koniseski; Paulson; Young; McMurtrey; Kam; Stewart; Laird; Poland; Bierschenk; Smith; Walton
Peckman; Hogenson; Cosner; Morris; Clebsch; Feth; Mundorff; Heindl
Walker; Richardson; DeBuchananne; Brown, R.; Fowler; Hampton; Lohman; Waite; Walters
Nelson; Schneider; Snyder; Brown, S.; Lofgren; Evenson; Newcomb; Sinnott
Stevens; Swenson; Sumsion; Hadley; Akers; Schmalz; Wood; West
Whitcomb; Gordon; Bartholomew; Kilburn; Ferris; Conover; Foxworthy
(Johnson and Bennett not shown)



J.E. Powell
L.E. Young
R.W. Carter
J.W. Odell
C.W. Lane
W.H. Robinson
C.E. Knox
G.S. Hayes
A. Homyk
W.I. Travis
A.A. Fischback
E.J. Kennedy
W.D. Mitchell

M.M. Miller
W.J. Drescher
D.B. Bogart
J.W. Gambrell
W.L. Broadhurst
E.P. Patten, Jr.
R.R. Meyer
R.R. Bennett
J.L. Poole
R.T. Sniegocki
C.J. Robinove
H.M. Erskine
L.B. Coy

F.F. Schrader
C.V. Youngquist
A.E. Johnson
J.E. McCall
F.T. Schaefer
E.R. Leeson
J.W. Geurin
G.E. Harbeck
R.S. Lord
E.A. Moulder
F.M. Bell
O.M. Hackett
R.L. Nace

C.S. Conover
J. Horton
J.W. Wark
S.W. Wiitala
L.B. Laird
K.A. MacKichan
W.F. White, Jr.
D.M. Culbertson
A.D. Ash
R.F. Brown
J.H. Feth
H.M. Babcock
L.C. Crawford

R.C. Heath
H.D. Wilson
G.E. Ferguson
M.L. Mitchell
F.E. Clarke
E.L. Hendricks
R.H. Lyddan
W.W. Hastings
M.R. Williams
J.T. Callahan
G. Meyer
S.K. Jackson
W.H. Durum

H. Hulsing
T.G. McLaughlin
R.H. Tice
A.N. Cameron
L.A. Wiard
K.B. Young
G.F. Worts
S.W. West
L.E. Newcomb
H.C. Riggs
J.J. Molloy
J.E. Barclay
W.C. Griffin

T. Twichell
W. Hofmann
M. Deutsch
T. Arnow
W.R. Eaton
J.S. Cragwall
M.D. Hale
R.B. Sanderson
E.B. Rice
H.O. Wires
D.R. Dawdy

Figure VII-12. Attendees at WRD conference, Dayton, Ohio, November 2–3, 1965.

# PART VIII—WATER ISSUES AND EVENTS

Reviewed *by* George E. Ferguson

## Major National Issues

The years from 1957 through 1966 were a period of increasing awareness and public involvement in environmental matters and recognition of water as an indicator of environmental change. A ground swell of concern developed about stream and lake pollution and ground-water contamination from agricultural practices, mining operations, and from the disposal of industrial and municipal wastes.

At the same time, however, needs for more and more water-resources development to satisfy demands posed by economic growth persisted throughout the Nation. Water-quality and water-quantity objectives, frequently competitive between themselves, began to face still another contender—public demands for protection and preservation of natural-resource values, also usually involving the water resources. A national clamor for set-asides of wilderness areas, wild and scenic rivers, more national parks, and other natural-resource preserves stimulated new issues to confront both water-quantity and water-quality management. Water facts for public decision assumed new dimensions of needs and interests.

In the late 1950's, there was little Federal involvement in water-quality control except those regulations administered by the Public Health Service (PHS) of the Department of Health, Education, and Welfare (HEW) that were integral with its public-health responsibilities. Also early in this period of WRD history, plans were made and implemented for water-resources development projects by Federal agencies without adequate interagency coordination and without an effective and systematic means to accommodate input from State agencies that had vital interests in those developments. There were also jurisdictional disputes between agencies of the Federal Government over responsibilities within the field of water resources from collecting hydrologic data to abating pollution in major river systems. Accompanying those disputes was an absence of centralized authority and leadership at the national level in water planning and research. There was a perception of lack of coordination and duplication of effort in water-resources activities such as hydrologic research and data collection. Examples of specific issues that involved WRD during the period follow.

### Colorado River Salinity

A jurisdictional issue surfaced in 1962 that required 2 years, the President's Science Advisory Committee, and congressional intervention to quell. In 1962, the PHS began a 4-year study of Colorado River salinity problems under the project title, "The Colorado River Enforcement Project" and, according to the PHS, under the authorization contained in its 1945 Appropriation Act.

Circumstances that led the PHS into this venture were the Colorado River water-quality problems that justified WRD's Upper Colorado River Basin project (See Part IV, "Upper Colorado River Project") and President Kennedy's special message to Congress on February 23, 1961. In his message, the President proposed the establishment "of a special unit within the Public Health Service under the Department of Health, Education, and Welfare where control measures to prevent and limit pollution of our water will be developed."

Questions of program coordination followed the establishment of about 70 water-quality sampling sites by the PHS to supplement the extensive data-collecting program of USGS in the Colorado River Basin. An objective of the PHS project was to construct a model of the basin that would permit forecasts of water-quality changes in relation to other parameters including withdrawals by, and return flows from, water users, including irrigators. The PHS objective, the project title, and the history of developments in the basin created a perception by observers, including State water agencies, of a jurisdictional intrusion on BOR programs. For years, the BOR had been the builder and operator of the major water-resources projects in the basin.

In October 1964, a panel of the President's Science Advisory Committee was appointed to investigate the issues. Hearings were held during November in Washington; Salt Lake City, Utah; Denver, Colo.; and Phoenix, Ariz., that involved Luna Leopold, Roy Hendricks, Charles McDonald, Ken Love, and Hal Langford, and representatives of the BOR, PHS, and State water agencies within the basin. BOB Circular A–67, with its emphasis on water-data coordination, was new and was the subject of considerable interest by members of the panel. Leopold stated that the position of WRD, within the context of Circular A–67, was that of coordinating, not policing, data collecting. (See "Water Data Coordination, BOB Circular A–67.")

The conclusions of the panel, expressed in a letter of December 21, 1964, from Donald F. Hornig, Chairman of the President's Science Advisory Committee to Secretary, HEW, were as follows:

1. The HEW activities do not duplicate those of any other agency.
2. The HEW activities are technically sound.
3. The HEW program will yield results that are technically sound.
4. Termination of the study of (sic) this time would result in a loss of substantial Federal investment in the effort.

Newspapers reported that during the Phoenix hearings, Arizona Governor Paul Fannin and representatives of the State Land Department and the Interstate Streams Commission objected to the PHS program. They maintained that because of Interior's long experience and extensive activities in the basin, it could have done the job more effectively.

Opposition by Lawrence T. Sparks, Director, Colorado Water Conservation Board, was direct and his means, effective. Sparks took up the issue with the Colorado Congressional delegation to have the PHS funding for its "Colorado River Enforcement Project" removed from the bill providing HEW appropriations. The 1965 Appropriation Act of HEW contained the following provision:

> Except upon approval of the President's Science Advisory Committee, none of the funds herein appropriated shall be used to conduct****any program***in the field of salinity control or of irrigation water quality in the***Colorado River and its tributaries.

## Rocky Mountain Arsenal Waste Injections

In the late 1950's, pesticides at concentrations toxic to crops were found in water pumped from irrigation wells near the U.S. Army Rocky Mountain Arsenal near Denver. With the assistance of Paul C. Benedict, Russell H. Langford of Benedict's Lincoln, Nebr., staff was made available to study the problem. Using salinity measurements to trace the plume of contaminated water, the source was found and reported to the Army, which was pumping wastes into a 12,000-foot-deep well. The high static-head pressure at depth, augmented by the pumping pressure, resulted in rock fracturing, threatening contamination of water in the Fox Hills Sandstone, an important regional aquifer, and earth tremors that were felt throughout the Denver metropolitan area. Robert S. Stallman, John D. Bredehoeft, Marvin W. Skougstad, Leonard A. Wood, Robert Brennan, and others from WRD worked with Geologic Division staff to provide a quick report to the Army. Injection was discontinued and wastes were accumulated in lined pits, leaving the problem "in storage" and leading to its later classification as a Superfund cleanup site.

## Senate Select Committee on National Water Resources

(Much of the detail that follows is from the "History of the implementation of the recommendations of the Senate Select Committee on National Water Resources" by Theodore M. Shad and Elizabeth M. Boswell, published as a Committee Print of the Committee on Interior and Insular Affairs, 1968.)

Since the end of World War II, no less than eight major commissions or committees made studies of and recommendations on national water-resources policies. Neither President Truman's 1950 Water Resources Policy Commission report nor other reports dealing with national water-resources policy had resulted in congressional action. Most of the recommendations of the Senate Select Committee on National Water Resources were implemented by legislation within a few years after they were adopted.

Senate Resolution (SR) 48, effective April 20, 1959, established a Select Committee (Senator Robert S. Kerr of Oklahoma as Chairman) to study the development and coordination of the water resources of the Nation. The Geological Survey was early advised that it would be asked to supply material to the Committee describing the availability, use, and problems associated with water. A work group in WRD was formed to develop narrative and exhibit material needed by the Committee. Luna Leopold made the first presentation before the Committee on July 9, 1959. By March 1960, five Committee Prints were available containing information provided by WRD. They were Committee Prints No. 1, Water Facts and Problems; No. 3, National Water Resources and Problems; No. 4, Surface-Water Resources of the United States; No. 19, Water Resources of Alaska; and No. 20, Water Resources of Hawaii.

Committee Print No. 29, Report of the Select Committee on National Water Resources, 1961, acknowledged the assistance given to the Committee by David D. Harris, Walter B. Langbein, Luna B. Leopold, Glennon N. Mesnier, Kenneth A. MacKichan, Roy E. Oltman, Frank H. Rainwater, Herman A. Ray, Thomas W. Robinson, and Horace G. Thomasson.

The Committee soon focused on needs for improved coordination of and Federal assistance in water-resources planning and research and made four recommendations, the first, second, and fourth of which were on planning. Those three recommendations were incorporated into the Water-Resources Planning Act of 1965. The Committee's third recommendation was on water-resources research and was accommodated in the Water-Resources Research Act of 1964. The two acts and their impacts on the Division are discussed below.

The Committee's fifth recommendation was to reduce flood losses by regulating flood-plain use and delineating flood-hazard areas. Congress took action on the use of flood plains even before the Committee report was completed. Section 206 of the Flood Control Act, approved July 14, 1960, authorized the Chief of Engineers to compile and disseminate information on flood hazards at the request of State or responsible local government agencies. (See Part IV, "Flood Inundation Mapping.")

## Water-Resources Research Act of 1964 (Public Law 88–379)

The third recommendation of the Committee was that the Federal Government undertake a coordinated, scientific research program on water, aimed at increasing available water supplies and making more efficient use of existing supplies. It recommended expanding basic-research programs; developing a more balanced and better constructed program of applied research for increasing water supplies; expanding the programs of applied research for water conservation and making better use of existing supplies; and evaluating completed water-resources development projects to make them more effective in meeting changing needs and developing improved guidelines for future projects. The Committee suggested that the Executive Branch develop a coordinated research program, based in part on a review of ongoing research, and submit it to Congress in January 1962 so it could be considered with the FY 1963 budget.

President Kennedy delivered his natural-resources message to Congress on February 23, 1961. He said that he had asked for reports on the status and recommendations on natural-resources research from the National Academy of Sciences and from the Federal Council for Science and Technology. Before their reports were completed, however, the President's budget for 1963 was submitted to Congress containing a proposal to establish an Institute of Water Research in the Geological Survey. The proposal was deleted by the House Committee on Appropriations "because it was felt that inadequate time had been spent in developing the expanded program and in determining how it should be coordinated with the work of other Federal water-related agencies."

Senator Clinton P. Anderson, who had served on the Select Committee and was Chairman of the Interior Affairs Committee, introduced a bill on July 27, 1962, to establish and fund a system of water-resources institutes at land-grant universities. No action was taken on the Anderson Bill during that session; however, after he reintroduced the bill on January 14, 1963, it became law on July 17, 1964. The Anderson Bill vested responsibility for administering the program and for managing the allotment of funds by "grants, contracts, matching or other arrangements with educational institutes (other than the established institutes as defined elsewhere in the Act), private firms or individuals and with [other] government agencies***" with the Secretary of the Interior.

There is nothing in the record that describes the sequence of events in Interior or in the Geological Survey immediately after passage of the Anderson Bill. Assistant Director Lyddan recalled that Director Nolan turned down the Secretary's offer to house the new research organization in the Geological Survey. Nolan was evidently loath to take on a program that involved contracts and grants and that might, through financial relationships with universities, subject the Survey to political influences.

After Nolan rejected the Secretary's proposal, several senior members of WRD petitioned Nolan, by memorandum, to reconsider, arguing that management and funding of water-resources research external to the Survey would likely create competition for the support the Division had sought in its quest for an Institute of Water Research only 2 years earlier. Their arguments were effective and Nolan relented, but too late. The decision had been made to establish and staff an Office of Water Resources Research (OWRR) as an independent unit in Interior, reporting directly to the Secretary.

The establishment of OWRR and its need for staff created new problems for the Division. In notes to C. Lee McGuinness (who had served on a temporary detail to OWRR), Raymond N. Nace, O. Milton Hackett, G. Earl Harbeck, and Harold E. Thomas in November 1964, Leopold said he expected them to be contacted for positions in OWRR, two of which were at the GS–16 grade. Thomas' reply to Leopold was that it would in the best interests of the Division if "two of our best" were assigned to OWRR, but he ended his reply saying, "But, its gotta be somebody else, not me!"

More than "two of our best" did transfer to OWRR. Roy E. Oltman was the first, followed by Luther C. Davis and Herbert A. Swenson and later, by Robert Schneider.

Guidelines were prepared regarding working relationships with the State institutes and OWRR. The

GHB was designated to review research proposals from OWRR and it was suggested that WRD field officials serve on advisory committees to institutes, if requested. Many District Chiefs did serve.

A system for governmentwide dissemination of scientific information on water research was established within OWRR that later became the Water Resources Scientific Information Center.

## Water Resources Planning Act of 1965 (Public Law 89–80)

Approval by the President of the Water Resources Planning Act on July 22, 1965, was the culmination of years of debate, testimony, and legislation relative to river-basin planning. As pointed out by Schad and Boswell in their "History of the Implementation of the Recommendations of the Select Committee on Natural Resources," 1968, "The recommendations of the select committee fell on a seedbed nurtured by decades of discussion and experimentation." Among the significant activities that preceded the Water Resources Planning Act of 1965 were the four-party Federal Interagency River Basin Committee (FIARBC), called "Firebrick," under whose auspices were formed interagency field committees in the Missouri River and Columbia River Basins and river-basin planning committees for the Arkansas-White-Red Basin, the New England-New York Basin, and the Delaware River Basin. Also in the seedbed were legislative acts in 1958 that established the Texas Basins and the Southeast Basin Study Commissions and the Water Resources Planning Acts of 1961 and 1963.

The Water Resources Planning Act of 1965 accommodated the first, second, and fourth recommendations of the Select Committee. The first recommendation of the Select Committee called for the Federal Government, in cooperation with the States, to prepare and keep up-to-date plans for comprehensive water development and management of all the major river basins of the United States. The second recommendation was that States participate in the planning process, aided by Federal grants. The fourth recommendation was that a periodic assessment of water-supply-demand relationships be made biennially for water-resources regions and submitted to Congress by the Executive Branch, beginning in January 1963.

The Water-Resources Planning Act of 1965 authorized the creation of the Water Resources Council made up of the Secretaries of the Interior; Army; Agriculture; Health, Education, and Welfare; and the Chairman of the Federal Power Commission. It authorized establishing river-basin commissions in each major basin but exempted the Columbia River Basin in recognition of the long-standing and effective activities of the Columbia River Basin Interagency Committee that were directed toward similar goals. It divided the Colorado River Basin into two basins, above and below Lees Ferry, in deference to the division of water-management and interstate agreements at Lees Ferry.

## Water Resources Council

Title I of Public Law 89–80 created the Water Resources Council (WRC), which was made up of the Secretaries of the Departments of the Interior; Army; Agriculture; Health, Education, and Welfare; and Transportation, and the Chairman of the Federal Power Commission. The first Chairman of the Council was Secretary Udall, DOI, and its first Director was Henry M. Caulfield, former head of Secretary Udall's Resources Program Staff.

The WRC was charged to provide periodic assessments of the Nation's water resources; coordinate river-basin planning among the Federal agencies; provide oversight of the Federal-State river-basin commissions; and provide financial assistance to the States in developing comprehensive water- and related land-resources plans.

### National Assessment

Section 102 of the Water Resources Planning Act required the WRC to maintain a continuing study and to prepare biennially, or at less frequent intervals as the Council may determine, an assessment of the adequacy of supplies of water necessary to meet the requirements of each water-resource region in the United States.

Planning the first national assessment began almost immediately after the Council was organized with assistance from Douglas R. Woodward of the Director's Office, formerly of WRD, Garald G. Parker, Sr., and William J. Schneider. Clayton H. Hardison supervised assembling data on natural runoff; C. Richard Murray provided water-use data; and Rodney Hart and Clarence W. Anderson did the preliminary drafting for the first assessment report. Those from WRD who contributed to Part 3, Chapter 2, "The Water Resource" were Henry C. Barksdale, A. Rice Green, Clayton H. Hardison, Francis A. Kohout, S. Kenneth Love, Gerald Meyer, and William J. Schneider. Herbert H. Swenson helped write Part 5, Chapter 1, "Domestic and Municipal Uses"; William J. Schneider, Part 5, Chapter 2, "Floods and Flood Damage"; S. Kenneth Love, Part 6, Chapter 3, "Water Quality"; Albert N. Cameron and

Medford T. Thomson, Part 6, Chapter 2, "South Atlantic-Gulf Region"; William J. Drescher, Part 6, Chapters 3 and 6, "Great Lakes and Upper Mississippi Region"; Malcolm D. Hale, Part 6, Chapter 4, "Ohio Region"; William H. Robinson, Part 6, Chapter 7, "Lower Mississippi Region"; Harlan M. Erskine and Quentin F. Paulson, Part 6, Chapter 8, "Souris-Red-Rainy Region"; G. Lawrence Bodhaine, Part 6, Chapter 16, "Columbia-North Pacific Basin"; and Mearle M. Miller, Part 6, Chapter 19, "Hawaii Region."

The first national assessment, "The Nation's Water Resources" was transmitted to the President on November 1, 1968, by WRC Chairman Udall. It was to be another decade before the second national assessment was released.

## Other Legislation

Congress enacted other legislation during this period of WRD history that strongly reflected the Nation's environmental concerns, including the Wilderness Act, the Wild and Scenic Rivers Act, and the Water Quality Act of 1965. The Wilderness and Wild and Scenic Rivers Acts had little impact on WRD programs. The Water Quality Act of 1965 required State agencies to establish water-quality standards for interstate streams and that had to be done within the context of existing conditions of quality. Therefore, many State agencies turned to the local WRD or QWB District for assistance. After the Federal Water Pollution Control Administration was placed in DOI in 1966, WRD staff at Headquarters became heavily involved with that new agency.

The Appalachian Regional Development Act of 1964 took over the regional planning functions of the Appalachian Regional Commission that was established in 1963. The Commission was to plan the economic recovery of Appalachia by utilizing its natural resources. Using funds made available through the Commission or its successor, WRD began studies of the water resources of Appalachia. USGS Circ. 526, "Stream quality in Appalachia as related to coal-mine drainage," by J.E. Biesecker and J.R. George, and Hydrologic Atlas 198, "Water resources of the Appalachian region, Pennsylvania to Alabama," by W.J. Schneider and others, were published in 1965 to aid the planning effort.

## Interagency Committees and Commissions

For decades prior to the enactment of the Water Resources Planning Act, various solutions to problems of coordinating had been tested ranging from the Tennessee Valley Authority Act of 1933, which placed water-resources planning and development for a basin in one independent agency, to the Pick-Sloan Plan in 1944, which authorized development of the Missouri River Basin and divided the work between the U.S. Army Corps of Engineers and the BOR.

In Washington, an agreement on water-resources development between the Army Chief of Engineers, the Commissioner of Reclamation, and the Land-Use Coordinator of the Department of Agriculture was in effect for a few years. It gave way in 1943 to the four-party Federal Interagency River Basin Committee (FIARBC or "Firebrick") with the addition of the National Resources Planning Board of the Executive Office of the President.

Field interagency committees and national technical subcommittees were formed soon after the end of World War II under the auspices of FIARBC to coordinate planning and to pool Federal-agency expertise and experience for the solution of regional technical problems. No States or local agencies were involved in the FIARBC interagency committees. In the mid-1950's, FIARBC evolved into the Interagency Committee on Water Resources (ICWR) and "Firebrick" became "Icewater" in the vernacular of its participants. Its functions were assumed by WRC in 1966.

### Subcommittee on Hydrology

Based on material provided *by* Bruce Parks

The Subcommittee on Hydrology met regularly, usually bimonthly, through 1966 and beyond, as it had since its first meeting in October 1945. Agency members included the Departments of Agriculture; Army; Commerce; Health, Education and Welfare; and Interior; the Federal Power Commission; and the Tennessee Valley Authority. WRD continued as Interior's representative throughout this period of history and BOR was alternate. Adrian H. Williams and Elwood R. Leeson chaired the Subcommittee during most of the years 1957 through 1966. Albert N.Cameron was Secretary when Williams was Chairman and Wallace T. Miller was Secretary when Leeson chaired the Subcommittee.

Standing and temporary work groups of the Subcommittee were water quality, hydrologic stations and networks, water-use data, radio frequencies, river-basin maps, bibliography on hydrology and sedimentation, basic data coordination, ground water, hydrologic data for Alaska, flow frequency analysis, and river-mile determinations.

S. Kenneth Love led the Water Quality Work Group during this period of history, assisted at times by Sumner G. Heidel, Felix H. Pauszek, Herbert A. Swenson, and Thomas H. Woodard. WSP 1786 (1964) was a product of the work group.

Robert M. Beall chaired the work group that prepared a revised nationwide edition of "River basin maps showing hydrologic stations." John E. McCall was also involved in that effort.

Henry C. Riggs, with members from other agencies, prepared WSP 1546 (1962), "Annotated bibliography of hydrology and sedimentation, United States and Canada, 1955–58." That publication was followed by similar bulletins published by the Subcommittee, with assistance from WRD.

The Work Group on Hydrologic Data for Alaska provided oversight to the Interagency Technical Committee for Alaska beginning in 1963. Marvin J. Slaughter, the first Committee chairman, also served on a subcommittee for stream-gaging programs. Melvin V. Marcher and Robert G. Schupp chaired subcommittees on ground-water and quality-of-water programs. Slaughter, Marcher, and Schupp helped write the "Ten-year comprehensive plan for collection of basic climatologic and hydrologic data for Alaska," published in 1964.

Coordinating hydrologic-data collection, a matter of much interest to the Subcommittee, received renewed attention with the issuance of BOB Circular A–67 and the establishment of OWDC. George E. Ferguson, O. Milton Hackett, James R. Jones, and William W. Doyel appeared before the Subcommittee in 1965 and 1966 to explain functions and plans of OWDC.

In early 1962, a ground-water work group within the Subcommittee chaired by Joseph T. Callahan, then by Gerald Meyer, began inventorying ground-water activities of Federal agencies. Their work was published in 1966 as Bulletin 12, "Federal sources of ground-water data."

Manuel A. Benson served on the Flow Frequency Work Group from its beginning in late 1963 and was a key member in compiling methods of flow-frequency methods used by member agencies. A Subcommittee report on flow-frequency methods was published in 1966.

A temporary work group on standards for river-mile determinations was formed in mid-1965 with Conrad D. Bue as chairman, and its work was underway in mid-1966.

Others from WRD who assisted the Subcommittee or appeared as speakers at Subcommittee meetings during the years 1957 through 1966 include Roy B. Sanderson, Walter B. Langbein, William L. Isherwood, Francis J. Flynn, Luna B. Leopold, James F. Wilson, C. Lee McGuinness, James R. Randolph, Louis P. Denis, Solomon M. Lang, Harry H. Barnes, Charles R. Showen, George W. Whetstone, Herbert T. Hopkins, and Charles J. Robinove.

### Subcommittee on Sedimentation

Based on material provided *by* Douglas G. Glysson

The Subcommittee on Sedimentation shared a common ICWR background with and was organized and functioned much like the Subcommittee on Hydrology. Its agency membership was the same. BOR was Interior's representative on the Subcommittee and WRD, the alternate. Raymond B. Vice regularly attended the bimonthly meetings; S. Kenneth Love attended occasionally. Roy E. Oltman attended the meeting in December 1964 and told of the Amazon River measurements by the Survey. In December 1965, George B. Magin of AEC (formerly of WRD) spoke to the Subcommittee about the development of the nuclear sedimentation gage.

A major function of the Subcommittee was overseeing (through its Technical Committee) the Federal Interagency Sedimentation Project at the St. Anthony Falls Hydraulics Laboratory, Minneapolis, Minn. (See Part IV, "Geomorphic and Sediment Processes.")

The Subcommittee published Bulletin 6, "Summary of reservoir sedimentation surveys made in the United States through 1953," in April 1957. In the early years of this period, 1957–66, effort continued to correct and update the data in Bulletin 6. Also on behalf of the Subcommittee, WRD updated Bulletin 4, "Inventory of published and unpublished sediment load data in the United States, 1946 to 1950," through 1960 and published the work as WSP 1547 by Kay F. Harris (1962).

The Subcommittee continued to publish annually throughout the period its report, "Notes on sedimentation activities," a summary of member agencies' work in sedimentation.

The Sedimentation Subcommittee sponsored a Federal interagency conference on sedimentation in Jackson, Miss., in 1963, and published the proceedings in June 1965 (USDA—misc. pub. 70).

In May 1965, the Subcommittee met with the Technical Committee in Chattanooga, Tenn. WRD was represented by Benedict, Brynon C. Colby, and Vice. In April 1966, Skinner reported on progress, problems, and plans for the St. Anthony Falls Project.

In 1966, the Subcommittee was updating its Reservoir Sedimentation Summary Data Report for the years 1954–60.

## Field Committees and Commissions

In the mid-1960's, several interagency committees began preparing comprehensive river-basin plans. Those in the Missouri River Basin and the Southeast River Basins were well underway by June 1966.

The Pacific Southwest Interagency Committee (PSIAC) chose a role for itself that closely resembled that of ICWR. Its Subcommittee on Sediment developed a technique for estimating sediment yield from arid lands in the Southwestern United States that became widely used. The PSIAC also sponsored a Subcommittee on Phreatophytes. In 1958, Thomas A. Robinson, Menlo Park, Calif., chaired the Phreatophyte Subcommittee's task force on research and coordination.

In 1958, the Texas Basins Study Commission and the Southeast Basins Study Commission were formed (see Part X, "Georgia"). They were soon followed by Federal interagency coordinating committees in the Arkansas-White-Red River, New York-New England, Delaware, and Potomac River Basins.

With increasing attention being given to river-basin planning and all based on a common foundation of water and related land resources, Director Nolan established guidelines for Survey participation. In a June 21, 1963, memo to Division Chiefs and Survey Field Committee representatives, Nolan accurately predicted that costs of the contemplated planning would preclude new field studies and that the Survey role would be in the summarization, synthesis, and analysis of existing information. The Director's advice was reiterated in WRD memorandum 65.2, more emphatically stating that WRD contributions to river-basin planning must be based on presently available data bearing on the occurrence, distribution, availability, and quantities of the water resource and the environmental framework of the hydrologic system. The preparation of comprehensive plans involved WRD staff in regional and district offices. Particularly noteworthy were the WRD contributions to the plans for the Southeast River Basins and, very late in this period of WRD history, in the Missouri River Basin.

## Water-Data Coordination (Bureau of Budget Circular A–67)

The BOB issued Circular A–67 on August 28, 1964, assigning to DOI the responsibility for coordinating Federal activities in acquiring data on streams, lakes, reservoirs, estuaries, and ground water; to develop a national plan to acquire those data; and to maintain a central catalog of information on the national network and specialized water data and on Federal activities being planned or conducted to acquire such data. DOI, in turn, assigned the responsibilities of A–67 through the Assistant Secretary for Minerals to the Geological Survey.

Circular A–67 stemmed from a perception by the BOB of a lack of coordination among the growing number of Federal agencies that had legitimate jurisdictional interests in water resources and of duplication of effort among those agencies in acquiring data. The strong and cogent case made for designed networks of water-data acquisition systems by Langbein and Hoyt in their book, "Water Facts for the Nation's Future," published in 1959 influenced the BOB circular.

Leopold called on Medford T. Thomson, then on George E. Ferguson, to apply their organizational skills and program knowledge to the task of getting A–67 underway, pending selection of a permanent staff. Ferguson had as his assistant for this temporary assignment George W. Whetstone District Chemist, QWB, Columbus, Ohio. By late September 1964, an implementation plan had been prepared that called for an Office of Water Data Coordination (OWDC) in WRD. OWDC was to be organized into units to provide network planning and operations evaluation, program analysis, and information dissemination. The plan also proposed the formation of a Federal Interagency Advisory Committee on Water Data and an Advisory Committee on Water Data for Public Use (the latter referred to for brevity, as the Non-Federal Advisory Committee).

The first meeting of the Federal Advisory Committee was held October 9, 1964, in Washington. Director Nolan chaired the meeting, staff work for which was done by Ferguson and Whetstone. Representatives of nearly 30 agencies participated, offered numerous comments, confirmed support, and voiced no objections to the plan for implementation of A–67.

In a December 23, 1964, memo to District Chiefs, Leopold announced the selection of O. Milton Hackett, then Chief, GWB, as Chief, OWDC, and of Whetstone as Assistant Chief. He also announced that the first meeting of the Non-Federal Advisory Committee would be held in the spring. Hackett was formally installed as Chief, OWDC, on January 3, 1965.

The first meeting of the Non-Federal Advisory Committee did not go well. Hackett recalled later that the meeting, organized and chaired by Leopold, was a "dog and pony show" that did not offer adequate opportunity for the advisors to express themselves. Several called Hackett after the meeting to voice their dissatisfaction. The next meeting was chaired by Director Pecora, whose philosophy was to give the advisors free rein to voice their views. This and subsequent meetings were increasingly productive.

The OWDC and its staff, most of whom were serving as detailees during much of 1965, were immediately faced with the vexing problem of network design, indeed, of an acceptable definition of networks. About a year elapsed before a rationale as an approach to network planning was accepted, if not universally embraced. The rationale, advanced by Harold E. Thomas, was based on three levels of information. At considerable risk of oversimplification, level I would provide a water-resources data base for broad national planning, level II would meet the needs for water-resources planning within a subregion, commonly a river basin, and level III would meet the data needs of management. This approach met with less than enthusiastic response within WRD. Surface-water network design based on geographic coverage and accuracy objectives was already in place, and ground-water hydrologists resisted any concept of hydrologic data-collection networks as applicable to ground-water studies.

Other policy and operational matters that were given immediate attention were to (1) establish a catalog system to make available and furnish on request the source of data or data compilations available in the national network, and information on source and availability of data not in the national network; and (2) establish a system to examine current and proposed data-acquisition programs for use of all Federal agencies in relating their programs to the national-network plan and in justifying agency budgets for such programs.

According to the January 1, 1966, Organization and Personnel Directory, the OWDC staff consisted of O. Milton Hackett, Chief; George W. Whetstone; Herbert G. Stewart; Helen H. Moore; and Joan A. Madar. Others who joined the staff by mid-1966 were William W. Doyel, Kay F. Harris, Russell H. Langford, Alvin F. Pendleton, John C. Rapp, and John A. Shanton. By June 30, 1966, most of the 10 professional positions in OWDC's table of organization had been filled and OWDC was housed in Room 1000, 801 19th Street, N.W., a few blocks north of the Survey's headquarters building. Inventory forms, overlay maps, and procedures for the compilation of the first catalog were available.

## Compacts, Treaties, and Court Adjudication

By June 30, 1966, nearly 50 interstate compacts, adjudications, and international treaties were in effect and others were being negotiated on June 30, 1966. Most involved WRD.

### Interstate Compacts

[John C. Kammerer supplied many details on interstate compacts. Some of the following material is from two publications, both of which are titled "Documents on the use and control of the waters of interstate and international streams," 1956 and 1968, by T. Richard Witmer. The 1956 edition was a publication of DOI, and that of 1968 was published as House Document No. 319, 90th Congress, 2d Session.]

*Arkansas River.* (Colorado and Kansas) Carl G. Paulsen, appointed chairman and Federal representative in August 1957, served until his death in 1961. He was succeeded by Francis M. Bell, who served until 1967. Compacts between Kansas and Oklahoma and between Oklahoma and Arkansas were under negotiation in May 1959 with Trigg Twichell serving as Federal representative on both. John R. Erickson, WAE in the Santa Fe, N. Mex., SWB District office was consultant to Twichell. The compact between Kansas and Oklahoma was ratified by each State and approved by Congress in November 1966. Twichell was appointed Federal Commissioner in March 1967. The proposed compact between Oklahoma and Arkansas had not been perfected by June 30, 1966.

*Bear River.* (Utah, Wyoming, and Idaho) [From information supplied by Wallace T. Jibson.] The Bear River Compact was approved by Congress in 1958. Prior to its approval, W. Vaughn Iorns served as Chairman of the negotiating commission's Engineering Committee. He was succeeded by Wallace T. Jibson, who served the Commission as administrative officer, then as Federal representative and Chairman of the Commission. Jibson headed the SWB field office, later the WRD project office, in Logan, Utah.

*Columbia River.* (Idaho, Montana, Nevada, Oregon, Utah, Washington, and Wyoming) Thomas R. Newell, the Federal representative in negotiations to create a compact, was appointed in May 1955, retired as District Engineer, SWB, Boise, Idaho, in October 1955, and was still serving the compact negotiating committee on June 30, 1966.

*Klamath River.* (Oregon and California) As of March 1960, Kenneth N. Phillips, District Engineer, SWB, Portland, Oreg., was Federal representative. Although he retired in 1962, he continued to serve through June 30, 1966.

*Niobrara River.* (Nebraska, Wyoming, and South Dakota) According to a WRD headquarters compilation of compacts and compact administrators dated March 22, 1960, Henry C. Beckman, former

Regional Hydrologist, MCA, was "USGS Coordinator" for the compact. The proposed compact was not approved by June 30, 1966.

Pecos River. (New Mexico and Texas) Berkley Johnson, District Engineer, SWB, Santa Fe, N. Mex., was the Federal representative on the group that negotiated the compact which became effective December 3, 1948. Johnson continued as the Federal Representative through June 30, 1966.

Red River and tributaries. (Arkansas, Oklahoma, Louisiana, and Texas) The compact was being negotiated in May 1959 with Henry C. Beckman as Federal representative and chairman. The compact was not perfected by June 30, 1966.

Rio Grande. (Colorado, New Mexico, and Texas) Berkley Johnson was chairman and Federal representative through June 30, 1966.

Sabine River. (Louisiana and Texas) S. Keith Jackson was chairman and Federal representative through June 30, 1966.

Yellowstone River. (Wyoming and Montana) Frank Stermitz, District Engineer, SWB, Helena, Mont., was Federal representative and chairman of the Commission until 1966, when he was succeeded by Harlan M. Erskine, District Chief, WRD, Bismarck, N. Dak.

### International Treaties

### (See Part IV, "International Programs")

Columbia River. The Columbia River Basin Cooperative Development Treaty between the United States and Canada became effective January 17, 1961. Its approval followed years of work by the International Engineering Committee on which Carl G. Paulsen was the U.S. representative and Fred M. Veatch, alternate. According to Charles C. McDonald (written commun. to Hudson, March 1989) the Engineering Committee was served by a "Working Group" of which McDonald was a member, assisted at times by Henry C. Riggs, G. Lawrence Bodhaine and Wilbur D. Simons.

Souris-Red Rivers. During 1959 and 1960, Charles C. McDonald was a member of the International Souris-Red Rivers Engineering Board of the International Joint Commission (IJC). He was succeeded in August 1960 by Ernest L. Hendricks. As of June 30, 1966, the proposed treaty had not been perfected.

Pembina River. McDonald, followed in June 1960 by Hendricks, served on the Pembina River Engineering Board of the IJC. No treaty had been perfected by June 30, 1966.

Poplar River. (From information provided by George M. Pike and Robert C. Averett.) Plans by Canadian power authorities to build a large coal-fired powerplant in the Poplar River Basin near the Montana boundary led to preparing a joint U.S.-Canadian environmental impact assessment under the aegis of IJC. Preparing the assessment began before June 30, 1966. George M. Pike, District Engineer, SWB, Montana, was the principal U.S. contact at field level.

St. Johns River. McDonald served as member and chairman of the St. Johns River Engineering Board until in August 1960 when he was succeeded by Hendricks. The treaty was not perfected as of June 30, 1966.

St. Mary and Milk Rivers. (From information provided orally by George M. Pike) Luna B. Leopold, as were all previous Division Chiefs, was the ex officio Accredited Officer for the United States in measuring and apportioning the flows of the St. Mary and Milk Rivers between the United States and Canada. This function became a responsibility of the Division Chief (or organizational equivalent) in 1907 when the Reclamation Service was separated from the Survey. (See Part IV, "International program")

### Court Adjudication—Delaware River Master

[Condensed from material provided *by* Robert E. Fish *and* reviewed *by* Francis T. Schaefer *and* George W. Edelen. Beverly Roberts assembled much of the background information.]

Carl G. Paulsen was the first Delaware River Master. (See Volume V, page 55, for an account of the early history and functions of the Delaware River Master.) He was appointed in 1954 and served until his death in January 1961. He was succeeded by Joseph V.B. Wells, whose appointment was effective May 7, 1961. Wells served through June 1966 and beyond. Although Paulsen and Wells remained headquartered with WRD in Washington, field operations supporting the court decree were from the Office of the Delaware River Master in Milford, Penn.

The Office of the River Master remained on Broad Street in Milford during the period from 1957 through 1966. W. Vaughn Iorns was engineer-in-charge until January 1958 when he was transferred to Salt Lake City, Utah. Robert E. Fish arrived from SWB, Raleigh, N.C., in May, 1958, as Iorns' successor and remained through 1966 and beyond as Deputy Delaware River Master. Other members of the Milford staff were engineering assistants Walter R. Scott, from 1955 to 1960; Bernard Dunn, from 1960 to 1962; and Patrick N. Walker, from 1962 to 1966. Walter E.

Hendrian entered on duty in 1958 and served through 1966 and beyond as a technician. Pauline L. Hendershott was secretary from 1957 through 1966.

The cost of maintaining the staff and operations of the Milford operations was $36,000 in FY 1957 and increased about $2,000 per year to $57,000 in FY 1966. Costs were borne equally by the States of Delaware, New Jersey, and Pennsylvania and the city of New York.

Operations of the Office of the River Master were dominated by droughts since the office was established. Severe droughts occurred in the Delaware River Basin in 1955, 1957, and from 1961 through 1966. During the droughts of 1957 and during the years 1961 to 1966, the terms of the decree could not be fully met. The drought that lasted from 1961 to 1966 is especially noteworthy because of its length and severity.

Reports were made at least annually to the Court, governors of the States, and the mayor of New York City. Monthly reports were sent to the parties and weekly reports were available to interested persons. With the annual report for 1962, a section was included on the municipal use of water throughout the basin.

During the 1957 drought, large releases almost emptied the reservoirs. Reservoir releases and other flows did not meet the specified flows of the Montague Formula on many days June to November. Shortages were considered extremely serious by the parties to the decree from the lower part of the basin, and they questioned the efficacy of the decree. However, with flow increases in December and in the next years, tension eased.

The year 1961 began with very low temperatures and above-normal snow cover. Reservoir releases during the winter were required for the first time and transit time increased by as much as 24 hours because the thick ice impeded the flow. Pepacton and Neversink Reservoirs filled by April and normal conditions followed for several months. Precipitation was much below average in September and October, which marked the beginning of the lengthy, severe drought of 1961 to 1966. The drought was moderate to severe in the northeast part of the United States and was worst over the upper Delaware River Basin. Runoff during 4 months in 1964 was the lowest in 60 years.

Through a plan suggested by Maurice Goddard and John C. Thompson, Pennsylvania and New York representatives of the River Master Advisory Committee, and programmed by Pennsylvania Power & Light Company in collaboration with the River Master in 1961, releases were to be made from Wallenpaupack Reservoir on some weekends to assist in maintaining the minimum specified rate of flow at the Montague gaging station. This plan was followed for several years and was helpful at times of other unavoidable restrictions in meeting flow requirements. Later, Orange and Rockland Utilities, Inc., aided by providing improved forecasts of discharges from its powerplant. New York City pumped from Croton Reservoir for several months beginning in 1963 to raise water into its intermediate-level distribution system to utilize more of that water and conserve the Delaware River supply.

At a meeting of the River Master and the Advisory Committee in early 1963, the River Master described water-supply conditions in the basin and presented a plan of operation should the drought persist. The plan involved assumption on the part of the River Master of controls on operations of the Delaware-system reservoirs that had not been considered necessary in previous years. New York City complied under protest with the restricted diversion plan. Late in the year, with supplies critically low, the River Master reduced the diversions to zero for 19 days and continued to direct releases. The city felt the temporary denial of its diversions relieved it of the requirement to make releases exceeding the inflow to the reservoirs. New York City announced a citywide plan to conserve water. The River Master again permitted diversions, but the city did not take them for several weeks.

In 1964, some restrictions on diversions were continued to May and resumed in November. Conservation measures were continued by New York City and the Pennsylvania Power & Light Company. High rates of runoff of West Branch Delaware River increased storage in Cannonsville Reservoir during the winter and spring and appeared likely to inundate parts of the reservoir-construction project. In conferences between the River Master and the River Master Advisory Committee, concurrence was obtained for a method to reduce the storage of water in Cannonsville Reservoir in a manner that would serve the best interests of the water users in the basin. Later, diversions and releases exceeded inflow to Neversink Reservoir. At the suggestion of the River Master, the city ceased diversions from that reservoir and continued releases. The reservoir reached maximum depletion November 16. Pepacton Reservoir was depleted by December 26. A special monthly report, supplemented during the low-flow season by an "outlook" for 1 month, was made available on a restricted basis to representatives on the Advisory Committee.

Below-average runoff continued in 1965 and was felt more acutely than in the previous 4-year period. The River Master met four times with the Advisory Committee, removed the excess release rate of flow at the Montague gage because, in effect, there was no "excess water," but could not find feasible and mutually acceptable further modifications of operating procedures. On June 14, New York City reduced releases to the approximate amount of inflow to the reservoirs but continued to divert large quantities of water. The city ignored an order from the River Master to stop diversions until ordered releases were complied with until July 8, when the Delaware River Basin Commission assumed the responsibility for the direction of releases and diversions under the authority granted it in its Organic Act. In a public hearing called by the Commission on July 7, statements were heard from the River Master and others on hydrologic conditions and water needs and the Commission adopted Emergency and Conservation Orders under its authority. Orders pertained to temporary modifications of diversions, releases, and powerplant discharges in the basin and the River Master accepted them. New York City began the modified diversions July 8.

New York City intensified its conservation campaign, and by late 1965 the city had decreased water consumption by 20 percent. Annual runoff at the Montague gage was the lowest since records began in 1940.

A slight improvement in runoff occurred in 1966. Diversions and releases from the nearly completed Cannonsville Reservoir helped the water-supply needs. New York City reconstructed a pumping plant on the Hudson River at Chelsea, N.Y., and pumped 100 million gallons per day (mgd) to the city system on many days, which assisted in alleviating the effects of the drought in the Delaware River. Mayor John V. Lindsay announced relaxed restrictions on several water uses because of the improved conditions. By April 1, limits on diversions to the city were raised to 490 mgd and the flow at the Montague gage was raised to the minimum basic rate of 1,525 cubic feet per second (cfs), which was considered sufficient to protect the water-supply intakes of Philadelphia from unacceptable chloride comcentrations. The state of emergency was continued through the year.

### Snake River Water Master

In 1957, Lynn Crandall, District Engineer, SWB, Idaho Falls, Idaho, was the water master for State Irrigation District No. 36. On Crandall's retirement at the end of 1958, Henry C. Eagle, Engineer-in-Charge of the SWB office in Idaho Falls, Idaho, became water master and served through June 30, 1966.

## Floods, Droughts, and Other Hydrologic Events

[George W. Edelen provided the following flood details and served as reviewer.]

In 1957, in the Southwest, a severe drought was ending that began about 1942, lasted for about 14 years, and afflicted most of the area from California to Texas. The drought was said by Harold E. Thomas, who coordinated and wrote much of Professional Paper 372, "Drought in the Southwest, 1942–56," to be one of the most severe droughts to occur in the region since the 13th century. The eight chapters of PP 372 were written by Joseph S. Gatewood, Alfonso Wilson, John D. Hem, Lester R. Kister, Harold E. Thomas, and George D. Scudder and were published in 1962, 1963, and 1964.

Another drought was beginning in the tier of States from New Mexico and Colorado to Iowa and Missouri as drought conditions began to ease in the Southwest. This drought was described in WSP 1804, "Drought of the 1950's—with special reference to the Midcontinent," by R.L. Nace and E.J. Pluhowski, 1965. According to Nace and Pluhowski, low flows of streams in eastern Kansas were at recurrence intervals of greater than 50 years. The severity and regional extent of the drought approached a national emergency in late 1956 and early 1957.

The drought was decisively broken in Texas during 1957 when persistent rains over most of the State kept streams from the Red River to the Rio Grande near or above flood stages from April through June. Peak discharges that exceeded the maximums of record occurred at only a few gaging stations; however, the volume of runoff was extraordinary. I. Dale Yost, author of WSP 1652–B, "Floods of April–June 1957 in Texas and adjacent States, 1964," estimated 38 million acre-feet of runoff, adjusted for storage in major reservoirs, occurred during this 3-month period.

The Nation was spared serious drought conditions over large areas for several years; then in the early 1960's, drought conditions reappeared in central Pennsylvania and by 1966 had spread south and northeast. HA 243, "Effects of drought on water resources in the Northeast," by H.C. Barksdale, Deric O'Bryan, and W.J. Schneider (1966) documented the hydrologic effects and regional extent of the drought.

According to the authors of HA–243, ground-water levels, as an index of drought severity, were at record or seriously low levels by March 31, 1965, throughout Pennsylvania, New York, Massachusetts, New Jersey, New Hampshire, Vermont, and Maine and south into Maryland, Virginia, and West Virginia. A year later and well into its fifth year, the drought was said to be the longest and most severe in the history of the region. (See also "Court Adjudication, Delaware River Master.")

In 1966, more than 100 public water-supply facilities in the Northeast were critically short of water and several failed. On August 18, 1966, President Lyndon B. Johnson declared a limited national emergency in the hardest hit areas and directed Federal agencies to assist communities having water-supply problems. WRD hydrologists identified and estimated capacities of sources of emergency supply for communities identified as having critical water-supply problems. It was reported in HA–243 that in no case was it impossible to locate suitable emergency supplies.

Even during drought years, damaging local and regional floods occurred in the United States and continued to be a major source of property loss and distress. At least 546 lives were lost, and flood damages exceeded $2.8 billion from 1957 through 1966.

Major floods (damages $10 million or greater) are shown in table VIII–1, adapted from National Oceanic and Atmospheric Administration list of catastrophic floods (1977). In the most damaging flood, September 10, 1965, in Florida and Louisiana (Hurricane Betsy) 75 lives were lost and estimated damages were greater than $1.4 billion.

Kentucky, Texas, and Indiana experienced floods in 1957; Louisiana in 1958; the Ohio River and Indiana in 1959; Nebraska and Puerto Rico in 1960; the Southeastern States in 1961; Idaho and Nevada, southwestern Florida, and Texas in 1962; California and Nevada in 1963; the Ohio River, Montana, and the far Western States in 1964; the Upper Mississippi River, Colorado, Arizona, New Mexico, Florida, Louisiana, and Hawaii, in 1965; and Utah, Texas, California, New Mexico, and Nebraska, in 1966. Those floods were documented in Survey publications or in open-file reports. The floods of June 1965 in the South Platte River Basin of Colorado and of December 1964 and January 1965 in the far Western States were especially noteworthy.

In WSP 1866, "Floods of December 1964 and January 1965 in the Far Western States," A.O. Waananen, D.D. Harris; and R.C. Williams reported that three storms hit Oregon, most of Idaho, northern California, southern Washington, and small areas of Nevada. The resulting floods cost 47 lives and more than $416 million in property damage. The rainfall intensities and soil conditions produced extremely high sediment loads. The sediment load of the Eel River at Scotia, Calif., was calculated to be 57 million tons on December 23—10 times the maximum load of record (1957–64).

In June 1965, several storm cells unleashed torrential rains for 3 days in three areas of the South Platte River south and west of Denver. In WSP 1850–B, "Floods of June 1965 in the South Platte River, Colorado," H.F. Matthai reported damage estimated at $415 million and 16 lives lost. About three-fourths of the damage was in the Denver area, where trees, buildings, and house trailers complete with propane tanks lodged against bridges and destroyed several in succession. The peak discharge of the Platte River at Denver, at 40,300 $ft^3/s$, was 1.8 times the previous maximum in a record that began in 1889.

Catastrophic floods were documented in 16 Water-Supply Papers (WSP), 8 Circulars (Circ.), and 75 Hydrologic Investigation Atlases (HA). In addition, annual summaries describing 249 other floods that were unusual hydrologic events in which large areas were affected, much damage resulted, or extreme discharges or stages occurred, were published in 10 WSP's (see table VIII–1).

The Water Resources Review, initiated by Walter B. Langbein in 1940 in response to a letter from the White House requesting the DOI to be alert to the then-current drought, contained current monthly streamflow, ground-water, and lake information. With its up-to-date information on flood and drought conditions, the Water Resources Review attracted a widespread audience and did much to publicize the work of the WRD. From 1957 through 1966, circulation increased from a few hundred to several thousand. It was prepared under the direction of William S. Eisenlohr, Jr., 1957–59, and by Glennon N. Mesnier, 1960–66.

Major earthquakes in 1959 and 1964 produced noteworthy hydrologic consequences. The first struck the Yellowstone National Park area of Montana and the second devastated much of the Anchorage, Alaska, area.

At 11:37 p.m. on August 17, 1959, an earthquake of Richter magnitude 7.1 struck the Yellowstone National park area. Its epicenter was near Lake Hebgen on the Madison River a few miles northwest of the Park. The shock was felt through an area of 600,000 square miles and as far as 350 miles from the epicenter.

In the monthly report of activities from the Chief Hydraulic Engineer to the Director for August 1959, the hydrologic effects of the earthquake were described as follows:

> The hydrologic effects of the severe earthquakes centered near Yellowstone Park on August 17 and 18, although centered in the Park area, were reported from such widespread places as Florida and Hawaii. The quakes caused water levels in wells in many parts of the country to rise and fall

Table VIII–1. Major floods during 1957–66

[Adapted from National Oceanic and Atmospheric Administration, 1977, Climatological data, National Summary, Annual Summary, Volume 28, No. 13, and from information furnished by the Federal Disaster Assistance Administration]

| Date | | Area | USGS report (WSP) | Lives lost[1] | Estimated damages (millions of $)[2] |
|---|---|---|---|---|---|
| 1957 | Jan. 29–Feb. 6 | Southeastern Kentucky and adjacent areas | 1652–A | 14 | 61 |
| | Feb. 24–28 | Washington, Oregon, and Idaho | 1652–C | -- | 21 |
| | April–June | Texas and adjacent States | 1652–C | 18 | 105 |
| | June 28–July 4 | Indiana and Illinois | 1652–C | -- | 63 |
| 1958 | Feb. 19–27 | Northern California | 1660–B | -- | 12 |
| | April 1–7 | Central California | 1660–B | -- | 23 |
| | April 1–May | Louisiana and adjacent States | 1660–A | 3 | 21 |
| | June 8–15 | Indiana | 1660–B | -- | 57 |
| 1959 | Jan.–Feb. | Ohio and adjacent States | 1750–A | 32 | 95 |
| 1960 | March–April | Eastern Nebraska and adjacent States | 1790–A | 5 | 14 |
| 1961 | Feb.–March | Southeastern States | 1810 | 4 | 47 |
| 1962 | Feb. 10–15 | Southern Idaho, northern Nevada and Utah | 1820 | -- | 10 |
| 1963 | Jan.–Feb. | California and Nevada | 1830–A | 10 | 19 |
| | March 4–19 | Ohio River tributaries, Alabama to West Virginia and Ohio | 1830–B | 26 | 98 |
| | June 24 | Nebraska | 1830–B | 3 | 13 |
| | July 27–Aug. 7 | Buffalo, New York | 1830–B | -- | 35 |
| 1964 | March | Along the Ohio River | 1840–A | 18 | 81 |
| | June | Northwestern Montana | 1840–B | 31 | 54 |
| | Sept. | Northern Florida and southern Georgia (Hurricane Dora) | 1840–C | 1 | 147 |
| | Dec. 1964 Jan. 1965 | Far Western States | 1866–A | 47 | 416 |
| 1965 | March–May | Upper Mississippi, Missouri and Red River of the North Basins | 1850–A 1850–E | 16 | 181 |
| | May 16–17 | Brazos River Basin, Texas | 1850–E | -- | 31 |
| | June 14–20 | South Platte River Basin, Colorado | 1850–B | 16 | 415 |
| | June 16–18 | Arkansas River Basin, Colorado, Kansas, and New Mexico | 1850–D | 16 | 58 |
| | July 18–23 | Northwestern Missouri | 1850–E | 9 | 24 |

Table VIII–1. Major floods during 1957–66 --Continued

[Adapted from National Oceanic and Atmospheric Administration, 1977, Climatological data, National Summary, Annual Summary, Volume 28, No. 13, and from information furnished by the Federal Disaster Assistance Administration]

| Date | | Area | USGS report (WSP) | Lives lost[1] | Estimated damages (millions of $)[2] |
|---|---|---|---|---|---|
| | Sept. 10 | Florida and Louisiana (Hurricane Betsy) | None | 75 | 1,420 |
| 1966 | March–April | Red River of the North Basin, northwestern Minnesota | 1870–D | -- | 10 |
| | April–May | Sabine and Trinity River Basins, Texas | 1870–B | 14 | 20 |
| | Aug. 12–14 | Loup River Basin, Nebraska | 1870–D | -- | 11 |
| | December | Arizona, California, Nevada, and Utah | 1870–A, C, D | 4 | 19 |

[1]No entry (--) indicates information is not available, but probably fewer than 10 lives were lost.

[2]Most reliable damage estimates available from National Weather Service, U.S. Army Corps of Engineers, and other sources.

rapidly. The largest fluctuations reported were 10 feet in a well in Idaho and 5 feet in one in Utah. The immense landslide downstream from the Hebgen Reservoir dammed the Madison River and impounded the waters released from Hebgen Reservoir. By the end of August, about 60,000 acre-feet was stored behind the slide dam. Overflow of the dam through a broad prepared spillway channel is expected when the total inflow has reached about 85,000 acre-feet. Some increases in flows of springs and streams occurred in the upper Madison and Gallatin Rivers in Montana and in the upper Henrys Fork basin in Idaho. Increased flow in some springs was accompanied by turbidity which in some cases has persisted. Other springs have ceased to flow.

In the late afternoon of March 27, 1964, an earthquake of magnitude 8.4–8.6 occurred beneath Prince William Sound, southeast of Anchorage, Alaska. The hydrologic effects of the earthquake were described in three chapters of PP 544 [PP 544–A and B, by R.M. Waller (1966); and PP 544–C, by R.C. Vorhis (1967)].

The earthquake occurred when Alaska's streams and lakes were low and most were covered by ice several feet thick. The shock broke ice on streams and lakes as far as 450 miles from the epicenter, and the oscillation of the Earth's surface temporarily dewatered some lakes.

Ground-water levels were drastically affected, mostly in unconsolidated aquifers for at least 160 miles from the epicenter. Within 100 miles of the epicenter, vast quantities of sediment-laden water were ejected onto flood plains of the glaciofluvial valleys. Deep aquifers in unconsolidated sediments were also affected. At Anchorage and in parts of the Kenai Peninsula, ground-water levels in artesian aquifers dropped as much as 15 feet.

Outside Alaska, more than 1,450 water-level recorders in all States except Connecticut, Delaware, and Rhode Island registered the earthquake. Water-level recorders on wells in Canada, England, Denmark, Belgium, Egypt, Israel, Libya, the Philippine Islands, South Africa, and Australia also registered the earthquake. The largest reported well fluctuation was 23 feet, registered by a pressure recorder on a well near Belle Fourche, S. Dak. Fluctuations of more than 10 feet were recorded in wells in Alabama, Florida, Georgia, Illinois, Missouri, and Pennsylvania.

The largest recorded seiches were 1.85 feet and 1.45 feet on reservoirs in Michigan and in Arkansas.

The earthquake figured prominently in the activities of WRD in Alaska (see Part X, "Alaska").

## Authorization of the National Center

Although construction, occupancy, and dedication of the National Center occurred after June 30, 1966, authorization for construction, appropriation of funds for planning, the selection of architectural firms for preplanning and site evaluation, and final site selection were accomplished during the years from 1959 through 1966.

In 1957, Survey headquarters were in the old Interior Building, now the GSA Building, a block north of the (new) Interior Building. Growth in programs and staff necessitated occupancy of additional office, laboratory, and warehouse space in the Washington area until in 1960, more than 2,000 employees were housed in more than 20 buildings from Arlington, Va., to Beltsville, Md.

The Survey's long quest for its own building began to look promising in 1962, when a prospectus describing the Survey's building needs was approved by resolution of the Public Works Committees of the House and the Senate. The resolution had been prepared and submitted to Congress in 1959 for a Geological Survey building of 603,700 net square feet, at a total cost of $32,240,000, including the building site and design.

In 1964, Congress appropriated $2,025,000 to GSA for site acquisition and design and the Senate Appropriations Committee added $100,000 to the Survey's budget for preliminary planning and site study. The $100,000 was transferred to GSA which provided a larger working fund and more impetus toward completing the preliminary details. In June 1964, a contract was awarded by GSA to two architectural firms, Skidmore, Owings, and Merrill of Chicago and H.D. Nottingham and Associates of Arlington, Va., for a predesign study of the Survey's space requirements including the evaluation of six possible sites in the Washington metropolitan area.

The sites under consideration were at the National Training School for Boys in Washington, Suitland Hall in Prince Georges County, Md., Congressional Manor, and the Gold Mine site in Montgomery County, Md., Bureau of Public Roads land in Fairfax County, Va., and an area in Reston, Va., which, at that time, was a new town being developed by the Gulf Reston Corporation. The Gold Mine site was actually the site of an old gold mine near the Potomac and had long been considered by Director Nolan as a choice location. Assistant Director Lyddan, in later years, recalled that the other five sites were less-favorably viewed, particularly by Nolan, because of their distance from the Survey's "center of gravity," meaning where most employees lived. Lyddan also recalled that Nolan considered the Reston site the least desirable of all.

The predesign and architectural-design firms worked closely with a Survey building committee made up of representatives from each Division and chaired by Lyddan. The architects sought to accommodate every existing individual- and group-space requirement for each Division and for the Survey as a whole. Their study was completed on February 22, 1965. Total space requirements exceeded the 603,700 net square feet authorized by Congress in 1962 by 150,000 square feet. The decision as made to defer the relocation of Map Distribution and a portion of Paleontology and Stratigraphy.

Also in 1965, the Survey made an exhaustive analysis of the six candidate sites in and around Washington. The final site selection was made easy when Gulf Reston donated 50 acres for the building in Reston. The Secretary of the Interior, on behalf of the Survey, accepted the land on February 1, 1966. Two days later, GSA signed a contract with Skidmore, Owings, and Merrill and H.D. Nottingham and Associates for a more detailed development study of the Reston site and for design of the new National Center. The site study was completed in April 1966 and reviewed and approved by the Survey and GSA. Approval by the National Capital Planning Commission came in July 1966. By midsummer, arrangements had been made for the purchase of an additional 35 acres adjoining the building site for $245,000 with an option to buy 20 more adjoining acres within 3 years for $7,000 per acre.

## PART IX—PUBLICATIONS AND INFORMATION SERVICES

Based on information provided *by* Erwin S. Asselstine, reviewed *by* Donald E. Hillier.

[Note.—Early in 1957, Erwin Asselstine of the Albany, N.Y., office of the New York-New England GWB District, was requested by Assistant Division Chief Raymond L. Nace to come to Headquarters to study reports-handling procedures and problems in the Branches and to develop plans for a Division Publications Section. By late March 1957, Asselstine had completed the assignment, made his recommendations, and returned to Albany believing that his mission was completed. Within a few weeks, however, Asselstine was asked to transfer to Washington to take the job he had planned for someone else. By July 1957, Asselstine was chief and sole staff of the WRD Publications Section. By January 1, 1966, Asselstine had the assistance of 10 full-time assistants. He made the observation many years later, "It was a long and painful but challenging and exciting process. It was also a process that was much easier to plan than to execute." See Part III, "Organization," for details of the evolution and staff changes in the Publications Section as reorganization progressed.]

## Policy and Procedural Changes

The years 1957 to 1966 were characterized by emphasis on publications. This was a natural outgrowth of major expansion and broadening of the Division's programs during this period. However, formidable report and publications problems faced Leopold when he became Division Chief. Early in this period, action was taken to remedy the problems.

By memorandum of January 30, 1958, Associate Chief Nace established a temporary committee to examine reports problems and to recommend corrective actions. The committee was made up of Philip E. LaMoreaux, District Geologist, GWB, Tuscaloosa, Ala.; M. Gordon Wolman, GHB, Washington, D.C.; Joseph S. Cragwall, SWB, Washington, D.C.; George H. Taylor, Staff Engineer, GWB, Lincoln, Nebr.; and Eugene Brown, District Chemist, QWB, Sacramento, Calif. Erwin S. Asselstine, Chief, WRD Publications Section, was special advisor to the committee.

Assignments were made to each committee member on project planning and supervising and report writing, reviewing, editing, and printing. Each member received assistance as needed from the Branches. In September 1958, the committee report, "Our Product: Reports," containing the recommendations, basic ideas, and philosophies of the committee on the Division's reports problems and proposed remedies was tendered. The report was endorsed by Leopold and copies were immediately distributed to all supervisory personnel.

The committee made 15 specific recommendations based on its conviction that reports were the fundamental product of the Division. Its major recommendations were as follows:

1. Because the process of report preparation, review, and publication is adapted to modern methods of operating analysis, a study based on time and costs of execution of work should be made by an Operations Research group within the Division to establish optimum schedules of operations. Because editing and printing time is excessive, similar studies should be made of Bureau editing and illustrating and the printing processes.

2. Studies should be made of the format and content of Survey publications to determine our report audience, their needs for information, readership levels and acceptance.

3. The timely release of data and information must be more adequately considered and current policies regarding the release of press notices, basic-data type reports, and similar items, should be thoroughly re-evaluated and provisions made to permit the authorization of the release at the lowest practicable organizational level consistent with the type and importance of the data being released.

4. The Committee believes inadequate project planning and unrealistic schedules for project execution have contributed substantially to the excessive delay in report production and recommends the development of adequate project description and work-plan forms and their universal use for all projects in the Division. Recommended also is the development of an effective control document (charts, tables) summarizing phase-execution times from the project descriptions and work plans. The control document should be used by District Chiefs, Branch Area Chiefs, staff specialists or equivalent supervisory levels to insure completion of work in accord with the plan.

5. Proficiency in report writing and review should be recognized in consideration for promotion. Authors as well as supervisors must be judged by their ability to produce a suitable and timely report. Care should be exercised not to apply this criteria, however, to those who have not been given responsibility or opportunity to prepare reports. Future promotional policies and practices should give greater weight to report writing attitudes, capabilities, and potentials when assigning supervisors to positions requiring those qualifications. With this objective, the Division should exert greater effort to discover, develop, and make better use of potential writers among its employees.

7. An author, responsible for a project report, should be retained on the investigation until he has at least prepared a manuscript acceptable to his supervisor.

8. In addition to the standard guides, a looseleaf manual should be prepared which can be easily kept current and in which existing memoranda on report preparation and policy are compiled and condensed.

10. Division policy should establish priorities for manuscript preparation, review, and revision over all other assigned duties, except seasonally con-

trolled or emergency work. All personnel competent to review manuscripts should be expected to do so on request.

11. Technical and editorial review of manuscripts should be minimized and consistent with the intended use of the product. A comprehensive review by no more than three reviewers should suffice.

13. To avoid unnecessary duplication, the principal control of the processing of manuscripts at the Washington level should be by the Branches; Division control could be exercised principally by periodic examination of the Branch control charts or by periodic Branch reports to the Division Publications Officer.

15. The development and use of a routing sheet and checklist should be extended to all Branches at an early date and they should be used by the Branch Area Chiefs and Specialists as another means of control of report production in the Division.

There followed an aggressive move into this problem area with the view of improving the quality of reports and the scheduling of their production so that better reports were published more promptly. Policy was put forth in three separate memoranda to all professional personnel from the Chief Hydraulic Engineer—in Policy Statement 1, June 4, 1959; Policy Statement 2, March 7, 1960 (issued May 27, 1957, to administrative staff); and Policy Statement 3, March 7, 1960 (previously issued April 6, 1959, to staff). Because of the importance of these policy statements, they were issued on colored paper to command attention and were called the "pink-terror memos."

The scope of these policies was summarized in the opening paragraph of Policy Statement 1:

> The effectiveness of the Water Resources Division depends largely on its ability to produce reports that meet the great variety of needs for water information.... We must emphasize the production of reports in as timely manner that will appraise the Nation's water resources, describe techniques and methods to meet water problems, and inform the public generally about water.

In order to accomplish these goals, new policy retained some of the old procedures but instituted vast changes such as fostering new modes of publication and format and establishing responsibilities at all levels of report preparation. In fact, the responsibilities of the authors, their immediate supervisors, and all others in the reports channel were specifically spelled out. Responsibility for the technical and editorial adequacy of report review was placed on the immediate supervisor of the author with the discharge of that responsibility being an important factor in promotion and assignments. Recommendation 13 of the 1958 LaMoreaux committee presumed continued Branch control of manuscript processing. This changed, also, with the establishing of the Division Publications Section in 1957 and it becoming the controlling agent for reports as the Branch reports sections were phased out.

In May 1958, the fifth edition of "Suggestions to Authors of the Reports of the U.S. Geological Survey" (STA), prepared at bureau level with significant input from the Division Publications Section, was distributed to each professional and technical employee in WRD and to others who worked with reports and required desk copies. The fifth edition, more than twice the size of the fourth edition, contained the accumulation of more than 60 years of guidelines for authors, reviewers, illustrators, and editors of Survey reports. Division policy required full use of STA in report preparation.

Revision of STA and other publications decisions at bureau level were overseen by the revered Hugh D. Miser, Chairman of the Survey Publications Committee. Miser contributed much to the quality of WRD reports as the Director's spokesman who reviewed and approved (or rejected) reports for the Director. A WRD report was approved by Hugh Miser the day before his sudden death in 1969 at age 84.

In June 1959, a task group made up of Division Operations Research representatives—Irving E. Anderson, George C. Taylor, and Herbert A. Swenson and under the direction of Raymond L. Nace—was formed to study report formats and contents and to identify report audiences and their needs for information and readership levels. Their charge was recommendation 2 of the 1958 LaMoreaux committee. They were to determine what "report content" was best suited to the need for which it was written and to evaluate report effectiveness in the various publication series.

Because of the importance of illustrations, including base maps, to WRD reports and the delays and expenses that can be engendered by improper preparation, there was established in 1961 in the Publications Section the position of Map Editor to oversee illustrations. The first Map Editor was Donald R. Wiesnet. He was succeeded within the years covered by volume VI by James C. Warman, then Harold E. McGovern, and then by Donald E. Hillier.

During 1962, 1963, and 1964 Branch reports sections were discontinued. A system of colleague review by qualified persons was begun in which the supervisor, perhaps with the author, was to select one or more (normally two) reviewers competent in the subject of the report and preferably not directly associated with preparing the report. This review was for technical soundness only and was not to be time consuming. Branch Area Chiefs were to read samples of manuscripts. A "policy" review was required by the Area Committee for every report from their area as a basis for judging the scientific and technical quality of the report and its compliance with Survey and WRD policy. An Area Committee member who made the decision on acceptability was not to review reports in detail but might do so for some as a basis for evaluating procedures and standards within the Districts in his area.

In 1963, in direct response to recommendation 8 of the 1958 LaMoreaux committee, the Publications Section assembled the first Water Resources Division Publications Guide, patterned after and designed to supplement "Suggestions to Authors." In a loose-leaf binder, it permitted easy replacement of reports instructions and policy statements, and many updates were issued to reflect policy and procedural changes thereafter. The Publications Guide became the means of disseminating reports procedures on such subjects as press releases, routing sheets, base maps, nomenclature, camera-ready copy, and preparing illustrations.

The first of the regional reports specialists moved into their new assignments in 1963 and by 1964 all were in place. They were Leopold A. Heindl, ACA; Charles J. Robinove, MCA; P. Eldon Dennis, RMA; and Willis L. Burnham, PCA. Robinove and Dennis served in that capacity for the remainder of the period. Heindl was succeeded by Joel O. Kimrey and Burnham by John H. Feth before this period ended. At about the same time, district reports specialists were also named to serve as local reports advisers and instructors and to be the district repository of information on report techniques and policies.

Also in 1963 and 1964, a series of report-improvement seminars was set up in each WRD region to acquaint technical personnel with report-improvement activities, to review report policy and processing procedures, and to discuss concepts and guidelines of report planning, preparing, reviewing, and revising. A noteworty by-product of the seminars was "Suggestions to Reviewers," prepared by Leopold A. Heindl, Charles J. Robinove, P. Eldon Dennis, and Willis L. Burnham under the direction of O. Milton Hackett.

Under the new policies, the Division Publications Section acted as a central clearing point for all reports. The Publications Officer, as Chief of the Section, did not assume that all reports were in acceptable condition. The Publications Officer occasionally sent reports to Division Headquarters staff members for their perusal. The Publications Section transmitted the manuscripts to the Director's Office for approval, was the initial recipient of their comments and instructions, and also helped interpret Bureau policy and coordinated report processing and publication, giving special attention to fiscal planning and setting priorities for WRD reports. It also acted as principal contact with units outside the Division such as the Publications Division and the Director's Office in matters pertaining to reports. Thus, there was one office to maintain records and control documents needed for constant surveillance of the quality, progress, and production schedule of reports.

Under the new reports policies, each project was to produce a publishable product within a reasonable time, usually 1 or 2 years after the project began. Administrative release and open filing of reports were not to replace formal publication. Negotiations with other agencies for work to be done was to be with the understanding that the Survey would be free to publish the results even if the other agency had no interest in the documenting of work done on their behalf. The number of reports was not a major criterion. The Division was more interested in their quality.

The report of the LaMoreaux committee, the pink policy memoranda, the centralizing of reports processing at Headquarters, and the delegating of responsibility to the field greatly influenced and improved preparing and processing reports. All these factors led to training skilled authors, and once a sound product was prepared, provided a system to move the report efficiently toward publication. In the words of Luna Leopold, "The way to build the reputation of an organization is to help develop each individual in it to his greatest capability and to do whatever is possible to enhance the scientific reputation of each research scientist."

## Mode of Publications

The Geological Survey has traditionally given its members freedom in technical work and in publishing the results of their work. The Survey has always assumed the responsibility of making the results of scientific investigations widely and promptly available as technically sound reports. The years 1957 to 1966 saw a tremendous change in the degree to which this traditional philosophy was effected within WRD. Leopold's fervid advancement of research and the application of data to water problems as "interpretive reports" is reflected in the enormous changes in numbers and types of reports. Previously, many reports were written with inadequate guidelines and without considering, in the early stages of an investigation, the form of publication. This often resulted in costly delays and revisions and, at times, in a less effective report. Also, the available options had included only limited types of staid formats that were utilized with little imagination as to how they could be made more attractive to a larger audience. The following discussion of the new and different modes and format of publication illustrates those changes.

***Hydrologic Atlases***

The Hydrologic Atlas (HA) has been one of the most successful of the map series used by WRD. HA 1, "Hydrology of the San Bernardino and eastern San Gabriel Mountains, California," by H.C. Troxell and others, was published in 1954 as an experiment to present the results of a water-resources investigation on maps, amplified by charts and limited text around the margin and on the reverse side. It was issued in fancy library folio with cover but was somewhat bulky and, at $3.50 each, expensive. Walter Langbein suggested simplifying the HA format so it could be packaged as a letter-sized folio. While only a few HA's were published in the next few years, they later became especially well suited to documenting floods in which areas inundated by past floods and by floods of certain frequencies were shown and were therefore useful in planning and managing flood plains and in determining rates of flood insurance. Between 1959 and 1966, 67 flood maps were published—HA–14, the first, to HA–229. (See Part IV, "Flood Inundation Mapping.")

The HA series was used also for many other topical investigations. Clearly the HA is well suited to presenting information on maps or in graphic form, but it also offers advantages over illustrations in book reports because of larger sheet size and use of color. Like other Survey maps, HA's are kept in print for many years, whereas formal book reports are normally maintained as sales to the public by the Superintendent of Documents for few years. Thus, atlases have long-term sales availability—important to the engineering and consulting users of such information.

***Geological Survey Research-Annual Review***

For years there had been a need for more rapid publishing of short research papers by Survey scientists than was offered by outside journals. The need was filled in 1960 with the introduction of an annual issue in the Professional Paper series entitled "Geological Survey Research." Each annual issue contained synopses of the results of the Survey's hydrologic and geologic investigations. Because of the nature of the synopsis chapter and, by extension, other chapters in the volume, the series became commonly termed the "Annual Review." The 1960 volume consisted entirely of the results of Geologic Division research, but beginning in 1961 WRD became a major contributor. In 1964, the traditional Professional Paper cover was replaced by a specially designed cover for the Annual Review. The widely diverse subject matter and the quality and attractive format of the papers and illustrations made the Annual Review a successful means of publishing more than a hundred research reports each year. George H. Davis and Frank W. Trainer were on the Annual Review staff during this period of WRD history.

***Water Primers***

Three Primers on Water were prepared at the instigation (including authorship) of Luna Leopold to provide general information to the public on water principles and problems. The Primers on Water were written in nontechnical language to enable readers to better understand water as a part of nature and, through understanding, to better participate in solutions to water problems by conservation, proper use, and control. "A Primer on Water" (1960) by Luna Leopold and Walter Langbein was a basic description of the occurrence, use, and management of water. Next was "A Primer on Ground Water" (1963) by Helene Baldwin and C. Lee McGuinness that described the general location, measurement, and availability of ground water and dispelled some folklore about its nature and occurrence. It was followed by "A Primer on Water Quality" (1965) by Herbert A. Swenson that dealt with the usefulness of water as determined by its chemical properties. Prices of the primers were low because of the large numbers of each that were printed. The primers were especially useful as an aid in teaching about water and in responding to inquiries from the public. As part of the effort to increase readership they were attractively covered and illustrated. Demands surpassed expectations and resulted in repeated reprinting. "The Primer on Water" became a best seller among Government publications.

***Lay-Reader Reports***

In 1961, Helene L. Baldwin became a WRD employee to work on special reports, to help design covers, to improve illustrations by making them more attractive and easier to comprehend, and to help authors popularize texts—all to make WRD reports more appealing and useful to an expanded audience. After the success of "Primer on Water," Baldwin's help was enlisted on a special Water-Supply Paper, "Water problems in the Springfield-Holyoke area, Massachusetts" (WSP 1670, 1962). That report was chosen because it illustrated the basic problems of water and water management which were outlined in the "Primer on Water" (1960) and illustrated water problems and concepts that prevailed in many parts of the Nation. John C. Kammerer was the senior author of this popular report.

Generous use of color in WSP 1670 was approved when it was demonstrated that use of color permitted juxtaposing data that would otherwise be difficult to format, and that complex problems could then be presented in a relatively simple and understandable way. It was written in laymen's terms and generously illustrated with photographs, maps, and easily understood graphs describing the water resources of an important area. WSP 1670, a handsomely printed 68-page booklet, was available for 40 cents from the Government Printing Office. Soon there were other reports for the informed public on the water resources of States. (See Part IV, "Water Resources of States.")

A popular report requested and sold by the U.S. Park Service was WSP 1766, "The water supply of El Morro National Monument" (1965), by Samuel W. West and Helene L. Baldwin. The report was printed in sepia and the cover was a photograph of Inscription Rock with the title overlaid. These successes in popularizing certain reports opened up a new format for specialized reports in other publication series of the Survey including Professional Papers, Bulletins, and Circulars.

### Covers and Design—Other Products and Outlets

Although Survey reports have traditionally been valuable, if not essential, to the development and management of water and mineral resources, there had been no special effort made to make those reports attractive to and more readable by the nontechnical public. Nor had there been specific efforts to acquaint the public or members of Congress with the accomplishments of Survey programs. In brief, the Survey had never seriously considered its public relations. This changed in 1962 when Frank Forrester was hired as the Survey's first full-time Public Information Officer. A meteorologist by training, Forrester was a well-known Washington-area television weatherman. As a member of Director Nolan's relatively small staff, his position assured high-level support in his public-information objectives.

Forrester's public-information skills worked hand in hand with Leopold's efforts to gain recognition of WRD reports. Improvement was made in the number and exposure of announcements to the public. Press releases announcing WRD reports and other newsworthy activities were sent to Forrester for final drafting and benefited from his expertise and media contacts.

It was also with Forrester's encouragement and help that the Division began preparing free leaflets, the first of which was entitled "Water and Industry" (1962). It was in color on slick stock and made for letter-size envelopes—convenient for answering inquiries. Another leaflet, "The National Water Resources Data Network" (1963), explained the function of stream-gaging stations, observation wells, and water-quality sampling stations. Written by Helene Baldwin, James F. Wilson, Charles J. Robinove, and Herbert A. Swenson, it was available only 10 weeks after planning began. Others followed including "What is Water?" by Helene Baldwin and L.B. Marman, Jr.

Also begun during this period was the use of attractive, attention-catching covers for certain reports when seen on a desk, library rack, or book shelf. About six cover designs showing water themes were developed for use on alternating reports. Art work was prepared on blanks so that it was necessary to add only the appropriate stick-on type and the cover was ready for printing—a rather quick and inexpensive procedure. These covers were used extensively on the Circular series. One of the first of the new covers was used on Circular 456, "Estimated use of water in the United States, 1960" which was reprinted many times. Another of the special covers enclosed large numbers of reprints of "National water resources and problems," (1960) Senate Select Committee on National Water Resources Print No. 3, 86th Congress. (See Part VIII, "Senate Select Committee on National Water Resources.")

Technical society journals containing papers by USGS authors were normally sent only to libraries and member subscribers. In order to make these papers more widely distributed, orders for reprints prior to journal publication were encouraged. Special covers for reprints were made available that showed the Geological Survey name and logo with the article title and appropriate journal reference. Artistic blanks with stick-on type created an attractive document.

A cover was especially prepared for Arthur M. Piper's WSP 1797, "Has the United States enough water?" (1965) that provided estimates of water supplies and projections of demand to the year 2000 in 19 major drainage basins. Its blue cover was illustrated with a map of the continental United States showing the major drainage basins.

Among the special documents prepared during this period was the recruiting brochure, "Professional challenges in water resources" (1963), compiled by Helene Baldwin. Containing 24 pages, it was spectacular in its use of color and photographs. The Division provided illustrations and a cover design for the CSC pamphlet announcing the new hydrologist series in 1964. (See Part VI, "Recruitment of Professional Employees" and "Establishing the Hydrologist Series.")

## Output

For many years, there had been reports problems resulting from insufficient effort, time, and money devoted to the report relative to that devoted to conducting the study that preceded the report. Actions to alleviate these problems began early in this period of history.

An almost immediate improvement was in the prompter receipt at Headquarters of reports in better condition for processing. Table IX–1 lists the reports of all types approved by the Director for release or publication for each of the 1957-to-1966 years. The numbers of unapproved reports returned to authors was less than prior to 1957.

It may be seen from table IX–1 that the number of reports for Survey publication greatly increased during the period 1958 to 1961. This was due to the expansion of the Division's research and investigative programs and also to the emphasis on publications and to the need for timely, publishable products. Table IX-1 also reflects catching up on the backlog of manuscripts that had accumulated during previous years.

In FY 1957 through 1960, costs of reports increased each year by approximately 20 percent for printing and associated costs incurred by the Branches of Texts, Technical Illustrations, and Map Reproduction of the Publications Division. However in 1961, funding was increased by 40 percent—not easy to accomplish and impossible without a major commitment by the Division to the publications program. Money was a necessary ingredient but was by no means the only important factor. Leopold had great success in obtaining full cooperation from Robert Morevetz, Chief, Publications Division, without whose assistance streamlining copy preparation and printing would not have been achieved. The Publications Division, WRD, and the Government Printing Office (GPO) developed methods of handling proof copies that greatly reduced the time normally required for printing reports. Time was saved by hand delivering proof copies between the two Divisions and the GPO, elimination of the galley proof, going directly to page proof, and by severely curtailing proof changes. There were also backlog problems in the Publications Division, however, that were resolved through frequent and personal contact with members of the several Publications Division Branches that were involved.

Reference to figure IX–1 shows a nearly constant output in the number of administrative reports and open-file releases in contrast to the increase in Survey and outside publications during the period. This was a

Table IX–1. Water Resources Division manuscripts approved by the Director, fiscal years 1957–66

| | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|---|
| Water-Supply Paper | 64 | 63 | 71 | 89 | 163 | 107 | 75 | 75 | 60 | 61 |
| Hydrologic Atlas | 0 | 0 | 6 | 35 | 21 | 23 | 54 | 46 | 31 | 45 |
| Circular | 7 | 6 | 8 | 21 | 20 | 17 | 9 | 6 | 18 | 11 |
| Bulletin | 1 | 1 | 2 | 6 | 9 | 3 | 3 | 8 | 7 | 2 |
| Professional Paper | 2 | 1 | 4 | 14 | 22 | 20 | 18 | 21 | 25 | 17 |
| Special Booklet | 0 | 0 | 0 | 2 | 2 | 0 | 2 | 1 | 5 | 0 |
| USGS Publication subtotal | 74 | 71 | 91 | 167 | 237 | 170 | 161 | 157 | 146 | 136 |
| Outside Publication | 233 | 265 | 260 | 334 | 335 | 425 | 398 | 410 | 459 | 489 |
| Open-File Report | 70 | 57 | 62 | 51 | 76 | 73 | 79 | 82 | 82 | 79 |
| Administrative and Official Use | 54 | 11 | 53 | 52 | 56 | 46 | 44 | 56 | 44 | 50 |
| Totals | 431 | 404 | 466 | 604 | 704 | 714 | 682 | 699 | 731 | 754 |

Note: State-level publications of basic water data, begun in 1961, are not included above.

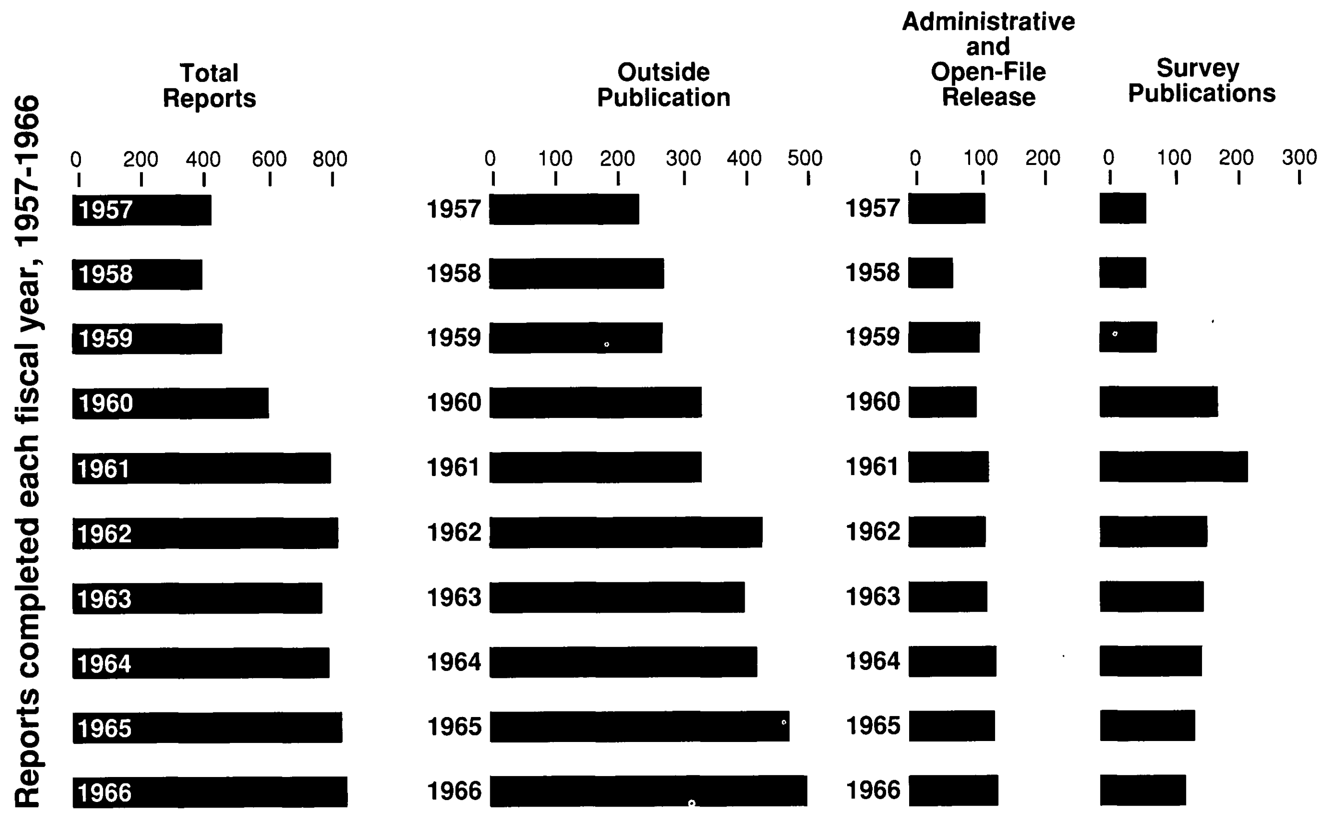



Figure IX-1. Reports completed each fiscal year, 1957–66.

consequence of a Division directive restricting administrative and open-file reports in preference to formal publication. Administrative and open-file releases were not to replace formal publications but, in a limited way, were steps on the route to publication.

Table IX–1 shows that the use of outside publications, largely technical society journals, increased from 233 in 1957 to 489 in 1966, or a 110-percent increase. It was emphasized by Division leaders that publication outside the Survey was not an alternative to or a substitute for Survey publication but was a by-product and a means of exchanging ideas and establishing a claim to ideas with a limited, specialized audience.

As shown in table IX–1, the large number of Circulars published during the years 1957 to 1966, and especially during 1960 to 1962, resulted largely from studies of the water resources of industrial areas, reports for which the Circular series was well suited. These studies, begun in 1958, covered major industrial areas, and their reports became a significant share of the publication output during the period. The use of Circulars gained favor because they were quickly reproduced in the Interior Duplicating Section by the photo-offset process and, as free documents, were free of restrictions attached to sales distribution.

Similarly HA's became a major publication medium from 1960 to 1966 (table IX–1). In addition to the reasons mentioned earlier (see "Mode of Publication," above), an important factor was prompt publication. The Atlases were printed by the Branch of Map Reproduction, Publications Division, with complete in-house processing and control.

Prior to 1957, the Bulletin series was rarely used by WRD authors. As the investigative work of the Division broadened, a number of reports were prepared in which the principal emphasis was not on water supply but on the hydrogeologic environment, and those reports were aimed at an audience of geologists. For example, a number of site reports for nuclear facilities prepared for the AEC and relating to waste diposal and the hydrogeologic environment rather than water supply were published in the Bulletin series. Although small in number in any single year (table IX–1), their total was an important part of the WRD output of publications during the period.

The Professional Paper series also had limited use by Division authors prior to 1957. The expansion of the research program and the production of more comprehensive reports that were major contributions to the hydrologic sciences made this series a desirable outlet. Many of the reports cited in Part IV, "Special Programs and Projects," were published in the Professional Paper series. The numbers in table IX–1 illustrate the importance of the Professional Papers.

Most reports prepared in WRD for USGS publication as Water-Supply Papers were interpretive or basic-data reports. To draw conclusions as to the type and magnitude of output in this series from the numbers contained in table IX–1 may be misleading. The State data reports that came into being in 1961 replaced Water-Supply Papers as the primary outlet for streamflow, ground-water, and water-quality data generated largely at District level. The State-level reports are not represented in the table or graphics. Arrangements were made to have these noninterpretive reports bypass Director's approval and the normal publication channels and satisfied recommendation 3 of the LaMoreaux committee. The 5-year compilation reports of streamflow data (see Part IV, "Compilation of Streamflow Data") were published as WSP's. The large increase in the number of WSP's in 1961 and 1962 was due in part to printing the compilation reports in addition to the final WSP annual data reports, of which there were 20 volumes of surface-water data, 4 of ground-water data, and 1 of quality-of-water data, the publishing of which was being accelerated. The changeover at this time to the State-level data reports decreased the overall number of WSP's in the following years because the annual WSP series was no longer used for this purpose.

Not included in table IX–1 but worth mentioning were the State index maps that were first published in 1961. The index maps bore the title "Water Resources Investigations in (State)" and contained maps showing water-resources investigations underway, hydrologic data-collection sites, lists of selected reports published by the Survey and by cooperating agencies, and a brief statement summarizing water use and availability. Several Districts submitted drafts after the index maps were proposed, and the draft submitted by the Tennessee WRD Council was selected as the prototype because its format was reproducible without redrafting and required little additional work to update. Updating and reprinting was approximately every 5 years. As the index maps contained no new or interpretive information, the normal report-processing channels were bypassed.

A description of the growth of the Division's programs and resultant publishing of its findings necessarily involved tabulation of types of outputs and numbers of reports. However, there was no misconception during this period that volume was a primary goal. Quantity was not the emphasis. At the beginning of the period the Division faced two paramount aspects of a problem with respect to its publications: QUALITY and TIMELINESS. A problem that was faced by the Division during this period was expressed in a quote from a report of the President's Science Advisory Committee in "Science, Government, and Information," dated January 10, 1963:

> Transfer of information is an inseparable part of research and development. All those concerned with research must accept responsibility for the transfer of information in the same degree and spirit that they accept responsibility for research and development itself. The technical community generally must devote a larger share than heretofore of its time and resources to its discriminating management of the ever-increasing technical record. Doing less will lead to fragmented and ineffective science and technology.

# PART X—DISTRICT ACTIVITIES

## Introduction

The accounts of District activities that follow are presented in alphabetical order on a State-by-State basis as the boundaries of most Districts conform with the State boundaries, and this arrangement continues the organization chosen by Follansbee and Ferguson in Volumes I–V. In the northeastern part of the United States and occasionally elsewhere, the boundaries of each of several Districts encompassed more than one State, each Branch District may have included a different set of States, and some District boundaries were changed during the period.

Immediately after the decision was made to prepare a history of the Division for the years 1957–66, Chief Hydrologist Philip Cohen, in a memorandum dated April 6, 1988, advised his Headquarters staff, the Regional Hydrologists, and District Chiefs of the plan and requested their full cooperation.

The next several steps in the preparation of this part of Volume VI were concurrent. The search began of records in Headquarters files, the National Archives, and the National Records Center to locate personnel, program, and funding records to be duplicated and furnished each District author. George W. Edelen, Jr., reemployed annuitant, provided most of this service. Joseph S. Cragwall, Jr., who was Tennessee District Chief during most of this period, wrote an account of that District to serve as an example of format and content. Hugh H. Hudson recruited the authors.

Ideally, one selected as the writer of District activities had served in the District for all of the period 1957–66, was in a key position during at least part of the period, and still lived near the District headquarters where access to former associates and to the files would be facilitated. But realistically, WRD employees moved about during their careers and retirement found some, by choice or by chance, great distances from their former headquarters. Although the foregoing criteria, of necessity, had to be compromised, there is no indication that the product was compromised. Examples of writing from locations far from former headquarters are numerous and include "Indiana" being written from Jewell, Ga., "Georgia" written in part from Baton Rouge, La., "Hawaii" written from Denver, Colo., "Michigan" from Sioux City, Iowa, and "Iowa" from Sun City, Ariz. Coauthors also collaborated across great distances. This is a tribute to the writers and to their desire to be a part of a successful effort to portray the people and programs of their former Districts.

In 1957, all Districts operated as branch Districts, and many ended this period yet to be reorganized as Division Districts. Consequently, the experiences, points of view, and program exposure of many of the District writers were limited to the operations of their branch. This, however, proved to be no major problem. The author wrote the account with generous input from members of the other branches, or coauthors were selected, each with a branch responsibility commensurate with his background.

Readers of this part will detect different writing styles and may perceive a difference of opinion among the authors as to the relative importance of the elements or topics that portray District activities. Some authors are people-oriented and chose to describe their District activities with an emphasis on the individuals who made up the staff. Others who were product-oriented devoted more of their allotted space to reports and to the activities that generated reports.

Authors were encouraged to identify the significant or major or principal reports that resulted from the activities of his or her District. This was done, but over well-reasoned protests. Ted Arnow, author of "Utah," pointed out with characteristic logic, that his selection of reports would be a different list if selected by any other author. It is therefore acknowledged that the major reports identified by each author may not reflect a consensus.

There were several nationwide activities in which each District participated and are therefore not recounted in each District activity, such as water-use surveys that resulted in Circulars 456 and 556 and in the flood-frequency studies that were published in the WSP series for all major river basins in the United States. Also, all Districts were affected by the change in the annual WSP-publication of streamflow data after 1960 to District-level data reports thereafter. This change and its related benefits are not generally recounted in the district histories.

The material retrieved by Edelen and provided to each District writer consisted of the following documents:

Annual program summaries. The format of these documents changed between 1958, when that form was introduced, and 1966, but all recorded the funds available for each project, from all sources, and for most years for each branch. This excellent program reference, however, was recovered for all years for very few Districts.

Lists of projects. A compilation of projects for each State by project number, project chief, project title, and beginning and ending dates.

Water-Resources Investigations in (State). Beginning in the early 1960's, a flyer was prepared for each State that summarized the current WRD projects within that State and cited the reports that were thought to be of special interest to the public. These were updated at about 5-year intervals, and two, typically 1962 and 1968, were furnished each writer.

Reference documents from other sources that were furnished were:

Personnel lists. Lists of personnel, copied from WRD Organization and Personnel Directories, were furnished each writer for his or her District or State. Prior to 1962, Headquarters occasionally distributed memorandums listing the names of those who transferred within or left WRD service since the last such memorandum. Copies of the recovered memorandums were also provided to each writer as appropriate to his or her District.

District activities, 1947–57. Each writer was provided with a copy of the account of the WRD activities for his or her State from Ferguson's then-unpublished Volume V in order to provide a common starting point and to preclude duplication of material in volumes V and VI.

"Tennessee," by Cragwall. Although "Tennessee" was written to serve as an example of recommended format and content, adherence to "Tennessee" was not obligatory. Several writers departed from the example with no loss of the desired content.

It was acknowledged to the writers that the foregoing material was little more than a starter kit and that an accurate, adequate portrayal of District people and programs would depend largely on memory, recollections of contemporaries, and material that could be located in the files of the District or cooperators.

Approximately 250 participants were involved in the preparation of this part of Volume VI. All of the authors and most of the reviewers were retirees. Active members of District staffs, however, took part in the search for old records, compiled data, and reviewed the finished product. Several of the accounts of District activities were typed by wives of the authors. Cooperators at the State level assembled information and contributed their knowledge of the cooperative program by serving as reviewers. This part of Volume VI could never have been prepared without those volunteer participants. Their contributions reflect the high calibre of public servants who served with the WRD.

## Alabama

Based on material provided *by* William J. Powell, assisted *by* Jerald F. McCain, John C. Scott, *and* E. Grady Ming

The years 1957 to 1966 witnessed major changes in the organization and philosophy of program development of the WRD in Alabama. In 1957, only the SWB and GWB operated continuing programs in the State. District headquarters for the SWB and GWB were in separate cities. Alabama's water quality interests were administratively within the domain of the Ocala, Fla., QWB District, later the Baton Rouge, La., District. Branch cooperation and program coordination, under the circumstances, were less than ideal.

From 1961 to 1965, the Branches were coordinated by a WRD Council. SWB and GWB were represented on the Council by their District supervisors; however, the QWB had no local representative until 1961 when a QWB field headquarters was established in Tuscaloosa. Although the purpose of the Council was to promote interbranch cooperation in matters of program development, it was less than fully successful.

In March 1965, WRD operations in Alabama were integrated under the direction of William L. Broadhurst, formerly District Geologist for the GWB in Texas and, more recently, with the Texas Board of Water Engineers.

### Surface Water Branch (1957–64)

In 1957, the District headquarters of the SWB was in the new Post Office Building in Montgomery. Melvin R. Williams was the District Engineer. Williams had no formally designated first assistant after William H. Robinson transferred to Mississippi in June 1957. Williams' staff included Laurence B. Pierce, Mack R. Stewart, Samuel C. Moore, and Charles O. Ming, engineers, and Ernest G. Ming, Jr., and Clifford L. Marshall, engineering aids. Stewart transferred to the Floods Section at SWB headquarters in early 1959. Also in 1959 Williams was transferred to Washington, D.C., to become Chief, SWB Research Section.

In October 1959, Lamar E. Carroon was transferred to Montgomery from Albany, N.Y., as Williams' replacement, but his residence in Montgomery was not for long. The District headquarters was soon to move to Tuscaloosa for closer coordination with GWB and to place the SWB management staff in closer proximity to the Geological Survey of Alabama (GSA), both of which had been headquartered in Tuscaloosa for many years. The move, in 1961, was to the Oil and Gas Board Building on the University of Alabama campus, which building also housed the GWB District headquarters and the GSA.

Accompanying Carroon in the move from Montgomery to Tuscaloosa were Pierce, Moore, and Billie L. McDonald. Concurrent with the move to Tuscaloosa was the selection of Charles F. Hains, from Menlo Park, Calif., as Assistant District Engineer. Hains also arrived in Tuscaloosa in 1961.

Also in 1961, a field headquarters was established in Tuscaloosa with McDonald as Engineer-in-Charge. He was soon joined by Ector E. Gann, a recent civil engineering graduate of the University of Tennessee.

Cullman, in north-central Alabama and centrally located with respect to the gaging stations operated for the Tennessee Valley Authority (TVA), had been the location of a Subdistrict office since June 1956. John S. Stallings headed the Cullman office until 1961 when he was selected as Engineer-in-Charge of the Montgomery office immediately following the relocation of the District headquarters to Tuscaloosa. Joe R. Harkins replaced Stallings in Cullman. The Cullman staff, in early 1964, consisted of Harkins, Paul W. Cole and Tommy R. Duvall, both engineering technicians, and Reba S. McHenry, clerk-typist. Harkins directed a study of the surface-water resources of Calhoun County that was published in 1965 as GSA Circular 33.

The Montgomery office staff remained rather stable during much of the period of this history. Following the move of the District headquarters to

Tuscaloosa, Stallings had 10 members on his staff. In 1964, prior to reorganization and integration of Branch operations, there were nine employees who reported to Stallings, including Charles O. Ming, Ernest G. Ming, Jr., Clifford Marshall, Franklin D. King, Fletcher C. Sedberry, George H. Nelson, Jr., and Vickie L. Welch. Also reporting to Stallings was Jerald F. McCain, assigned to the field headquarters in Mobile.

The Montgomery office was responsible for the operation and maintenance of gaging stations in central and south Alabama and for the hydraulic and hydrologic analyses of bridge sites for the State Highway Department, statewide. Charles Ming, the District high-water specialist, performed most of the highway-program work.

McCain's assignment to Mobile was primarily to study the hydraulics of the Wragg Swamp Canal for the Alabama Highway Department and the City of Mobile. The results of his work were published by the Highway Department in 1965 as HPR Report 15.

Laurence B. Pierce reported on the flow duration of streams in Alabama; the report was published in 1957 by the Alabama Water Improvement Commission (AWIC). That report was followed in 1959 by "Low flow and flow-duration data for Alabama streams," also published by the AWIC. It was also in 1959 that Pierce's report "Surface-water resources and hydrology of west-central Alabama" was published by the GSA as Special Report 24. Pierce collaborated in this project with James W. Guerin, then head of the QWB office in Ocala, Fla.

Pierce's next major study was of the flow characteristics of streams in Tuscaloosa County. He teamed up with Rodney G. Grantham of the Ocala, Fla., QWB office who provided the water-quality expertise. Their report was published in 1962 by the GSA as County Report 9. Pierce then did a study of streamflows in southwestern Alabama in collaboration with Stanley M. Rogers of the Lake Charles, La., QWB office. Their report was also published by the GSA in 1966 as Bulletin 84. That was followed in 1967 by Pierce's "7-day low flow and flow duration of Alabama streams" that was published by the GSA as Bulletin 87.

### Ground Water Branch (1957–64)

In 1957, the GWB District headquarters was on the University of Alabama campus in a barracks-type structure that had been converted into an office building within a block of the State Geologist's office. Philip E. LaMoreaux was District Geologist and on his staff in Tuscaloosa were Doyle B. Knowles, William J. Powell, George W. Swindel, Joseph W. Cagle, Jr., and a dozen or so junior professionals, technicians, and clerks. Also on LaMoreaux's staff as a part-time employee was Lyman D. Toulman, professor of geology, University of Florida, and an expert in the geology of Alabama's coastal plain. Knowles, an engineer, transferred to Madison, Wis., in 1958, but returned to Tuscaloosa in 1962 to join the staff of the GSA. Powell, a geologist, supervised projects in the Paleozoic area of the State. Swindel transferred to Lake Charles, La., in late 1960. Thomas A. Simpson moved to Tuscaloosa from Bessemer in late 1958, as his work on mining hydrology in the Birmingham area was nearing completion. Also in 1958, LaMoreaux was appointed Area Hydrologist for the Mid-Continent Area and was succeeded by Powell. In January 1959, LaMoreaux transferred from Tuscaloosa to Washington, D.C., to become Chief, GWB.

Studies of the geology and ground-water resources of counties were major components of the District program in the 1950's and 1960's. In order to place staff for county and other studies close to their project areas, field headquarters were established in several locations. In 1957, there were eight field headquarters housing 15 geologists and technicians. By early 1964, as the county studies were winding down, only five members of the District were assigned to four field headquarters. During the period 1957 to early 1964, field headquarters were or had been maintained at Anniston, Bessemer, Grove Hill, Huntsville, Linden, Montgomery, Robertsdale, Sheffield, Athens, Decatur, and Russellville.

James C. Warman was in charge of the Anniston office where he and Lawson V. Causey did the Calhoun County study that was published by the GSA in 1962 as County Report 7. Warman transferred to Tuscaloosa in mid-1960 and to Headquarters in Washington, D.C., in 1963. He later resigned from the Survey to head the Water Resources Research Institute at Auburn University, Auburn, Ala.

Chester L. Dodson was in charge of the Decatur office, established about the beginning of this period of history, as he worked on the Morgan County study. His report, coauthored with Wiley F. Harris, Jr., and J.C. Warman was published in 1964 by GSA as Bulletin 76. Dodson later headed the Water Resources Research Institute at West Virginia University in Morgantown.

William M. McMaster staffed the one-man Athens field headquarters established in 1959, when he and Wiley F. Harris, Jr., worked on the Limestone County project. Their report was published by the GSA in 1963 as County Report 11. McMaster transferred to the Oak Ridge, Tenn., Subdistrict office, in 1961.

The one-man Russellville office, established in 1960, was manned by Richard R. Peace, Jr., who authored the Franklin County report, published in 1963 by the GSA as Bulletin 72. Peace later resigned from the Survey to accept a job with a regulatory agency in North Carolina.

Among the other county reports completed during this period were those by L.V. Causey for Etowah County (GSA Info. Ser. 25, 1962), St. Clair County (GSA Bull. 73, 1963), and Cherokee County (GSA Bull. 79, 1965); for Colbert County by H.B. Harris, G.K. Moore, and C.R. West (GSA County Rept. 10, 1963); Lauderdale County by H.B. Harris, R.R. Peace, Jr., and W.F. Harris, Jr. (GSA County Rept. 8, 1963); Lawrence County by W.F. Harris, Jr., and W.M. McMaster (GSA Bull. 28, 1965); Wilcox County by LaMoreaux and C.D. Toulmin (GSA County Rept. 4, 1959); Marengo County by J.G. Newton, Horace Sutcliffe, Jr., and LaMoreaux (GSA County Rept. 5, 1961); Tuscaloosa County by Q.F. Paulson, J.D. Miller, Jr., and C.W. Drenner (GSA County Rept. 6, 1962); those by J.C. Scott for Macon County (GSA Info. Ser. 16, 1959); Autauga County (GSA Info. Ser. 21, 1960), and Bullock County (GSA Info. Ser. 29, 1962); and those by K.D. Wahl for Pickens County (GSA Bull. 83, 1965) and Greene County (GSA Bull. 86, 1966).

Several other ground-water studies were completed during this period, including those for towns and cities such as Montgomery, Athens, and Huntsville.

### Quality of Water Branch (1961–64)

Alabama was a part of the Ocala, Fla., QWB District until 1960 when a reconfiguration of QWB District boundaries in the Southeast placed Alabama within the Baton Rouge, La., District. In 1961, a QWB field headquarters, administratively within the Baton Rouge District, was established in Tuscaloosa. James A. Averett of the Albuquerque, N. Mex., QWB District was named Chemist-in-Charge. This brought to fruition a long-held hope of LaMoreaux's that the three Branches would not only operate in Alabama but would be located in Tuscaloosa.

Before the QWB field headquarters was established in Tuscaloosa, the GWB District had maintained a small laboratory to perform limited analyses of water (chloride, iron, hardness, and pH). Rodney G. Grantham, a graduate chemist employed as a physical-science aid, had operated the GWB District chemical laboratory. He resigned in 1960. Averett manned the field headquarters alone during 1961, then hired a physical-science aid WAE in 1962 and moved his laboratory to expanded space on the third floor of Walter Bryan Jones Hall on the University campus.

### Water Resources Division Council (1959–64)

Lamar Carroon, on his arrival in 1959, became the first Council Chairman. The chair alternated each year between the GWB District Geologist and the SWB District Engineer. The QWB representative, prior to 1961, was Stanley F. Kaputska, District Chemist, Baton Rouge. Then Averett, on his arrival as Chemist-in-Charge, Tuscaloosa field headquarters, became the QWB member of the Council.

In 1962, the first investigation involving all three Branches began. The Council had agreed that a study of the water problems in the principal oil field of Alabama would be an appropriate subject for this first effort involving the three Branches. The investigation disclosed that the use of brine-disposal pits was a major source of pollution of the shallow aquifer extensively used for domestic water supplies in southern Alabama. The report on the study, authored by Powell, Carroon, and Averett, was published by the GSA in 1963 as Circular 22. Legislation was subsequently enacted that prohibited the use of pits for oil-field brine disposal.

It was also during the period of the WRD Council that the Branches planned, in cooperation with the GSA, a series of county water-availability reports. Each report was to include a description of the flow and chemical characteristics of streams. The ground-water part of each report was to contain contour maps indicating the elevation or depth to the principal aquifer capable of yielding sufficient quantities of water for domestic supplies and maps showing depth to aquifers capable of yielding water in sufficient quantities for municipal, industrial, or irrigation supplies with an evaluation of the chemical characteristics of the water from the various aquifers.

The first in this new series, for Barbour County, was written by John G. Newton, William J. Powell, Harold G. Golden, and James R. Averett and was published by the GSA in 1966 as Map 34. This was followed in 1967 by a report on Houston County by John C. Scott, Jerald F. McCain and James R. Averett, published by the GSA as Map 59.

The water-availability reports were immediately popular with the general public, developers, and municipal and State agencies and were responsible for an increase in the cooperative program and the corresponding need to increase the WRD staff in Alabama.

In 1964, Carroon was assigned to the staff of the Area Hydrologist in Denver to undertake a special study requested by the SWB.

### Water Resources Division (1965–66)

Branch operations in Alabama were abolished in March 1965 with the arrival of William L. Broadhurst as District Chief of an integrated WRD District. The reorganized WRD headquarters remained in Tuscaloosa at the Oil and Gas Board Building on the University campus. Senior members of Broadhurst's staff included Hains, Powell, Averett, and Pierce. Also, those who had moved to Tuscaloosa during the past few years from field headquarters and Subdistrict offices included James L. Patterson from Montgomery, Thomas H. Sanford, Jr., from Huntsville, and John G. Newton from Linden. Newton, by the way, was a physical-science aid in Linden and was one of a dedicated, energetic few in the District who earned promotions from subprofessional to professional status.

With reorganization and the initiation of multidiscipline projects throughout the State, the Subdistrict offices in Cullman and Montgomery added new staff. The SWB and GWB staffs in Cullman were combined in 1964 under Harkins' leadership. Principal GWB staff were Robert J. Faust and Lawson V. Causey. In 1965, Wiley F. Harris, Jr., a senior physical-science aid, moved to Cullman from the Huntsville field headquarters and Joe R. Willmon, engineer, was recruited from a math-teaching job in Oklahoma to augment the Cullman staff.

Prior to reorganization, John C. Scott was the one-man staff for GWB activities in Montgomery, later Geneva. With reorganization, Scott was returned to Montgomery and assigned to the otherwise all-SWB staff headed by Stallings. In 1965, Stallings was transferred to Columbia, S.C., and replaced by Harold G. Golden, who served as Hydrologist-in-Charge of the Montgomery office through the end of this period of history.

### Funding and Cooperation

#### *Funding*

Most of the District's funds were from the cooperative (Coop) program and from other Federal agencies (OFA). Federal (Fed) program funds were minor and were used to support a few long-term gaging stations and observation wells of national interest. The Alabama Power Company, a licensee of the FPC, provided funds for streamflow records.

Lack of reliable funding figures makes it difficult to determine significant program trends and to identify cause-and-effect relationships in funding variations. It appears evident from the following table, however, that the total WRD program was stable to diminishing during the first several years of this period and trended upward during the closing years.

Alabama District funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1958 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 331 | 352 | 334 | 306 | 338 | 288 | 398 | 497 | 479 |
| OFA | 24 | 29 | 26 | 28 | 27 | 40 | 44 | 43 | 54 |
| Fed | -- | -- | -- | -- | -- | -- | -- | 11 | 13 |
| FPC | 3 | 8 | 9 | 16 | 10 | 12 | 12 | 12 | 19 |
| Total | | | | | | | | 563 | 565 |

Note: Except for FY 1965 and FY 1966, which are from District program documents and are reliable, figures for the remaining years are from Headquarters compilations of unknown reliability. Federal program funding figures are not available except for FY 1965 and FY 1966.

#### *Cooperation*

The principal cooperator of the USGS in Alabama was the Geological Survey of Alabama. In fiscal year 1957, the GSA provided $27,500 for gaging-station operation and surface-water studies and $30,000 for ground-water investigations. By fiscal year 1966, the GSA was contributing approximately $186,000 as its share of hydrologic investigations in Alabama.

The Alabama Highway Department continued its cooperative program with the Survey that began in 1947. The program produced numerous bridge-site reports and supported other special studies of interest to the Highway Department including areal flood-frequency reports on small streams and the Wragg Swamp Canal investigation that also involved cooperation with the City of Mobile.

The cities of Huntsville, Montgomery, and Athens were also cooperators during this period. The Alabama Water Improvement Commission cooperated in several special studies including an analysis of the low flows of Alabama streams.

#### *Other Federal Agencies*

The TVA, with its extensive flood-control and hydroelectric-power operations through northern Alabama, was a major user of streamflow information and supported several gaging stations. The Corps of Engineers, through its Mobile District office, transferred funds to the Survey for streamflow information and for special studies, as needed. Occasional work was also done for the National Park Service.

## Summary of Program

As in other parts of the Nation, the collection, processing, and publication of water records continued to be a strong and stable component of the Alabama WRD program. Program growth, particularly during the last 3 years of this period of history, was in comprehensive hydrologic studies that produced reports on the occurrence and availability of ground water, streamflow, and the quality of both.

In 1962, at about the midpoint of this period, the following information was reported in "Water Resources Investigations in Alabama."

Streamflow Records.—A total of 117 gaging stations were in operation, of which 43 were long-term hydrologic, 50 were short-term hydrologic, and 24 were specific-purpose stations needed for water-management purposes.

Ground-Water Records.—The recording observation wells totaled 38 and nonrecording wells 3, for a total of 41 network wells in the State.

Quality of Water.—Three continuously recording temperature stations were maintained.

# Alaska

*By* Roger M. Waller *and* Larry S. Leveen with the assistance of Harry Hulsing, Buford Walling, Ronald I. Mayo, Melvin V. Marcher, *and* Jessie M. Skrzynski

It's the great broad land 'way up yonder.
It's the forest where the silence has lease;
It's the beauty that thrills me with wonder.
It's the stillness that fills me with peace."
(from "Spell of the Yukon," by Robert Service)

In Alaska, the period 1957 to 1966 witnessed the consolidation of the Branches into Division-level operations, the change from a Territory to a State, and the occurrence of one of the greatest earthquakes in recorded history on the North American continent. Statehood took effect in 1959, the Good Friday earthquake that affected the hydrology of south-central Alaska, both instantaneously and permanently, occurred in 1964, and the Division District was established in 1965.

## Organization and Personnel

### *Surface Water Branch (1957–65)*

The Alaska SWB District office was in Juneau in Room 117, Federal and Territorial Building. Ralph E. Marsh was District Engineer until he retired in August 1965, at which time the Division-level District was formed. Caroline J. Jensen, although nominally assigned to SWB, served as District Clerk for all three Branches. Jessie M. Skrzynski, clerk, served during the entire period.

Ronald I. Mayo, engineer, was in charge of streamflow operations in southeastern Alaska until he transferred to Columbus, Ohio, in 1960. He and his staff operated the 75-foot WATRES, a WRD-owned boat, and a chartered float plane.

The WATRES was commanded by Lloyd H. Bayers, Master, aided by Dennis A. Shepperd, Vessel Engineer, both of whom occasionally assisted in stream gaging. James P. Smalley, engineering aid, assisted during 1957. Shepperd resigned in 1960. The WATRES had living accommodations for five and was in the field for a week or more at a time with many trips extending to 3 weeks.

Charles E. Hinkson, Jr., engineer, transferred to Juneau from Santa Fe, N. Mex., in 1958, and served until 1960. Joseph M. Childers, engineer, transferred to Juneau from Palmer in 1958 where he remained until 1965 when he moved to Anchorage as Hydrologist-in-Charge of the new Subdistrict office. Steven G. Swingle was hired in Juneau in 1958 as an engineering aid and transferred to Palmer in 1959.

In 1960, Raymond E. Bartoo, engineering technician, transferred from Pittsburgh and Leo J. Whistler replaced Shepperd as Vessel Engineer. Both served through this period of history. James M. Mathison, engineer, transferred to Juneau in 1961 and resigned in 1962.

In 1962, Vernon K. Berwick, engineer, transferred from Salt Lake City, Utah, and Clark H. Benson, engineer, arrived from Champaign, Ill. Both remained through this period of history, with Berwick becoming Hydrologist-in-Charge of the Juneau Subdistrict when that position was created with the reorganization of 1965. Millard M. Hiner, engineering technician, transferred from Eureka, Calif., in 1963 and Margaret M. Fassett, clerk-stenographer, was hired in 1963. Hiner transferred to Palmer in 1964.

Five additional persons were added to the Juneau staff during 1964 to 1966. Charles W. Boning and James P. Meckel, engineers, transferred from Spokane, Wash., and Palmer, respectively. Engineering technicians, Robert L. Cartmill and Hubert L. White, Jr., were hired. Judith A. Hannan, clerk-typist, also entered on duty. Boning, White, and Hannan served through this period of history. Meckel transferred to Fairbanks in 1966 and Cartmill resigned.

Palmer Subdistrict.—In 1957, Palmer was a small, rural community with limited housing and a boardwalk on a graveled main street. To offset the lack of available housing, there was a cluster of government-owned, low-rent houses available to Survey personnel. The office was shared with the QWB on the second floor of the Wright Building over Bert's Drug Store, the town gathering place.

Marvin J. Slaughter was engineer-in-charge. The clerk-typist, Geraldine F. Lampard, resigned in early 1957 and was replaced by Betty J. McIntire. Ernest S. Denison, supervisory hydraulic engineer, Joseph M. Childers, engineer, Arthur A. Seldal, engineering technician, and Robert E. Pedley, engineering aid, served on the Palmer staff during part or all of this period of WRD history.

In 1958, Childers transferred to Juneau and Elmer H. Likes, engineer, moved to Palmer from Helena, Mont. Swingle transferred from Juneau in 1959 and resigned in 1964. Warren W. Woods, engineering aid, and Clyde V. King, Jr., gaging-station construction worker, were hired in 1959.

Woods, who became one of Alaska's most respected "bush" pilots after leaving the Survey, would often fly his 2-seat, single-engine airplane (at auto-travel mileage rates) to remote stations, landing on gravel bars or on ice-covered rivers.

King was very inventive and made two major contributions to stream gaging in Alaska. One was an ice auger driven by the powerhead of a chain saw that could withstand the rigors of the extreme cold. His auger eliminated the difficult and time-consuming effort of chiseling holes through several feet of ice by hand to measure streamflow. His other major contribution was a gasoline-powered portable sounding reel used to make discharge measurements from a boat on deep, wide streams such as the Yukon and Kuskokwim Rivers.

Seldal transferred to Tacoma, Wash., in 1959. Denison transferred in 1960 to Lincoln, Nebr. Eugene A. Oster, engineer, transferred from LaGrande, Oreg., to Palmer in 1960, and returned to Oregon in 1961.

In 1961, engineers Kevin L. Carey and James P. Meckel were hired. During 1962, Likes transferred to Lansing Mich., Frank O. Morris, engineer, arrived from Hawaii, John P. Hale, Jr., engineering technician, transferred from Missouri, and Lyle R. Booth, engineering technician, was hired. Carey went on leave without pay in 1963. Jack D. McKechnie, engineering technician, was hired in 1964.

Staff departures from Palmer at about the time Palmer operations were moved to Anchorage in 1965 included Morris' transfer to West Virginia and resignations of Booth and King.

### *Ground Water Branch (1957–65)*

The GWB District office was located in the Glover Building in Anchorage. Roger M. Waller was Geologist-in-Charge until August 1963 when he transferred to Washington, D.C. General technical supervision was provided by Raymond L. Nace, Boise, Idaho, who was area coordinator until the Branch-Area-Chief system was organized. The budget was handled by the SWB District office at Juneau.

A program of using college students for summer aid to the District, begun by Nace, continued successfully until 1962 when program expansion warranted full-time assistance. Jay L. Morgan, a retired Air Force sergeant and ex-POW, was hired as an engineering aid and remained on duty through this period of history. Morgan's collection of hydrologic data after the 1964 earthquake and under extremely difficult conditions earned him the Special Act Award of the DOI.

In 1958, Patsy R. Lord, the first clerk-typist for the GWB in Alaska, was hired. She remained on duty until 1960 and was replaced by Margaret M. Hayes. In 1965, Hayes became the Administrative Assistant for the WRD District. Also in 1958, the office was moved, along with the Conservation Division offices, to the Denali Building at 308 B Street. In 1960, the offices of both Divisions were moved to the new Cordova Building on Cordova Street between 4th and 5th Avenues.

Increasing work for other Federal agencies resulted in Alvin J. Feulner, geologist, being transferred from Columbus, Ohio, to Anchorage in July 1959. His wife, Catherine M., was hired in 1959 as an engineering draftsman, WAE.

In 1961, a research project on permafrost/ground water was begun with John R. Williams, geologist, formerly of the Geologic Division, in charge. He remained in Anchorage until shortly after the 1964 earthquake when he was transferred to Menlo Park. He and his family escaped injury during the earthquake although their apartment collapsed around them.

After Waller left the District in 1963, Melvin V. Marcher transferred from Nashville, Tenn., to be Geologist-in-Charge. Ruby J. Craig was hired as a clerk-typist WAE in 1963. Patsy J. Still, physical-science technician, was hired in November 1964. In November 1965, Marcher was transferred to Oklahoma City.

### *Quality of Water Branch (1957–65)*

The QWB District office was located in Palmer and shared the Wright Building with the SWB Subdistrict office. Administrative functions were handled by the SWB District office at Juneau and clerk-typist duties were provided by the Palmer Subdistrict office.

Faulkner B. Walling was District Chemist until 1961 when he transferred to Washington, D.C. Robert G. Schupp transferred from Sacramento, Calif., to replace Walling. Schupp then transferred to Oregon in the summer of 1965.

Other members of the District staff were Eleanor S. Brooks, physical-science aid, and WAE employees Eldred E. Annas, chemist, Mary M. Curry, engineering aid, and Carol A. Colberg, physical-science aid. Carl L. Blanchard and Alice J. Craig, physical-science aids, entered on duty in 1957. Craig (now Branton) resigned in 1961 and Blanchard, in 1965. George Childs and Larry S. Leveen, hydrologic field assistants, were hired for the 1957 field season to collect sediment samples at two remote sites: the Susitna River at Gold Creek and the Copper River near Chitina. Samples were shipped from Gold Creek by train but a field laboratory was used by Leveen to run analyses of daily concentrations. Brooks and Curry resigned in 1959, Colberg in 1961, and Annas in 1962.

Larry Leveen was promoted from hydrologic field assistant to engineer in 1958 to take over increasing sediment studies and transferred to the new Anchorage Subdistrict office in 1965. Elverda E. Lincoln, physical-science aid, was hired in 1961 and transferred to Anchorage as a clerk-typist in 1965. Barbara R. Swift, hired as the first QWB clerk-typist in 1963, resigned in 1965.

#### *Water Resources Division 1965–66*

With designation of Alaska as a Division-level District in July 1965, Harry Hulsing transferred from Menlo Park to Anchorage, location of the new District office, to become the first District Chief. The WRD District office was in the Skyline Building at 218 E. Street, on 3rd Avenue on the edge of one of the landslide scarps created during the 1964 earthquake. A subdistrict office was established in Anchorage with Childers in charge.

A glacier-studies project office was established in 1965 in the Federal Building at Fairbanks staffed by Lawrence R. Mayo, geologist, formerly of the Geologic Division, and Charles E. Behlke, engineer WAE, who had worked at the QWB office in Palmer in 1956. In 1966, the project office was converted to a field office with Meckel transferring from Juneau to take charge. Swingle transferred from Wisconsin (where he had rejoined the Survey) and Richard A. Tarkianian was hired.

Increasing cooperative programs, studying the hydrologic effects of the 1964 earthquake, and increasing oil discoveries required additional staff in Anchorage. Transferring from Palmer to Anchorage were Slaughter, Childers, Leveen, Hale, McIntire, McKechnie, and Swift. Other additions to the staff were Donald A. Morris, hydrologist; William W. Barnwell, geologist, formerly of Sinclair Oil Co.; Gary S. Anderson, hydrologist from the University of Alaska; and new hires David A. Sommers, geologist; Patsy J. Stall, physical-science technician; Ruth E. Rountree and Helen J. Robson, clerk-typists; Stanley H. Jones, engineer from California; Dennis K. Stewart, engineer from North Dakota; Raymond S. George, engineer from Idaho; and new hires Henry L. Heyward, chemist; George W. Carte, engineer; and Joseph P. Minnehan, engineer from Montana.

### Funding and Cooperation

In 1957, most of the operating funds for water-resources investigations in Alaska were from the Federal (Fed) program. FPC licensees provided small amounts for the operation of several gaging stations. As shown in the following table, cooperative (Coop) program funds and funds from other Federal agencies (OFA) greatly increased from fiscal years 1958 to 1966.

Alaska District funds, fiscal years 1958, 1965, and 1966
[In thousands of dollars]

| Fund source | 1958 | 1965 | 1966 |
|---|---|---|---|
| Coop | 5.7 | 110.7 | 134.5 |
| Federal | 195.3 | 302.4 | 326.2 |
| FPC | 5.5 | 5.5 | 8.2 |
| OFA | 43.6 | 255.0 | 258.2 |
| Total | 250.1 | 673.6 | 727.1 |

Source: District program documents; figures for interim years are not available.

#### *Cooperating Agencies*

In 1958, the city of Anchorage entered into the first-ever cooperative agreement with the Survey in Alaska to study the hydrologic effects of pumping its new well field that was constructed as a result of GWB studies in the early 1950's. The cooperative agreement also included funds from the Territorial Department of Health. The study was significant in that it was a first quantitative study in the Territory involving all three Branches, and it was the first interdisciplinary study for the current staff in Alaska—a learning experience for all. The Anchorage project was completed in 1960. Also in 1958, the city of Juneau entered into a cooperative program with the Survey to acquire streamflow data needed to plan and manage its water supply. In 1961 the city of Juneau expanded its program to determine the feasibility of developing ground water for municipal use. The project was successful, and as at Anchorage, the relatively warmer ground water led to fewer water-main freezes.

The Territorial Department of Health continued to need Survey assistance in evaluating village ground-water supplies. At some locations, the work was coordinated with, and funded in part by, the Bureau of Indian Affairs. Survey assistance ended in 1963, partly because the drilling industry had developed to the extent that private drillers could develop village water supplies. In 1962, the city of Cordova requested a cooperative test-drilling study. The 1-year project was conducted by Kenneth L. Walters, geologist, on loan from the Tacoma office. The Alaska Highway Department cooperated in funding a crest-stage gage program, bridge-site reports, and bed-scour investigations which continued through 1966 and beyond.

In 1965, the city of Anchorage provided funds for a cooperative water-resources appraisal which continued for many years. The Greater Juneau Borough began a similar cooperative program in 1965.

#### *Other Federal Agencies*

The U.S. Army Corps of Engineers, the BOR, and FPC licensees supported about half of the stream-gaging program in FY 1958. By FY 1966, the Public Health Service, Forest Service, Alaska Railroad Commission, and U.S. Fish & Wildlife Service were also involved, respectively, in studies of channel characteristics at Kootznahoo Inlet, forest streamflow, erosion, and streamflow as related to fish habitat. The Corps of Engineers funded investigations of water supplies at military bases during this period of history.

Brief reconnaissance appraisals of potential well sites were made for the National Park Service at Glacier Bay and for the U.S Coast Guard at Tree Point, south of Ketchikan, in 1957.

In 1959, the U.S. Air Force requested an investigation of ground-water supplies at remote sites—principally at Aircraft Control and Warning stations. The work continued and by 1965 included a substantial quality-of-water program.

The AEC funded an intensive water-resources/environmental study at Cape Thompson in northwestern Alaska from 1959 to 1961 for a proposed harbor development using nuclear devices. (See Part IV, "Project Chariot.")

A ground-water investigation for the National Park Service at McKinley Park in 1964 and 1965 was probably the first use in Alaska of dry ice and calgon to improve a well. Other short-term, site-specific, water-supply studies were funded by the Public Health Service, the Forest Service, the Bureau of Indian Affairs, and the Federal Aviation Agency.

#### *Federal Program*

As noted in the table showing District funding, the Federal Program in 1958 provided nearly 80 percent of the funds for water-resources investigations in Alaska. By 1966, with greatly increased Coop and OFA funding, the Federal program, though stable, amounted to only 45 percent of the total.

### Summary of Program

#### *Surface-Water Records*

A total of 104 continuous-record streamflow stations were operated in 1966. Primary (long-term) stations totaled 67, secondary (short-term areal hydrologic) stations totaled 36, and there were 11 water-management stations. There were 90 periodic-record stations: 4 for water-management needs and 86 to record peak discharges.

Alaska has 571,000 square miles within its borders and less than 1,500 miles of roads. Access to stream-gaging stations in the bush, which reached beyond Kotzebue to the north, to the Canadian border on the east, and to the western coastline, was by chartered aircraft.

Stream gaging during the open-water period (late May to September), with its long (up to 24-hour) days, biting insects in unbelievable densities, and equipment limited to what the plane could carry, required hardy and innovative hydrologists. No roads, hence no bridges, were available as streamflow-measuring platforms. Logistics, costs, and terrain ruled out cableways. Stream width and topography made taglines impractical. These were but challenges to the innovative and intrepid Arctic stream gager. A hand-held sextant, a targeted base-line, a reasonably seaworthy native boat, and standard streamflow-measuring equipment met the needs. One hydrologist served as stream gager and recorder as the other operated the sextant, throttle, and tiller to keep the position of the boat fixed during velocity observations.

A single-engine airplane equipped with skis was used to reach gaging stations during the winter. Many winter trips were made in a two-place airplane with the stream gager squeezed behind the pilot with all his equipment, survival supplies, and the essential "fire pot" used to warm the engine oil after a night when temperatures plunged to –40 degrees or lower. Field trips were often 2 weeks or longer and covered 2,000 to 3,000 miles.

Transportation to stream gaging stations in southeastern Alaska was almost always by the Survey-owned vessel, WATRES. A typical trip would involve two stream gagers, the vessel engineer, the cook, and "Kinky" Bayers, the captain, who was a legend in Juneau and knew the waterways of the southeast coast from Skagway to Ketchikan as well as any skipper of his time. After leaving the home port at Juneau, over 1,000 miles would be traveled before returning 10 to 20 days later.

Typically, after anchoring the WATRES in a sheltered bay, gaging stations were reached by rowing a skiff to shore and then hiking, sometimes for several miles and not always without incident. During one trip, Hiner and Bartoo were charged by a brown bear that emerged from the underbrush at such close range Bartoo had time only to fire his rifle from his hip. The wounded bear was tracked for several miles before it was found and killed.

#### *Ground-Water Records*

In August 1966, there were 86 wells in the observation-well network, 12 of which were equipped with recorders and 74 of which were measured periodically. The 12 recorder-equipped wells were located in the Anchorage area where an extensive study was underway. A periodic network was operated in the Matanuska Valley but had been discontinued in Fairbanks and other former project areas.

#### *Water-Quality Records*

In August 1966, temperature data were being collected at 24 continuous-record gaging stations, 9 periodic stations, and 27 wells. Sediment records were being collected at 8 continuous and at 28 periodic gaging stations. Chemical-quality data were collected at 8 continuous-record stations, 2 periodic stations, and 27 periodically measured wells. This period of history saw a large increase in the systematic water-quality-monitoring program.

#### *Other Program Activities*

The Alaska Railroad Commission continued its support of the study of the breakout of Lake George, a spectacular hydrologic phenomenon. A USGS pamphlet, "The breakout of Alaska's Lake George," provided data and descriptions of this spectacle.

Lake George is a seasonal lake, formed when the Knik Glacier advances against Mount Palmer in the winter. In spring, the lake fills with snowmelt water to depths of 160 feet above its minimum level. Water seeps through the 5-mile face of the Knik Glacier, erodes the ice, and breaks through, releasing millions of gallons of ice-choked water. Peak discharges of about 500,000 cubic feet per second have occurred at the gaging station some 20 miles downstream.

From 1958 to 1965, hydrologists from the Palmer office made numerous measurements of the many factors that affect the timing of the breakout and the magnitude of the flood. Each year, personnel were flown into three locations where they spent weeks monitoring the rise and fall of Lake George and reporting the changes to the Palmer office by radio. Their job, though isolated and sometimes arduous, provided a reward of spectacular wonder seen by few. They witnessed sections of ice 100 to 200 feet high falling from the glacier into the widening gorge as the discharging water scored the face of the glacier.

In 1962, support was given to Arvi O. Waananen, who compiled the water-resources information for an Interior and Insular Affairs Committee report on the water and mineral resources of Alaska.

Other reports completed or in preparation during 1957 to 1966 included those on the ground-water resources of the Matanuska Valley agricultural area by F.W. Trainer (WSP 1494, 1960); jet drilling in the Fairbanks area by D.J. Cederstrom and G.C. Tibbits (WSP 1539–B, 1961); ground-water resources of the Anchorage area, by Cederstrom, Trainer, and Waller (WSP 1773, 1964); the origin of a saltwater lens in permafrost at Kotzebue by Cederstrom (GSA Bull. v. 72, no. 9, 1961); test-well drilling at Cordova by K.L. Walters (WSP 1779–A, 1963); city of Anchorage pumping by Waller (WSP 1779–D, 1964); magnitude and frequency of floods south of the Yukon by V.K. Berwick, J.M. Childers, and M.A. Kuentzel (Circ. 493, 1964); galleries for shallow ground-water development in permafrost areas by A.J. Feulner (WSP 1809–E, 1964); an annotated bibliography of ground water in permafrost regions by J.R. Williams (WSP 1792, 1965); the water resources of the Homer area, south-central Alaska by Waller, Feulner, and D.A. Morris (HA–187, 1968); hydrologic effects of the Alaska earthquake by Waller (PP 542–D and PP 544–A and B, 1968); and the hydrology of the great Alaska earthquake of 1964 by Waller (National Academy of Sciences, v. 3, 1968).

### Other District Activities

The Alaska earthquake of 1964 brought requests for information on flooding, snow and land-slide potentials, subsidence or upheaval of the land, and well and spring failures. Survey scientists detailed from the "lower 48" to provide assistance included Warren G. Hodson, Kevin M. Scott, and Don M. Culbertson. Waller also returned to Alaska on a temporary assignment 2 days after the 'quake to represent the Survey on the State and Federal recovery task force that provided aid and assistance.

## Arizona

*By* Edward S. Davidson with the assistance of Charles S. English, William G. Garrett, Lester R. Kister, Jr., Rodney H. Roeske, George S. Smith, *and* Bert W. Thomson

### Organization and Personnel

The Arizona District coordinated its separate Branch programs through a WRD Council made up of the District Engineer, SWB, the District Geologist, GWB, and a representative of the QWB. The District was served by an Administrative Services Section, which also managed accounts for other Arizona-based WRD offices. Offices of the SWB and the Administrative Services Section were in the old Post Office building in downtown Tucson until 1958, and the GWB and QWB staff occupied a near-derelict building at 136 North Park Avenue, a few blocks south of the University of Arizona campus. In September 1958, all were moved to elegant quarters in a newly constructed Geology Building on the University campus. The Branch organizations of the Arizona District were phased into a single Division District during late 1963 to early 1964. Considerable fear, trepidation, and outright opposition accompanied the change, and it took some time for real benefits to be gained.

#### *Surface Water Branch (1957–63)*

Douglas D. Lewis, who transferred to Tucson in February 1957 from Lincoln, Nebr., was District Engineer through late 1963 when he retired. Wilbur L. Heckler, Lewis' first assistant, transferred to Santa Fe as District Engineer, New Mexico District, in June 1958. Roy B. Sanderson then moved from Phoenix to Tucson in 1958 to be the Assistant District Engineer. He transferred to Washington, D.C. in 1960. Sanderson's position was filled by James J. Ligner, who moved to Tucson from Washington Headquarters in September 1960. Alfonso Wilson, who had worked with Joseph S. Gatewood (retired April 1957), was placed in charge of the field unit of the Hydrological Studies Section, the new name of the previous "Special Reports and Investigations" Section of the SWB. Wilson was absorbed into the District program in 1960 and in 1963 transferred to the Tucson project office of the GHB.

### Lees Ferry, a special place

*By* Lucella Siberts (updated to July 1966)

Frank Dodge kept his word and remained at Lees Ferry until World War II ended. In July 1946, he resigned because his health became progressively worse. Since then, the list of hydrographers at Lees Ferry is a long one that, during the period of this history, includes D.O. Tidball (July 1954 to September 1961); S.C. Jones (September 1961 to July 1962); George Barnett (July 1962); L.E. Lopp (August 1962 to April 1964); J.H. Blee (April 1964 to March 1966); and Larry Mann (March to September 1966).

A major change in Lees Ferry operations, in 1958, was the installation, at the upstream cableway, of a power-driven, hydraulically operated cable car with the capacity to handle sounding weights up to 300 pounds. In March 1965, the downstream cable was moved to the gage, half-a-mile farther downstream. Travel from the upstream cableway to the gage, about 1 mile, was by motor boat.

Construction of Glen Canyon Dam, 16 miles upstream from Lees Ferry, began in 1957. Storage in Lake Powell, formed by Glen Canyon Dam, began March 13, 1963. Since then, the flow of the Colorado River at Lees Ferry has been completely regulated.

During November 1963, a gaging and sediment station was established on Kanab Creek near Fredonia, which was serviced and operated by the Lees Ferry hydrographer. At about that time, servicing five crest-stage gages was added to the responsibility of the hydrographer in charge. In October 1964, a new station was established on the Colorado River a mile downstream from Glen Canyon Dam that was also operated by the Lees Ferry hydrographer.

In the early 1960's, plans were made to build a new residence and laboratory at Lees Ferry. Construction funds were included in the FY 1965 appropriations to the Survey, negotiations between the National Park Service and the Survey for the construction were completed, and in June 1966, Larry Mann, Lees Ferry hydrographer, and his family moved into the new residence. The new residence, located about one and a half miles downstream from the old residence, is on the right bank overlooking the Paria Rapids. Arizona Public Service put in a powerline, and the old days of cranking a "cranky" generator are but memories. A bridge across the Paria River, constructed in 1964, eliminated fording the river between the gaging station and the cableway.

Lees Ferry is still quiet and restful; however, there is more than one "close" neighbor now. The Ferry continues to be an important part of the Geological Survey, and streamflow data obtained there continues to be essential to managers and administrators of the Colorado River.

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Subdistrict offices were maintained during this period of WRD history in Flagstaff, Phoenix, Safford, and Yuma, and field headquarters were at Davis Dam, the Grand Canyon gaging station, Lees Ferry, Show Low, Blythe, Calif., and Boulder City, Nev. The Flagstaff office was headed by James G. Rickher (1957–62) and Charles J. Cox (1963). The Phoenix office had Sanderson (1957–58) and James E. Bowie (1959–64) as engineers-in-charge. At Safford, Arthur V. Todd (1957–58) and Gerald W. Armentrout (1959–61, transferred to Wyoming) were engineers-in-charge, followed by Milton W. Edington in 1962 who was named engineering technician-in-charge through 1967.

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"Sam just came in—Eagle-Willow—just about lost—rear wheels, axle, and drive shaft.—able to pull the vehicle together with the winch." "Returned a distance of a hundred miles." Armentrout; The Arizona Water Wheel News, Vol. 22, No. 3, July 1959.

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The Yuma office was led by Angelo Dalcerro from 1957 through 1963. All SWB offices and the field headquarters offered work, training, and solace to many hydrologists and technicians not previously mentioned, some of whom later rose to great accomplishments in the WRD. Included were: Fred S. Anderson (Tucson); Carol A. Babcock (Tucson); Charles Arlo Baker (Tucson); Lona C. Barbour (Tucson); Ruth E. Bellinoff (Phoenix); Robert L. Carter (Phoenix); Dallas Childers, Jr. (Tucson); Alberto Condes de la Torre (Yuma and Tucson); Charles J. Cox (Safford, Lees Ferry, and Flagstaff); Thomas M. Davey (Tucson); Virginia R. Deely (Tucson); George R. Dempster (Tucson); Edward E. Denis (Tucson and Phoenix); Louis P. Denis (Tucson); Amelia M. Ellig (Phoenix); Kenneth E. Florian (Tucson); Ina H. Fox (Phoenix); William B. Garrett (Tucson); Joe B. Gillespie, Jr. (Phoenix and Flagstaff); Arnold J. Harms (Tucson and Safford); John J. Healey, Jr. (Tucson); Vince V. Higginbotham (Show Low and Phoenix); Edward B. Hodges (Tucson); Edward J. Jones (Phoenix); Samuel C. Jones (Grand Canyon, Safford, Lees Ferry, and Blythe); Lawerence E. Lopp (Lees Ferry); Tallas D. Margrave (Phoenix); Sammie G. May (Tucson); Paul Nady (Phoenix); Wilfred R. Oeltjen (Flagstaff and Yuma); Orville M. Peterson (Phoenix and Show Low); Dale A. Reynolds, Jr. (Yuma); Jane R. Rickher (Tucson); Rodney H. Roeske (Tucson); Thomas D. Rose (Grand Canyon and Tucson); Reino A. Rukkila (Phoenix); Paul F. Russ (Phoenix); Arle M. Saltnass (Tucson); George R. Scarbrough (Yuma and Blythe); Mabel K. Schuetz (Tucson); Lucella W. Siberts (Tucson); Virginia R. Slate (Tucson); Bert W. Thomsen (Tucson and Phoenix); Dean O. Tidball (Lees Ferry and Flagstaff); Arthur Todd; Richard J. Trenck (Safford and Boulder City); James H. Watkins (Yuma and Blythe); Leonard L. Werho (Phoenix); Albert H. Wieder (Tucson); Florence M. Willey (Wyman and Tucson); Dennis T. Winsten (Tucson).

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"Just got back from a lower Gila trip—it seems the rattlesnakes down at Calva are in such a bad mood that they have begun killing each other. —I came up on a snake that had just ministered the coup de grace to another rattler." Sam Jones; The Arizona Water Wheel News, Vol. 22, No. 5, September 1959.

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### *Ground Water Branch (1957–63)*

John W. Harshbarger was District Geologist until July 1959 when he left the Survey to join the faculty of the Geology Department of the University of Arizona. Leopold A. Heindl was then appointed Acting District Geologist. Heindl transferred to Washington, D.C., in July 1960 to join the Headquarters reports-review group. P. Eldon Dennis transferred to Tucson in late January 1960 and was District Geologist until early 1963 when he moved to Denver, Colo.

Subdistrict offices were maintained in Phoenix and Holbrook. Donald G. Metzger (1957–60) and William Kam (1960–63) were Geologists-in-Charge in Phoenix. J.P. Akers (1957–60), Neal E. McClymonds (1961), and Elvoid L. Gillespie (1962–63) were in charge of the Holbrook office. Most data collection and projects were managed from the Tucson and Phoenix offices. The personnel to early 1963 included J.P. Akers (Holbrook and Tucson); Ruth S. Allison (Tucson); Ruth L. Blubaugh (Tucson); Maurice B. Booher (Tucson); Stuart G. Brown (Tucson); James M. Cahill (Phoenix); Robert E. Cattany (Tucson); Maurice E. Cooley (Holbrook and Tucson); Oliver J. Cosner (Tucson); Edward S. Davidson (Tucson); Charles S.

English (Tucson); Elvoid L. Gillespie (Holbrook and Flagstaff); William F. Hardt (Holbrook and Flagstaff); Leopold A. Heindl (Tucson); Ann C. Hill (Phoenix); Ted Hollander (Tucson); Marlene F. Howard (later Smith) (Holbrook and Tucson); Carol L. Jenkins (later Hicks) (Holbrook and Tucson); Phillip W. Johnson (Tucson); Peggy Johnson (Phoenix); William Kam (Holbrook and Phoenix); Mary E. Kambitsch (Tucson); Donald W. Layton (Tucson); Henry Leon (Surface Water, Tucson); James Lieurance (Tucson); Richard A. McCullough (Tucson); Neal E. McClymonds (Tucson and Holbrook); Eddins K. Morse (Tucson); Harry G. Page (Tucson); Fred E. Pashley (Tucson); Robert D. Penley (Phoenix); William Potts (Tucson); George S. Smith (Holbrook and Tucson); Ronald S. Stulik (Phoenix); Richard L. Thompson (Tucson); Floyd R. Twenter (Phoenix); and Natalie D. White (Tucson).

#### *Quality of Water Branch (1957–63)*

The QWB, during 1957–63, was represented by Lester R. Kister, Chemist-in-Charge. He arrived Tucson in July 1957, having worked with Lewis of the SWB, on the Missouri River Basin studies out of Lincoln, Nebr. Eugene S. Buell and Neal Carmony worked in the QWB programs in this period and later.

#### *Administrative Services Section (1957–66)*

This section, headed by administrative assistant Charles T. Pynchon and answering to the Arizona WRD Council, was the budgeting and payment service section of all the Branch District offices and other WRD projects in Arizona. Pynchon used occult and arcane methods to keep books on the several budgets that ran monetary affairs through his empire, and in the precomputer era, it was almost impossible to estimate costs. Whatever the cost or budget available, a project was destitute prior to midyear and had to scrimp until a month or so before the end of the fiscal year. Pynchon's able crew included Rosa M. Gould; Shirley E. Klaus; Julia B. Lamski (Brincko); John T. Palmer; Caroline J. Sneed; Lucille F. Southard; Mary I. Sterrett (Phoenix); and Nancy A. Tilghman.

#### *Water Resources Division (1963–66)*

The separate Branch operations were combined as a Division organization in late 1963, concurrent with the arrival of Horace M. Babcock, who was formally named District Chief in February 1964. Lewis retired in January 1964 and Ligner was named Assistant District Chief.

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"Bab—on—February 27—go to—East Pakistan. He's been reading—and states that he now is an 'expert' on all things Pakistanian.—I predict that East Pakistan will be reorganized by the time Bab leaves." Ligner; The Arizona Water Wheel News, Vol. 29, No. 7, February 1967.

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A Subdistrict office was set up in Tucson in 1963, headed by Fred S. Anderson. Joe B. Gillespie was the Hydrologist-in-Charge of the Flagstaff Subdistrict and the Phoenix Subdistrict was under the leadership of James E. Bowie (1963–64) and Rufus H. Musgrove (1966). The Safford office was managed by Milton Edington and Yuma by Angelo Dalcerro. Personnel who joined the District in the period 1963–66 were Byron N. Aldridge (Tucson); Thomas W. Anderson (Phoenix); Freddy E. Arteaga (Phoenix); Lois J. Barnes (Tucson-Admin.); Craig B. Bentley (Tucson and Kingman); John W. Blee (Lees Ferry); Phillip C. Briggs (Phoenix); Eugene S. Buell (Tucson); Durl E. Burkham (Tucson); William E. Burnett (Grand Canyon); David E. Click (Tucson); John R. Condon (Tucson); Janet D. Dunipace (Tucson-Admin.); Jay Dusard (Tucson); John R. Edmonds (Tucson); Lorenzo L. Flake (Safford); Rebecca K. Harper (Phoenix); Dewey A. Hicks, Jr. (Tucson); Hjalmar W. Hjalmarson (Phoenix); Robert L. Laney (Tucson); Edwin H. McGavok (Holbrook); Jack Mernaugh (Tucson); Rita Michunivich (Phoenix); James L. Moffet (Show Low); Otto Moosburner (Phoenix); Marshall E. Moss (Yuma); Rufus H. Musgrove (Phoenix); Larry J. Neff (Flagstaff); Joanne M. Peterson (Tucson-Admin. Eng. Aide); Thomas J. Phelan, III (Phoenix); Felix H. Rascop (Tucson); Clara L. Rauh (Tucson); Herbert H. Schumann (Phoenix); Wesley J. Smith (Phoenix); Harold W. Steppuhn (Phoenix); Alvin F. Sutheimer (Tucson); Richard L. Thompson (Tucson); Varlyn E. Watson (Safford); William Werrell (Tucson); Rudolph H. Westphal (Yuma); and Norman Whaley (Tucson).

### Funding and Cooperation

Funding figures for the three Branches, and later the unified Division programs in the Arizona District, from available consolidated work plans are shown in the following table. The cooperative (Coop) funds provided the largest amount of financial support and steadily increased from slightly more than $300,000 in fiscal year 1958 to more than $800,000 in fiscal year 1966. The Federal (Fed) program funds increased from $85,000 to almost $240,000 in the same period. Funds from other Federal agencies (OFA) decreased from

$171,000 to $137,000. Mainly because of the increased cooperative work, total program funding more than doubled during the 9 years to a total of $1.2 million.

Arizona District funding, fiscal years 1958, 1962–66
(In thousands of dollars)

| Fund source | 1958 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|
| Coop | 315.2 | 548.7 | 613.2 | 614.6 | 733.1 | 836.7 |
| Federal | 85.3 | 77.5 | 88.4 | 115.3 | 175.2 | 238.6 |
| OFA | 171.0 | 112.6 | 134.0 | 157.0 | 198.7 | 137.0 |
| Total | 571.5 | 738.9 | 835.6 | 886.9 | 1,107.0 | 1,212.3 |

The largest cooperative programs were with the Arizona State Land Department, which financed basic-data collection and analyses; the Arizona Interstate Stream Commission, which funded collection of surface-water and quality-of-water data; and the Salt River Valley Water Users Association, which funded streamflow-records collection. Other cooperators included many of the irrigation districts in the State, the two largest counties (Maricopa and Pima), the Navajo Tribe, several cities, the State Highway Department, and the University of Arizona.

The principal Federal agency providing funds to the District was the Bureau of Reclamation. The Department of Defense, Corps of Engineers, U.S. Air Force, Bureau of Indian Affairs, National Park Service, U.S. Fish and Wildlife Service, Bureau of Land Management, Federal Power Commission, the Forest Service, and Soil Conservation Service also were long-term funding sources. The needs of these agencies included streamflow data and analysis and information on quality of water and on ground water.

## Summary of Program

### *Water Records*

The collection of streamflow records doubled from 1957 to 1966, and other information such as that on floods, sediment, chemical quality, temperature, and flood profiles were increasingly needed toward the end of the period. The collection of ground-water level measurements decreased; there was a major decrease in discharge measurements, but an increase in chemical quality and temperature measurements. The main quality-of-water work was in the Federal program and for the BOR. The BOR work consisted mainly of sediment content and chemical quality of streamflow but by 1966 included chemical analyses of ground water.

A bibliography of basic-data and other reports on the water resources of Arizona is contained in Arizona State Land Department Water-Resources Report No. 22 and the Arizona Water Commission Bulletin 2. Ground-water conditions throughout the State, including synthesis of the basic records and chemical quality, were published in the Arizona State Land Department annual reports during 1957 to 1966.

### *Areal and Topical Studies*

Most records of floods and chemical quality of surface water were documented in WSP's, but a few floods were of enough significance to warrant separate papers, generally given in public meetings and published as contributions to the meetings. There was also the documentation in Arizona State Land Department Report 34 of the locations and amounts of the inflows to the Colorado River located and measured during a float trip down the Colorado River in July 1960.

Most of the areal and topical studies prepared in the Arizona District described the occurrence, chemical quality, and interrelationship of surface and ground water and the average annual streamflow. The reports commonly estimated the water budget of and the storage in an area with the aim of identifying the usefulness of the water resource for various purposes. More than 90 reports or articles were published, most in the years 1962–66 and most as WSP's, as Arizona State Land Department reports, or as journal articles.

One of the reports of the period was "Arizona's Water," WSP 1648, by J.W. Harshbarger, D.D. Lewis, H.E. Skibitzke, W.L. Heckler, and L.R. Kister, published in 1966. Parts of the report appeared verbatim in a statewide-circulated newspaper, The Arizona Farmer Ranchman, prior to its approval for publication. The newspaper's editor, rather than reviewing and returning the text prior to its release to the public by the Director of the Geological Survey, decided, instead, to enlist the aid of his readers in the review. This inadvertent pre-approval publication caused considerable consternation within the Survey administration.

## Other Activities in the District

There were several activities in Arizona, not formally part of the District's program, that affected the work of the District. During the period 1957 to 1966, the State of Arizona was involved in a lawsuit over allocation of Colorado River water. The Arizona Interstate Stream Commission was the State's technical arm in the lawsuit and was also a principal cooperator with the District in its surface-water program. Irrigation-return flows to the Colorado River and loss of water through evapotranspiration were critical problems leading to Division research projects based in Yuma, Tucson, and Phoenix. Additionally, there were research projects in Phoenix, led by Herbert E. Skibitzke and Russell H. Brown, on the hydraulics of ground-water flow, methods of evaluating ground-water reservoirs, and on the development of electrical analog models and remote sensing techniques. (See Part IV, "Analog modeling of hydrologic systems," "Analog model unit," and "Hydrologic remote sensing.") By 1966, the WRD staff assisting the University of Arizona in developing its degree program in hydrology and engaged in research was larger than the District staff. Their presence in Arizona made available to the District a considerable body of technical expertise.

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"—Lees Ferry, where—a D–9 Cat completely demolished—our old buildings.—the Survey's history at Lees Ferry has been long—the news that an era has passed will bring a tear or two—. — offered to turn—buildings over the Park Service—they turned the idea down." Ligner; The Arizona Water Wheel News, Vol. 29, No. 7, March 1967.

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## Arkansas

Based on information provided *by* Richard T. Sniegocki that was reviewed *by* Marion S. Hines, Marion S. Bedinger, *and* Norman F. Williams

### Organization and Personnel

From 1957 to 1964, water-resources investigations in Arkansas were developed, administered, and performed by the GWB, SWB, and QWB. In 1964, the Branch programs and personnel were consolidated into a Division District.

GWB District headquarters was in Little Rock, initially at 215 Spring Street, and was moved to the Federal Building in 1961. In 1957, P. Eldon Dennis was District Geologist. He was reassigned to Tucson, Ariz., in 1960 and succeeded by Richard T. Sniegocki.

In 1957, SWB District headquarters was in Fort Smith with John L. Saunders as District Engineer. The headquarters was moved to the Federal Building in Little Rock in 1962 to join GWB. A five-person field headquarters was left in Fort Smith with Samuel R. Kennedy, engineering technician, in charge. Saunders retired in 1962 and was succeeded by I. Dale Yost.

QWB District headquarters was on the campus of the University of Arkansas in Fayetteville until 1962 when it, too, was moved to the Federal Building in Little Rock to join GWB and SWB. Merle E. Schroeder was District Chemist until 1961 (the position was titled Resident Chemist prior to 1960). He was succeeded by John H. Hubble in 1961.

A reorganization plan for combining the Branch operations into a Division District became effective in 1964 with Sniegocki as District Chief and Yost as Assistant District Chief. In the new organization was a three-person Administrative Services Section headed by Evelynne H. May; a Basic Records Section with R. Clifford Gilstrap in charge; and a Hydrologic Studies Section with Leland D. Hauth in command. Some 3-dozen engineers, chemists, geologists, technicians, and clerical workers were about equally divided between the two technical sections. The field headquarters remained in Fort Smith and Oscar J. Jacobs, engineering technician, manned the field headquarters in DeQueen. There were no organizational changes during the remaining 2 years of this period and few staff changes.

Among the highly trained, self-motivated, and physically active group who served in Arkansas during much of this period and whose efforts contributed greatly to the success of the program were Donald R. Albin, Guy A. Bearden, Marion S. Bedinger, Charles T. Bryant, Rulon C. Christensen, Joe Edds, Leo F. Emmett, Marvin W. Flugrath, Henry N. Halberg, Marion S. Hines, Glenmore M. Hogensen, Robert L. Hosman, Horace G. Jeffery, Terrance E. Lamb, Augustine H. Ludwig, Elmer P. Matthews, James L. Patterson, Jack P. Reed, Joe E. Reed, L. Dean Reed, Bobbie W. Vines, and John D. Warren. Many of those names appeared frequently in the Arkansas Geological Commission (AGC) Water Resources Summary Number 10, "Bibliography and Selected Abstracts of Reports on Water Resources and Related Subjects for Arkansas through 1975."

### Major Programs

A major interdisciplinary project that operated at the cutting edge of the state-of-the-art water-resource investigations was begun in 1957 by the GWB District for the U.S. Army Corps of Engineers. The purpose of the project was to provide the Corps with maps showing the effects on ground-water levels in adjacent farms of raising the level of the Arkansas River by constructing locks and dams for a navigation system. Analog modeling was the major tool used in preparing water-level projections up to 10 or 12 years in advance of dam closings. Followup studies after closing the dams showed that most projections were within 0.1 to 0.3 foot of actual postconstruction ground-water levels.

The results of the study played a major role in selecting lock-and-dam sites and aided the Corps in deciding to eliminate two locks and dams from the navigation system. The study cost the Corps about $1.2 million. The estimated cost of constructing a lock and dam was about $20 million.

Managing the Arkansas River navigation system required flow data at strategic locations on the river on a demand basis. The SWB District devised and installed electronic equipment to determine flows through turbines and through openings in gates and locks. A computer program was developed to compute the flow of the Arkansas River at key sites.

More than 100 reports were generated by this study during its 17-year life, most written specifically to provide information requested by the Corps. The data collected during the study also provided the basis for WSP 1669–L, "Ground-water potential of the alluvium of the Arkansas River between Little Rock and Fort Smith, Arkansas," (1963) by M.S. Bedinger, L.F. Emmett, and H. G. Jeffery. Information gained through the course of the study was also of great value to State water agencies.

The modeling experience developed on the Arkansas River project provided a springboard for completing a study of what was called the Cache River system in which it was shown that ground water moved from east to west through Crowleys Ridge, which always had been considered a nearly impermeable boundary. The study also showed that a large percentage of the ground water withdrawn from the "shallow" aquifer west of Crowleys Ridge came directly from the Cache River through infiltration.

Ground-water levels declined as much as 75 feet over a 1,000-square-mile area of Arkansas, known as the Grand Prairie region, from pumping water for rice irrigation. A study of artificial recharge through wells in the Grand Prairie region that began before 1957 and continued until 1963 was documented in WSP 1615–A through H (see Part IV, "Artificial recharge through wells, Grand Prairie region, Arkansas").

Other major needs for water information were not neglected. Floods became a major concern as flood plains became more developed. James L. Patterson wrote "Floods in Arkansas, magnitude and frequency," which was released to the open file in 1961. "The Flood of July 16–17, 1963, in vicinity of Hot Springs, Arkansas" by R.C. Gilstrap and R.C. Christensen documented a major flood and was open-filed in 1963.

Patterson also wrote "Storage requirements for Arkansas streams" that was published in 1967 by the Arkansas Geological Commission (AGC) as Water Resources Circular 10. The AGC published in 1965 M.S. Hines' "Water-supply characteristics of Arkansas streams" as Water Resources Circular 9. Although Arkansas is a water-rich State, there was much interest in the use of water, as evidenced by the publication by the AGC in 1960 and again in 1965 of "The use of water in Arkansas" by H.N. Halberg and J.W. Stevens as special ground-water report No. 9 and as Water Resources Summary No. 5.

Reorganizing and integrating the Branches and their staffs into an interdisciplinary group opened new opportunities for assistance to water-information users in Arkansas. Immediately after reorganization, plans were made to investigate and report on the water resources of groups of counties. Reports on streamflow, ground water, and the quality of both, for about a dozen counties were published as WSP's in 1966, 1967, and 1968 and more were in the pipeline. WSP 1857, "Water resources of Grant and Hot Springs Counties, Arkansas," (1968) by H.N. Halberg (geologist), C.T. Bryant (chemist), and M.S. Hines (engineer) typified the cross-discipline makeup of the District team who worked on this group of studies. Hines wrote the surface-water parts of the first five WSP's that were published on the county studies.

Notable studies were made on waste assimilation of Arkansas streams and the hydrology of Horseshoe Lake in eastern Arkansas.

### *Water Records*

Water records are summarized as of 1962, about the midpoint of this period of history, from information contained in "Water resources investigations in Arkansas, 1962."

Streamflow Records.—Exclusive of partial-record sites and gaging stations operated by the Little Rock, Memphis, Tulsa, New Orleans, and Vicksburg Districts of the Corps of Engineers, there were 86 continuous-record gaging stations operated by the SWB in Arkansas of which 45 were classified as primary, 17 as secondary, and 24 as water-mamagement stations.

Ground-Water Records.—The statewide network of observation wells totaled 534, and there were an additional 1,094 project wells in the Arkansas River Valley that were measured periodically.

Water-Quality Records.—Samples for chemical-quality analyses were taken daily at 10 streamflow stations, monthly at four, daily for suspended sediment at one station, and water temperatures were measured daily at 10 stations.

### Funds and Cooperation

The table that follows summarizes the amounts and sources of funds available for water-resources investigations by the District for most fiscal years from 1958 to 1966. The sources were the Federal (Fed), cooperative (Coop), other Federal agencies (OFA), and the Federal Power Commission (FPC). The FPC amount was paid by Arkansas Power and Light Company.

Arkansas District funds
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 134.0 | - | 142.2 | - | 212.8 | - | 241.1 | 264.4 | 276.7 |
| OFA | 134.5 | - | 131.6 | - | 104.3 | - | 132.3 | 235.8 | 242.7 |
| Fed | 53.1 | - | - | - | - | - | - | 20.1 | 24.3 |
| FPC | 1.0 | - | - | - | - | - | - | 1.4 | 1.4 |
| Total | 322.6 | - | - | - | - | - | - | 521.7 | 545.1 |

Source: Figures for 1958, 1965, and 1966 are from District program documents and are considered reliable. Those for 1960, 1962, and 1964 are from Headquarters compilations and are of unknown reliability.

During the fiscal years 1958 through 1967, the AGC, headed by Norman F. "Bill" Williams, State Geologist, was the principal State cooperator for the hydrologic-data programs and other water-resources studies. A major reason for SWB and QWB moving to Little Rock in the early 1960's was to enjoy closer proximity to the office of AGC. Continuity of a water-study program is of utmost importance. Few District programs can match the continued support of that provided by the AGC and Bill Williams for more than 40 years. The AGC's share of the Coop program nearly doubled from $50,000 in fiscal year 1958 to almost $100,000 in fiscal year 1966. The Universities of Arkansas and Missouri contributed small amounts of coop money, mainly for collecting hydrologic data, as did several other State agencies.

The State Highway Commission, with its cooperative support of such activities as reports on floods, bridge-site reports, and drainage-area compilations, was a major cooperator during most of this period. Its contribution to the Coop program in fiscal year 1966 was $26,000. One report to the Highway Commission by the District on the Red River near Fulton showed that the hydraulics of the design flood permitted reducing the elevation of the proposed highway 5 feet and eliminating several bridges planned to carry overbank flow. Savings to the Highway Commission were sufficient to pay their share of the cooperative program for years.

The Corps of Engineers contributed by far the largest amounts of OFA money during this period because of the magnitude of the work requested of the District for the Corps' Arkansas River navigation system. The Corps also repaid the District for its work on the White and Red River Basin comprehensive river-basin plans. Much smaller amounts were paid by other Federal agencies such as the Public Health Service and the Soil Conservation Service for short-term assistance.

The success of the District staff in accomplishing its mission was greatly abetted by asking for and using the assistance provided by Division experts and specialists located throughout the United States. Among those were Rolland W. Carter, Tyrus B. Dover, William J. Drescher, John C. Ferris, O. Milton Hackett, John D. Hem, A. Ivan Johnson, Donald Hillier, Hugh H. Hudson, Marshall E. Jennings, C. Lee McGuinness, Thad G. McLaughlin, Eugene P. Patten, Mervin S. Petersen, Henry C. Riggs, Stanley P. Sauer, Robert W. Stallman, and Timothy D. Steele.

## California

*By* Lee R. Peterson, Willis L. Burnham, *and* Stanley F. Kapustka with the assistance of retirees Charles F. Berkstresser, Jr., Robert Brennan, Robert M. Busch, Stuart H. Hoffard, Raymond Kiser, R. Stanley Lord, Glen A. Miller, Winchell Smith, Helen St. John, Arvi O. Waananen, James E. Weir, Jr., *and* Loren E. Young *and* current (1989) District staff members James M. Knott, Nancy Ordazzo, *and* John R. Ritter (Harrisburg, Pa.)

Programs continued to be developed, administered, and executed by the Branches until early 1964, when California was designated a Division District. By 1965 the District was functioning on a Division basis and continued so through the remainder of this period of WRD history.

The period 1957 to 1966 brought unprecedented growth in population, agriculture, industry, government installations, and a host of other large water-use facilities that could not be served without transfer and storage of huge quantities of water. The California Department of Water Resources (DWR) was the State agency primarily responsible for developing, designing, and constructing the California Water Plan (CWP) and continued to be the principal agency in the cooperative program with the Survey.

The importance of ground water and the geologic subsurface framework within which the resource occurs was driven home to California during and in the two decades following World War II. Ground water was critical in the CWP, and the State turned to the WRD to provide information and expertise to play out that role.

The forces that drove the growth of interest in California ground water were (1) the growing realization that much of the potable municipal and quality-controlled industrial water supplies must come directly from ground water; (2) large areas of newly irrigated agricultural lands above irrigation canals or outside areas serviced by surface water that were experiencing serious problems of declining ground-water levels, overdraft, potential water-quality degradation and land-surface subsidence; (3) land-surface subsidence caused by ground-water withdrawal and irrigation of lands never before irrigated that threatened the Delta-Mendota Canal and broad areas of San Joaquin Valley as well the city of San Jose; (4) seawater intrusion into coastal ground-water basins as levels of freshwater were drawn down, thus degrading or threatening loss of large municipal and industrial supplies; (5) effective design and operation of a new aqueduct system under the CWP required utilization of potential ground-water storage capacities and supply potential throughout the ground-water basins of the State. The State required every county, city, and water agency to assess water needs and resources and to declare their planned degree of participation in the CWP distribution system; and (6) existing Federal military and civilian installations continued to grow. Each required major reassessment and development of potable and operational water supplies from ground water. Military bases at Twentynine Palms and at Edwards, the Inyokern Naval Weapons Center, Camp Irwin Army Training Center, Barstow Marine Camp Supply Center, and several other military installations are all desert stations totally dependent on ground-water supplies. Camp Pendleton Marine Corps Base (MCB) and several other military and governmental installations were involved in water-right litigation. The WRD furnished technical guidance throughout those proceedings.

As these principal forces came into play, they impacted every level of adjacent and already established water-use systems. The Camp Pendleton adjudication involved Indian Reservation lands and water rights. Twentynine Palms MCB water development triggered litigation over the city of Twentynine Palms and Joshua Tree National Monument ground-water supplies, thus urging the National Park Service (NPS) to reassess its water-supply planning. All of these NPS reassessments included GWB studies or technical involvements. Many elements of the Federal-State cooperative program, and some other Federal agency studies, required a long-term data base and extended monitoring or continuing technical input. Few areas had an adequate hydrologic data base. The years 1957 to 1966, therefore, saw increases in programming and staffing to carry on the Division and Branch roles in the growth of utilization and management of water resources in California.

## Organization and Personnel

### *Surface Water Branch (1957–64)*

SWB activities in California included the continuation and extension of a substantial program of collecting streamflow data, reporting on floods, and making special studies that had evolved over a period of many decades. The program was developed and conducted largely in cooperation with many State and Federal agencies and numerous county and public agencies.

The data-collecting program was large and widespread. Operating, directing, and managing the program was facilitated through subdistrict offices and field headquarters.

The District office was at the Survey Center at 4 Homewood Place, Menlo Park, having moved there from San Francisco in March 1957. R. Stanley Lord was District Engineer until July 1959 when he became Branch Area Chief (BAC), PCA. He was succeeded by Walter Hofmann, formerly of the Los Angeles SWB office. Donald R. Milliken served as Assistant District Engineer until his resignation in January 1960, after which Lee R. Peterson served as the Assistant.

Rose Isaacman was District Clerk and later became Administrative Assistant. Other personnel assigned to the District office for all or part of the period included David E. Click, John R. Crippen, Russell W. Cruff, Charles F. Hains, Harry Hulsing, Leonard N. Jorgensen, Hallard B. Kinnison, Tom O. Miller, Saul E. Rantz, Herman A. Ray, Winchell Smith, and Loren E. Young.

Branch Subdistrict offices (earlier designated "area offices") were in Menlo Park, Sacramento, and Los Angeles. These offices performed all field and office work within their designated areas, except for gaging stations operated under provisions of FPC licenses and permits, which were operated from the Menlo Park Subdistrict office. Each Subdistrict contained several field headquarters.

One of the significant developments that occurred in this period of WRD history was the rapid increase in the use of technicians and the rise of several of them to positions of responsibility in the data-collection program. A partial list of male technicians in that category includes Terrel A. Cooper, John Duensing, Dwight S. Ewing, Eugene J. La Cornu, Jay R. Foulk, Donald T. Hartley, Thomas C. Hunter, Glenn Lang, Francis B. McGraw, Vincent Piro, and Robert E. Whitman. Entry of female technicians into the technical work force occurred toward the end of the previous decade and expanded during the current period. A partial list of senior female technicians included Elenere

A. Amidon, Lucile Coleman, Seraphine R. Coleman, and Sally E. Walker. By 1966 these individuals were carrying significant responsibilities in the analysis and publication of streamflow data.

Personnel assigned to each Subdistrict for all or part of the period included:

Menlo Park.—Peterson was Engineer-in-Charge until 1960, succeeded by Mearle M. Miller until 1962, by David B. Anderson until 1963, and then by Jorgensen until 1964 when the Branch District converted to a Division organization. Other personnel included Lucile Coleman, James L. Cook, Theron R. Dosch, Stanley H. Jones, John T. Limerinos, Tom O. Miller, Joe N. Robles, Robert J. Smith, and George Yamanaga. Numbers of support personnel varied from 13 to 22. Field headquarters in Eureka, Santa Rosa, and Salinas were supervised from Menlo Park.

Sacramento.—Willard W. Dean was Engineer-in-Charge, assisted primarily by Edward J. Jones. Franklin C. Craig, Donald Richardson, and Arnold C. Swanson were among those who served in Sacramento. Numbers of support staff varied from 20 to 30. Field headquarters supervised from Sacramento were in Redding, Merced, and Visalia.

Los Angeles.—William M. Littlefield was Engineer-in-Charge, assisted by Marion B. Scott. Clasen E. Burgess, John R. Crippen, Daniel E. Havelka, Walter Hofmann, Vito J. Latkovich, William C. Peterson, Bert W. Thomsen, and K. Fritz Schumaker were among those who served there. Support staff varied from 10 to 15 persons. Field headquarters supervised from Los Angeles were in Escondido, San Bernardino, and Solvang.

#### *Ground Water Branch (1957–64)*

The GWB in California during 1957 to 1964 started several new projects and continued the growth in significant accomplishments in areas established during the previous decade under the guidance of Joseph F. Poland and George F. Worts, Jr.

In late 1956, Worts was District Geologist with District headquarters at 2929 Fulton Avenue, Sacramento. He was assisted principally by George H. Davis and a staff of 11. Fred Kunkel was the geologist in charge of an Area Office at 221 Redondo Avenue, Long Beach, with seven assistants, and Harry D. Wilson, Jr., was the engineer in charge of an Area Office in the Post Office Building, Santa Barbara, with a staff of five.

By July 1957, Wilson had transferred to Sacramento as principal assistant to Worts, and the District office staff had grown to 20. The Long Beach office was now a Subdistrict headquarters with Kunkel in charge of eight personnel, and the Santa Barbara office was also a Subdistrict headquarters with Robert E. Evenson as Geologist-in-Charge, assisted by four. Because of California's size, geographic barriers, and the differences in emphasis and scope of various District program elements, each of the three offices operated as rather distinct, cohesive units. Their histories during this period can best be recounted by treating them individually, even though ground-water study needs for the various county and State cooperators and other Federal agencies were the central program threads common to all three offices.

District headquarters staff, involved in the subsidence research and mechanics-of-aquifer studies under Poland, included William B. Bull, Richard L. Ireland, Ben E. Lofgren, and Francis S. Riley. Other principal District headquarters staff working on San Joaquin and Sacramento Valley studies and other central coastal projects in 1957 were Wendell A. Cochran, Robert H. Dale, George H. Davis, Jack H. Green, George S. Hilton, Robert L. Klausing, Raymond E. Miller, and Perry R. Wood. Anne G. Husted continued as District Clerk, and Frank A. Shelton headed the drafting and illustrating activities. In November 1958, Worts transferred to Menlo Park to become Branch Area Chief and Wilson took over as District Engineer. About that time, Davis transferred to the Washington office and Glenmore M. Hogenson, Kenneth D. Wahl, and Elver J. McClelland joined the Sacramento office staff. Robert H. Meade, Jr., joined Poland's research group.

In 1960, Kunkel transferred from Long Beach to Sacramento to become Wilson's assistant until 1962, when he was designated District Geologist following Wilson's transfer to St. Louis, Mo. Other staff changes during this period at the District office included the reassignments of James J. French and Mack G. Croft, and the rehiring of Willis L. Burnham in 1962 as Assistant District Geologist.

In 1957, the Long Beach office was staffed with Geologist-in-Charge Kunkel, John S. Bader, Burnham, Lee C. Dutcher, Ronald W. Page, Marvin A. Pistrang, and Francis S. Riley. Lela M. Moore was principal clerk. Burnham resigned in mid-1957 to work for Los Angeles County on a project that led to construction of a freshwater barrier to seawater intrusion of coastal aquifers in the Los Angeles Basin. This project was based in large part on the earlier work of Poland, Arthur M. Piper, Horace G. Thomasson, Jr., Allen Sinnott, and Arthur A. Garrett (WSP's 1109, 1136, and 1461). The staff of the Long Beach office carried out a broad range of ground-water studies throughout southern California for the Army, Navy, Marine Corps, National Park Service, Bureau of Indian Affairs, and the Department of Justice and for the State of California and special studies for counties, cities, and water districts. Principal staff changes during this period included the reassignment of Kunkel as Assistant District Geologist to Sacramento and the transfer of Dutcher in 1960 to Tunisia. Dutcher returned in 1963 and headed the Subdistrict following the reorganization as a Division District. Glenmore M. Hogenson and Paul M. Johnston headed the office for brief periods and Henry B. Dyer, James J. French, Glen A. Miller, and James E. Weir, Jr., were senior members of the staff. With the reorganization, the office was moved to Garden Grove where all Division activities were consolidated under Dutcher, assisted by Marion B. Scott. By 1966, there were 18 professionals and a like number of technicians and clerks on the staff.

The Santa Barbara area office, in early 1957, was staffed by Engineer-in-Charge Wilson, Robert E. Evenson, Kenneth S. Muir, two engineering aids, and clerk Bernice F. Toucey. Principal program elements included detailed studies in the highly-developed agricultural coastal valley areas as related to the BOR and CWP plans. Ground-water studies at the Point Mugu, Hueneme, Vandenberg, and Point Arguello military bases were also carried out. Wilson was reassigned to Sacramento early in 1957, leaving Evenson as geologist-in-charge. Glen A. Miller joined the staff in 1958. Evenson transferred to the District staff in Sacramento in 1963 and was replaced by Miller, who transferred to Long Beach in 1964. Gilbert F. LaFreniere was then in charge, followed by Wolfgang Swarzenski. The office became a field office under the Garden Grove Subdistrict in 1964.

#### *Quality of Water Branch (1957–64)*

A systematic program of water quality (chemical) observations and analyses, started in 1951, was continued and expanded during this period of WRD history.

The QWB District office was at Sacramento in space adjacent to that of the GWB. Eugene Brown was District Chemist until August 1964 when he transferred to Denver, Colo. In 1956, the staff of 17 included eight chemists and nine technicians and clerks whose responsibilities included operation of the chemical and sediment laboratories.

The fluvial-sediment discharge program, begun in 1956 and 1957, included establishing a sediment laboratory at Sacramento. George Porterfield transferred to Sacramento from Albuquerque, N. Mex., in 1958 to develop and direct the program. He was assisted by Robert D. Busch, LeRoy Gamble, and Darrell Sloan. Others assigned to the District for all or part of the period included Robert Brennan, Addie Davis, Kay F. Harris, James Helm, Benjamin L. Jones, Raymond T. Kiser, James Knott, John Ritter, and William Silvey.

#### *Water Resources Division (1964–66)*

Upon designation of California as a Division District in early 1964, the District headquarters was established at Menlo Park with Hofmann as District Chief and Peterson as Assistant. The District was divided into three Subdistricts with headquarters in Sacramento, Menlo Park, and Garden Grove.

The Menlo Park Subdistrict covered the coastal areas north of the Santa Maria River drainage and was headed by Jorgensen, followed in 1965 by Burnham. The Sacramento Subdistrict, under Dean, was responsible for all of interior California north of the Tehachapi Range, and the Garden Grove Subdistrict, under Dutcher, worked in the southern and southeastern parts of the State. With reorganization came major shifts of personnel and offices, as well as office closures and consolidations to better service the large mix of District programs. The WRD Organization and Personnel Directory for 1964 shows 181 people working in 19 SWB, GWB, and QWB District, Subdistrict, and field offices. By 1966, there were 220 persons in 12 District, Subdistrict, and field offices. The Garden Grove Subdistrict experienced the greatest change. Operations of the SWB Subdistrict office in Los Angeles and field offices in San Bernardino and Solvang and the GWB Subdistrict office in Long Beach were moved to Garden Grove. The Santa Barbara GWB Subdistrict and Escondido field offices remained as field headquarters. Ongoing Branch programs were melded into Division District operations, and multidiscipline programs quickly erased the separate Branch identities.

### Funding and Cooperation

Prior to reorganization as a Division District in 1964, each of the Branch programs was developed and funded essentially independently of the others. Some coordination was achieved through the California WRD Council although its oversight was generally limited to programs with DWR and the BOR. From fiscal years 1957 to 1964, SWB program funds increased from about \$860,000 to \$1,500,000; GWB funds from about \$400,000 to \$500,000; and QWB funds from about \$160,000 to about \$200,000. The following table, although based on limited information, illustrates the total WRD program size and growth from about the beginning of this period of history through its closing years. Its total program budget for any year of this 1957 to 1966 period was larger than any other district.

Its funds were derived from the cooperative (Coop) program, other Federal agencies (OFA), the Survey's Federal (Fed) appropriations, and payments from power companies who were liscensees of the Federal Power Commission (FPC).

California District funds, intermittent fiscal years
[In thousands of dollars]

| Fund source | 1958 | 1966 | 1967 |
|---|---|---|---|
| Coop | 994.4 | 1,922.0 | 2,221.9 |
| OFA | 201.0 | 401.1 | 372.4 |
| Fed | 68.5 | 230.3 | 87.2 |
| FPC | 73.3 | 191.6 | 163.1 |
| Total | 1,337.2 | 2,745.0 | 2,844.6 |

Source: Available District program documents.

### *Cooperating Agencies*

Designing and constructing the CWP was proceeding at a rapid pace. The cooperative program with the DWR was structured to provide streamflow, ground-water, subsidence, and overall water-resource-appraisal data needed in that effort. The California Department of Fish and Game provided cooperative funding for several studies concerning water-quality information on the Sacramento and San Joaquin Rivers. Additional programs were in cooperation with more than 50 county, city, or local water districts, water agencies, or flood-control districts.

### *Other Federal Agencies*

There were three U.S. Army Corps of Engineers districts in California, and each provided funds for obtaining water-resources information in its respective area of activity. Numerous Navy, Army, and Air Force Bases provided funds for water availability and suitability studies at locations in California. The BOR provided funds for collecting streamflow information at several sites in central and northern California. The U.S. Forest Service provided funds for collecting streamflow information in two National forests and for data on floods from small drainage areas. The National Park Service provided funds for water-availability studies in several National Parks, Monuments, and Seashores throughout the State. By 1966, approximately 150 streamflow and reservoir records were obtained to meet the licensing requirements of the FPC, costs of which were paid by the licensee.

A federally funded program of long-term importance was the establishment, in 1961, of "Hydrologic Benchmark" sites for long-term monitoring of precipitation, streamflow, and water quality. (See Part IV, "Hydrologic Data Networks.")

## Summary of Program

The collection, processing, and publication of water records continued to be a strong and slowly increasing component of the District program. As the principal cooperator, DWR, entered into specific design phases of the CWP, some shift in emphasis in duration and purpose of data collection also occurred.

Changes in instrumentation and the introduction of the gas-purge manometer (bubble-gage) to obtain records of stream stage aided in establishing or relocating gaging stations.

Within other elements of the District program, application of network concepts gave new direction to data collection, as did the significant advances in remote sensing and computer processing of data. These greatly improved timeliness and usefulness of publications.

### *Water Records*

Data activities are summarized as of July 1966 from information contained in the annual District work plan.

Streamflow Records.—A total of 900 continuous-record stations were operated in June 1966, consisting of 204 classified as primary (long-term hydrologic), 238 as secondary (short-term areal hydrologic), and 458 as serving water-management needs. About 30 percent of the stations had been equipped with digital recorders. Data were also obtained at more than 310 crest-stage-gage stations and at 2 low-flow partial-record stations. Continuous water-level records were obtained at seven reservoirs and daily records of contents at 14 reservoirs.

Ground-Water Records.—In 1966, the District reported 1,123 wells in the observation-well network—265 equipped with recorders and 858 measured periodically. The network wells were continually evaluated, and wells were added or discontinued in accordance with long-established plans. In addition to the long-term basic network, regional observation-well programs were carried out as part of systematic collection of ground-water data for regional or site-specific investigations.

All the ground-water programs carried out by the District, other than those solely for collecting basic records and for the furnishing of technical expertise (advice to the Department of Justice and desert military installations, for example), involved obtaining geologic and hydrologic data about the subsurface. This information was generally open-filed on a current basis and used as appropriate in subsequent maps and reports. Of particular importance were the annual reports submitted to Edwards Air Force Base, Twentynine Palms Marine Corps Base, and other bases, appraising water supplies available to those military posts.

Water-quality records.—In 1957, most of the quality-of-water program of the District consisted of collecting and analyzing water samples from streams, wells, and springs, and publishing the data in the annual WSP series. Many chemical analyses were made in connection with numerous ground-water studies, and the results were open-filed. A statewide sediment-data-collection program was begun during the 1957 and 1958 in cooperation with DWR and the Corps of Engineers.

In 1960, the District acquired an emission spectrograph, which made possible the analysis of micro quantities of minerals in water. In 1961, a cooperative program with DWR was developed to determine trace metals at about 120 sites including streams, springs, and wells, and seawater.

In 1966, there were 35 sites at streamflow stations and at 13 reservoirs where daily water-quality data were obtained and at 172 streamflow stations where periodic water-quality data were obtained. Sediment records were obtained daily at 32 streamflow sites and periodically at 47 sites.

Other Data Activities.—During 1957 to 1966, priority attention was given to measuring and documenting notable floods. Details of the floods near Fortuna were reported by Young in HA–78 (1963); of January-February 1963 in California and Nevada by Young and Harris in WSP 1830–A (1966); and of December 1964 and January 1965 by Waananen, Harris, and Williams in WSP 1866–A and B (1971). Reports on the floods of November and December 1965 in southern California by Hedman and Pearson and on the flood of December 1964 in northern California by Rantz were released to the open file.

From data published annually in open-file reports, Young, Ray, and Waananen developed more reliable estimates of the magnitude and frequency of floods on small streams, using peak-flood data from more than 310 crest-stage-gage stations.

In 1957, the development of a flowmeter for measuring flow in streams and channels subject to variable backwater began in collaboration with the DWR, the Corps of Engineers, and the BOR. Flowmeter design was by the WRD Equipment Development Laboratory in Columbus, Ohio, and field testing and second-generation development were carried out by California District and Columbus Laboratory personnel. The project was ended in 1966 after a workable prototype system was developed, demonstrating that an Acoustic Velocity Flowmeter could be built to satisfactorily gage flow in streams subject to variable backwater. The work was summarized by Winchell Smith and H.O. Wires in an open-file report, "The acoustic velocity meter—A report on system development and testing" (1967). Acoustic velocity meters later became commercially available.

#### *Special Studies*

A more complete listing of reports on the many topical, areal, and site studies that were conducted all or in part within fiscal years 1958–66 is contained in USGS open-file report 89–29. Several of the significant studies and the resulting reports are noted as follows.

Matthai, Back, Orth, and Brennan summarized the available data on surface and ground water in the San Francisco Bay area in a form useful for industrial facilities planning (Circ. 378, 1957).

Ground water conditions and storage capacity in the San Joaquin Valley were reported by Davis, Green, Olmsted, and Brown (WSP 1469, 1959).

Craig reported the factors to be considered in establishing a rating between stage and discharge on the tide-affected flow of the Sacramento River (PP 424–C, 1961).

The effect of tunnel construction on flow of springs and small streams in the Tecolote Tunnel area of Santa Barbara County was investigated by Rantz, who also reported the source of ground-water seepage that adversely affects the quality of water carried by the tunnel (PP 424–C, 1961). Rantz also reported on the effects of the differences in geology and topography on the surface-water hydrology of the coastal basins of northern California and southern Oregon (PP 424–D, 1961).

Kunkel summarized the progress of ground-water studies in the western part of the Mojave Desert region and discussed areas where further study was needed to understand the source, occurrence, and movement of ground water (HA–31, 1962).

Burnham, Kunkel, Hofmann, and Peterson reported on a study to develop a potable water supply for San Nicolas Island, about 90 miles southwest of Los Angeles (WSP 1539–O, 1963).

An account of the San Joaquin "Lake," and how, through pumping tests, water-level measurements, and geologic, hydrologic, and chemical-quality studies, the necessary data on which to base intelligent water-management decisions will be accumulated, was written by

Dale, French, and Wilson (Circ. 459, 1964). The use of ground-water reservoirs for storage of surface water in the San Joaquin Valley was studied by Davis, Lofgren, and Mack (WSP 1618, 1964).

Harris and Rantz found that a substantial increase in volume of storm runoff coincided with the period of major urban development at Permanente Creek in Santa Clara County (WSP 1591–B, 1964).

The May 1959 sediment survey of Lake Pillsbury in Lake County, when the reservoir was about 38 years old, showed that the storage capacity had been reduced from 94,400 acre-feet to 86,780 acre-feet, according to Porterfield and Dunnam (WSP 1619–EE, 1964). Rantz demonstrated a rational approach to the problem of computing snowmelt runoff of a Sierra Nevada stream (WSP 1779–R, 1964).

Cruff and Rantz reported the results of regional flood-frequency studies made by several methods using flood data from the subhumid San Diego area and from the humid coastal area in northwestern California (WSP 1580–E, 1965).

Hulsing, Smith, and Cobb demonstrated a reliable method of computing the energy-head coefficient, alpha, from conventional current-meter discharge measurements. They found that the usual assumption that the alpha value equals 1.0 in a channel with no overbank flow is greatly in error, particularly in high-friction channels (WSP 1869–C, 1966).

## Caribbean

*By* Dean B. Bogart with contributions on personnel *and* reports by Ted Arnow *and* with the assistance of James W. Crooks, Donald G. Jordan, *and* William J. Haire

### What and Where is the Caribbean District?

The Caribbean District is composed of Puerto Rico and the U.S. Virgin Islands, which are part of the long chain of islands—Greater and Lesser Antilles—that separate the Atlantic Ocean from the Caribbean Sea.

Puerto Rico, including the three largest satellite islands, comprises 3,422 square miles. San Juan, site of the District office, is about 1,050 miles east-southeast of Miami, Fla. The three largest islands of the U.S. Virgin Islands comprise 133 square miles. Charlotte Amalie, on St. Thomas Island and capital of the Virgin Islands, is 72 miles east of San Juan.

### Genesis of the Caribbean District

At the invitation of the Commonwealth of Puerto Rico, Raymond L. Nace spent a week in Puerto Rico in the spring of 1957 with officials of the Puerto Rican government laying the groundwork for a water-resources investigation. That summer Dean B. Bogart, engineer, spent a month in Puerto Rico with Alonso Aguilar, Jr. (engineer, Puerto Rico Water Resources Authority), making a reconnaissance of the island, learning the extent of water records collected by Puerto Rican agencies, conferring with Puerto Rican principals, and evaluating the need for more water data.

In late 1957, Bogart transferred to Puerto Rico and was later joined by Ted Arnow, geologist. James W. Crooks, chemist, participated intermittently, and later transferred to Puerto Rico. They were the nucleus of the Caribbean District that grew to 27 employees by 1967. The chief of the project office, later the Caribbean District, was Dean B. Bogart. Other professional personnel who served in Puerto Rico at some time during 1957 to 1966 were J.P. Akers, Walter S. Bush, Eloy Colón-Dieppa, José R. Díaz, Ennio V. Giusti, Irving G. Grossman, Irby J. Hickenlooper, Donald G. Jordan, Frank P. Kipple, Miguel A. Lopez, Frank R. Mattei, Neal E. McClymonds, John J. Murphy, Jack P. Reed, Joe N. Robles, and Porter E. Ward.

Nonprofessional staff members in Puerto Rico included José Alicea-Ortiz, Angel F. Class-Cacho, Héctor M. Colón-Ramos, Rafael Dacosta, Rosario Vidal DeFuentes, Georgina M. dePiñeiro, José Ramon Gonzalez, Ralph González, Karl G. Johnson, Elizardo Lucero, Jane W. Montgomery, Rafael A. Nazario-Ramirez, William Oquendo, Lee S. Truxes, and Pedro Vazquez.

At different times, Héctor M. Colón Ramos and Neal E. McClymonds were stationed at a field headquarters in Ponce; otherwise, all personnel were headquartered in San Juan.

### Scope of Program

The Caribbean District was among the first Districts established on an across-the-board WRD technical and management basis. That is, it encompassed the occurrence and quantity of streamflow, the occurrence and quantity of ground water, and the chemical quality of the water. No project was undertaken without these principal and interdependent aspects of water being considered.

Increasing funds from fiscal years 1958 to 1966 for operating the Caribbean District reflected the broad recognition of the need for water in fast-growing sectors of the Puerto Rican and U.S. Virgin Islands economies and the increasing awareness that the District and the WRD had the know-how and technical resources to effectively conduct water-resources investigations.

### Organizational Sequence

Although it began on Branch basis, the District rocked along for several years with the interim form of a WRD Council, the first of its kind. Then in 1962, it was formalized as a consolidated WRD District—the "new look" that made technical and organizational sense. It also made it much easier to work with cooperating agencies.

## Puerto Rico

### Early Investigations

Puerto Rico has the distinction of being the subject of one of the early Water-Supply Papers, "Water resources of Puerto Rico," by H.M. Wilson (WSP 32, 1899). Considerably later, the Survey conducted several reconnaissance ground-water studies before the Caribbean District started full-scale investigations. One of the more recent reports of this type was prepared by C.L. McGuinness and published by the Puerto Rico Aqueduct and Sewer Authority as "Ground water resources of Puerto Rico" (1948).

The government of Puerto Rico had water studies made by consultants for irrigation, hydroelectric power, and water supply for many years. Continuous streamflow records for selected streams were started about 1944 (one nonrecording station in 1907) by territorial agencies. Similarly, data on ground-water levels were collected for specific projects.

### Cooperating Agencies

Financial cooperation began in 1957 between the USGS and the Puerto Rico Water Resources Authority, the principal cooperator, the Puerto Rico Aqueduct and Sewer Authority, the Puerto Rico Industrial Development Company, and the Puerto Rico Legislative Assembly. In 1961, the Puerto Rico Department of Public Works became a cooperator.

### Preliminary Approach and Areal Studies

One of the immediate goals was to establish data-collection stations for quantity and quality of surface water and an observation-well program for ground water. The data-collection program was concurrent with detailed studies of special areas where industrial development was imminent. The first of these areal studies was of the water resources of Tallaboa Valley. A report on the study by I.G. Grossman, Bogart, Crooks, and J.R. Diaz was published in 1972 as Commonwealth of Puerto Rico Water Resources Bulletin No. 7, following earlier open-file releases.

The rainfall-runoff regimen of Puerto Rico is such that low flow in streams occurs around the end of the calendar year. The Caribbean District was able to convince WRD headquarters that the water year for the islands should be the calendar year, a departure from normal practice for surface-water records. It thus was much easier to correlate streamflow with annual Weather Bureau records and with cooperators' annual records and operations.

#### *Flood Mapping Projects*

Floods in Puerto Rico are typically "flash floods" because of the steep terrain and resultant quick response of streams to rainfall. Flooding in the mountains is confined mostly to the narrow valleys, but floodflows from the mountains spread widely over the coastal plains.

Floods have occurred that have unit peak discharges comparable with the highest known anywhere. For example, the peak of the 1960 flood on Río Grande de Loíza at Carolina, Puerto Rico, was 197,000 $ft^3/s$ from a drainage area of 239 $mi^2$, or 824 $ft^3/s/mi^2$. This flood rated 127 percent on the widely accepted Myers flood rating where 100 percent commonly is considered to be the upper limit. Flood mapping of coastal areas was started by the Caribbean District in 1962 in cooperation with the Puerto Rico Department of Public Works. Additional information on floods in Puerto Rico during this period of WRD history may be found in Circular 451 and in HA's 77, 128, 261, 262, 265, 271, 288, and 289.

#### *Special Problems of Operations*

Puerto Rico is essentially a foreign country, despite close legal association with the United States, with Spanish heritage, insular customs, and with Spanish the predominant language.

Schistosomiasis, a serious health hazard in Puerto Rico, is caused by a water-borne parasite that can penetrate skin in less than a minute and can live many years in humans. Rubber gloves and other water-protective gear were used to avoid skin contact with streamwater, which made field work time consuming and uncomfortable in the tropical climate.

Because of the flashy nature of floods in Puerto Rico, it was seldom possible to measure flood discharges using current meters. Peak discharges had to be obtained by the more costly and time-consuming slope-area, contracted-area, and flow-over-dam methods.

#### *Summary of Program and Funding*

By 1966, 12 reports had been published and data for Puerto Rico were included in 4 other reports covering the United States and Puerto Rico. Of these reports, Bulletin No. 4, "Water resources of Puerto Rico" by Bogart, Arnow, and Crooks; published in 1964 by the Puerto Rico Water Resources Authority, has been considered to be the most useful to cooperating agencies, consultants, and the public. Bulletin 4 contained HA 197 (1965) by R.P. Briggs and J.P. Akers.

By 1966, seven areal flood maps had been published as HA's or were in press; the accumulated basic water data were being assembled for publication to meet the fast-growing demand for water information; and there were 12 areal hydrology projects in progress. Also by 1966, data were being collected at 209 sites by type and frequency as shown below:

| Type of station | Continuous record | Periodic measurement |
|---|---|---|
| Ground-water level | 10* | 68** |
| Streamflow | 37* | 70** |
| Sediment in streams | 2* | 22* |
| Total | 49 | 160 |

Chemical quality determined: *at all stations; **at most stations.

Beginning in 1966, rain samples were collected for determination of tritium content as part of a worldwide network of observation stations. The District maintained its own analytical laboratory for water quality and sediment analysis.

Fiscal year funds for Puerto Rico
[In thousands of dollars]

| Fund source | 1958 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|
| Coop | 50.0 | 128.0 | 173.5 | 203.4 | 220.7 | 239.8 | 277.4 | 337.0 |
| Fed | - | 1.0 | 1.0 | 1.0 | 1.0 | - | - | - |
| OFA | - | - | - | - | - | - | 10.0 | 10.8 |
| Total | 50.0 | 129.0 | 174.5 | 204.4 | 221.7 | 239.8 | 287.4 | 347.8 |

Source: District program documents. Figures for 1959 are not available.

## U.S. Virgin Islands

### Early Investigations

Several water-resources studies were made in the U.S. Virgin Islands prior to 1962, principally of ground water. Among the early studies and reports completed during this period of history were "Ground-water data from St. Thomas, Virgin Islands" by I.G. Grossman (open-file rept., 1959); "Development of the ground-water resources of St. Croix, Virgin Islands" by Gerth E. Hendrickson (open-file rept., 1962); "Ground water for public supply in St. Croix, Virgin Islands" by Gerth E. Hendrickson (WSP 1663–D, 1963); and "Water resources of the Virgin Islands," a preliminary appraisal, by P.E. Ward and D.C. Jordan (open-file rept., 1963).

#### *Need For and Availability of Water*

The need for more water in the U.S. Virgin Islands was similar in timing and urgency to the need in Puerto Rico, but for different reasons and even greater urgency. In the early 1960's, the Virgin Islands experienced a demand for water that greatly exceeded the developed supply.

Public water supplies on St. Thomas in 1962 consisted of hillside rainfall catchments (equipped with goats!), a few dug wells, and a small seawater distillation plant. St. John was served by a hillside catchment and a dug well. The St. Croix water supply was almost entirely from drilled wells. Private homes relied largely on roof catchments and cisterns. The cities of Charlotte Amalie, Christiansted, and Frederiksted were partly served by public-supply systems. Small amounts of streamflow were available seasonally in several intermittent streams on the islands, but sites for reservoirs were meager and impractical due to land costs.

Starting in the late 1950's, water was barged from Puerto Rico to St. Thomas, but there were problems of high cost, storage, and maintaining potability. Production started in 1962 from the first seawater desalting plant built in St. Thomas, a second desalting plant came on line in 1966, and plans were being made for a third, much larger plant.

### Office Established

In 1962, Governor Ralph Paiwonsky and the Office of Territories of the DOI requested the Survey to make a comprehensive evaluation of water in the Islands. The National Park Service participated later. A field headquarters of the Caribbean District was established in 1962 in Charlotte Amalie, St. Thomas, to determine the availability of natural freshwater. Donald G. Jordan, engineer (and geologist), transferred to St. Thomas to head the office and was assisted by Oliver J. Cosner and Leo Moore. For short-term studies, other personnel were brought in from San Juan.

#### *The Program*

The WRD approach to water investigations in the Virgin Islands was the same as that for Puerto Rico: studies of ground water, streamflow, and the chemical quality of both.

#### *Data Collection and Reports*

By 1966, data were being collected at 92 sites by type and frequency shown below.

| Type of station | Continuous record | Periodic measurement |
|---|---|---|
| Ground-water level | 8* | 68** |
| Streamflow | 9* | 4* |
| Sediment in streams | | 3* |
| Total | 17 | 75 |

Chemical quality determined: *at all stations; ** at most stations.

Three major reports on work done before 1966 but published after this period of WRD history ended were "Water in St. John, U.S. Virgin Islands" by Cosner (open-file rept., 1972); "Ground water in central St. Croix, U.S. Virgin Islands" by Robison (open-file rept. 72–319); and "A survey of the water resources of St. Thomas, Virgin Islands" by Jordan and Cosner (open-filed, 1973).

#### *Special Project*

Little was known of the water-yielding characteristics of the rock that makes up the hills and mountains of the U.S. Virgin Islands, except as learned from relatively shallow, drilled, vertical wells. Two horizontal holes, 562 and 803 feet in length, were drilled in 1966. The shorter hole produced no water and the longer hole, only a small amount. The negative result of the project was beneficial, however, for it stopped further speculation and investment in that type of drilling.

### Side Glances

The WRD families lived in temporary housing built by the military before World War II, but managed by the quasi-governmental Virgin Islands Corporation in the 1960's. The houses were not much to look at, but the roofs didn't leak, and other housing was too exorbitant to contemplate. There were some unique features, however. The rats in the ceiling never came downstairs, although Don Jordan thought they wore combat boots. Meet Charlie, a land crab that had burrowed under the foundation and lived beneath the Jordan's bathtub for several years. The house had a concrete floor, but the bathtub was fitted tightly above a same-size opening in the floor. Land crabs are large and they are noisy—they rattle.

Then there was the sparse, dry "lawn" that was peppered with hundreds of holes about an inch in diameter. Upon greeting the writer, the two young Jordan children gleefully plucked straws of grass, about 8 inches long, that they poked into two of the holes. When they withdrew the straws, it was startling, to say the least, to see a sizable tarantula on each straw! The children were unafraid and utterly delighted to demonstrate that the hundreds of holes contained tarantulas—their wildlife.

#### *Funds*

Fiscal year funds for the U.S. Virgin Islands
[In thousands of dollars]

| Funds source | 1958 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|
| Coop | 15.0 | - | - | - | 66.9 | 65.0 | 65.0 | 65.0 |
| OFA | - | - | - | - | 15.0 | 30.0 | 15.0 | 40.0 |
| Total | 15.0 | - | - | - | 81.9 | 95.0 | 80.0 | 105.0 |

Source: District program documents. Amounts for 1959–62 are not available.

## Colorado

*By* Robert Brennan assisted *by* Donald L. Coffin, John E. Moore, Stanley W. Lohman, Russell H. Langford, *and* Harold E. Petsch, Jr.

Streamflow, ground-water, and water-quality programs in Colorado were developed, administered, and conducted by the Branches throughout this period of WRD history.

### Organization and Personnel

In 1957, District offices of the SWB and GWB were located in Building 25 at the Denver Federal Center in Jefferson County about 3 miles west of Denver. In 1962, a QWB Subdistrict office (of the Salt Lake

City, Utah, District) was established at the same location. In 1963, the SWB and QWB offices were moved to an office builing on Ammons Street a mile east of the Federal Center and were again moved in 1965 to the Villa Italia shopping center, about 1.5 miles east of the Federal Center. The GWB offices were also moved at this time to the Villa Italia shopping center, again placing the three Branch offices together.

#### Surface Water Branch

The SWB District in 1957 was composed of the States of Colorado and Wyoming and was under the direction of Jack M. Terry, who succeeded Francis M. Bell as District Engineer when Bell was named SWB Area Chief in January 1957. Jack Terry was District Engineer until his death in November 1957. Wallace T. Miller was then District Engineer until 1961, when he was transferred to Branch headquarters in Washington, D.C. On Miller's departure, John W. Odell was transferred from Maryland to Colorado to be the District Engineer—a position he held through the remainder of this period of WRD history. It was also in 1961 that Wyoming became a separate District with its headquarters in Cheyenne.

In 1957, there were subdistrict offices in Denver and Grand Junction, Colo., in Casper, Wyo., and a field headquarters office in Lamar, Colo. In 1960, a field headquarters office was reestablished in Durango, Colo.

The Denver Subdistrict was headed by Cavis B. Ham until July 1958 when he was transferred to Albany, N.Y. Augustine N. DePaulo, who was in charge of operations in the Denver Subdistrict, succeeded Ham as Subdistrict Chief.

Edward J. Tripp was in charge of the Grand Junction Subdistrict until October 1957 when he was transferred to Denver as the Assistant District Engineer. Russell E. Whiteman was then placed in charge of the Grand Junction Subdistrict, a position he held through the end of this period of WRD history. Everett A. Hopper was transferred from Grand Junction to Durango in 1960 to head that field headquarters.

In 1957, the Casper, Wyo., Subdistrict was under the leadership of George L. Haines. When Wyoming became a separate District in 1961, Haines and the Casper staff reported to their new District headquarters in Cheyenne.

A field-headquarters office was in Lamar, Colo., with Ross W. Moor as Engineer-in-Charge throughout this period of WRD history.

Among other senior members of the SWB Colorado staff at various times during this 1957–66 period were engineers Joe L. Blattner (WAE), Robert L. Einarsen (WAE), Clifford T. Jenkins, Harold E. Petsch, Jr., George E. Phillipsen, Roger I. Smith, Robert J. Snipes, and Walter C. Vaudrey; and engineering aids and technicians Harold E. Burch, Harold E. Hodges, and Marvin W. Quinlan.

#### Ground Water Branch

In 1957, Thad G. McLaughlin was District Geologist for GWB operations in Colorado, continuing in that position until 1959 when he was named Branch Area Chief, RMA, succeeding Stanley W. Lohman. Edward A. Moulder became District Engineer in August 1959 and continued in this position until 1962 when he was named Branch Area Chief, PCA. Moulder was succeeded by Leonard A. Wood, District Geologist through the end of this period of WRD history.

Among the members of the GWB staff at various times during the period 1957–66 were geologists Matthew E. Broom, William D.E. Cardwell, George H. Chase, Donald L. Coffin, Lloyd A. Hershey (who began his career as a physical-science aid), James H. Irwin, Harold E. McGovern, John E. Moore, Rex O. Smith, Paul T. Voegeli, William G. Weist, and Frank A. Welder; and engineers R. Theodore Hurr and Edward D. Jenkins. Support personnel included physical-science aids Arnold J. Boettcher, Thomas J. Major, Paul A. Schneider, Jr., and engineering technician Woodrow W. Wilson. Early in this period, a field headquarters was maintained at Ft. Morgan with Neil M. MacNeill in charge.

#### Quality of Water Branch

Prior to August 1961, water-quality activities in Colorado within the Missouri River Basin were conducted by the Nebraska QWB District; the Arkansas River and Rio Grande Basins water-quality work was done by the New Mexico QWB District, and the Colorado River Basin water-quality activities were handled by the Utah QWB District. In August 1961, with the transfer of Russell H. Langford from Washington, D.C., to Salt Lake City as District Chemist, Utah District, all water-quality activities in Colorado were assigned to the Utah District. At about this time, C. Albert Harr was reassigned from the QWB research laboratory at the Denver Federal Center to the Utah District; however he retained his headquarters in Denver. In August 1962, Robert Brennan was transferred from Sacramento, Calif., to Denver to head the Denver field headquarters of the Utah District. Harr then moved to Salt Lake City as assistant to Langford. Later in 1962, the Denver field headquarters became a subdistrict office of the Utah QWB District. In addition to

Brennan, the Denver Subdistrict staff included physical-science aids Richard K. Glanzman (later, geologist) and John M. Klein (later, civil engineer).

### Funding and Cooperation

Funding for District operations were from the Federal (Fed) program, Federal-State cooperative (Coop) program, and from other Federal agencies (OFA). The table below shows the funding by sources for each of the Branches for fiscal years 1958 and 1966. During this period, total program funding doubled, due principally to increases in Coop and OFA programs. Funds for surface-water and water-quality programs increased relatively more than those for ground-water programs primarily because of a change from basic-data collection to emphasis on interpretive studies in the SWB and QWB programs in Colorado.

Colorado District funds, fiscal years 1958 and 1966
[In thousands of dollars]

| Fund source | 1958 | | | 1966 | | |
|---|---|---|---|---|---|---|
| | SWB | GWB | QWB | SWB | GWB | QWB |
| Coop | 141.6 | 125.8 | 2.2 | 313.5 | 258.0 | 25.0 |
| OFA | 35.9 | 50.1 | 17.1 | 145.8 | 2.3 | 58.2 |
| Fed | 67.4 | 3.8 | 33.6 | 107.5 | 0 | 16.3 |
| Total | 245.0 | 179.7 | 52.9 | 566.9 | 260.3 | 99.5 |

Source: Internal program documents of the Colorado District.

#### *Cooperating Agencies*

The principal cooperators of the SWB were the Colorado State Engineer and the Colorado Water Conservation Board. Its cooperation with the State Engineer was largely an evaluated-services program in which USGS matched funds expended by the State Engineer to operate its streamflow-measuring stations throughout the State. Most of those streamflow records were reviewed and published by the Survey and constituted a significant part of the streamflow data network in Colorado. Other SWB cooperators were the Denver Board of Water Commissioners, city of Colorado Springs, Colorado Department of Highways, Southeastern Water Conservancy District, Colorado River Water Conservancy District, and the Arkansas River Compact Administration.

The Colorado Water Conservation Board was a major cooperator with the GWB and ground-water investigations were also cooperatively funded by the Denver Board of Water Commissioners and the Ute Mountain Ute Tribe. The GWB cooperated with the Southeastern Water Conservancy District in the Arkansas River Valley of Colorado.

Virtually all of the Coop funds available to the QWB were from the Water Conservation Board—all for chemical-quality work. Much of QWB's Coop funding was to provide chemical-quality assistance to the GWB for studies in the Arkansas Valley and Piceance Basin.

#### *Other Federal Agencies*

The BOR was a major financial supporter of District activities in Colorado. Its support was largely through the Missouri River Basin (MRB) program (see Part IV, "Missouri River Basin Program") for streamflow, water-quality, and ground-water studies in the Missouri River drainage of the State. Elsewhere in Colorado, the BOR provided funds to obtain streamflow and chemical and sediment water-quality data for its Fryingpan-Arkansas project, mainly in the upper Arkansas River Basin; but streamflow data were also obtained in the upper Fryingpan River drainage where transmountain diversions were planned. Funds from the BOR also paid for streamflow and water-quality data from the Colorado River Basin.

The Kansas City and Omaha Districts of the U.S. Army Corps of Engineers paid the costs of operating several gaging stations in the Missouri River Basin, and the Albuquerque District of the Corps funded gaging-station operation in the Arkansas River and Rio Grande Basins as needed for its operations.

The SCS funded the collection of streamflow and sediment data in the Kiowa Creek Basin, tributary to the South Platte River. The data were needed to determine the efficiency of small reservoirs in trapping sediment and in reducing floodflows in tributaries to Kiowa Creek. The National Park Service funded several ground-water studies to locate drinking-water supplies in National Parks and recreation areas.

### Summary of Program

Collecting, processing, and publishing water records continued to be a major activity of the Branch Districts in Colorado, accompanied by an increasing emphasis on analytical hydrologic studies to meet the needs of water-development and management agencies.

#### *Water Records*

Streamflow Records.—In June 1962, there were 342 streamflow stations being operated by the SWB District and by the Colorado State Engineer, many of whose streamflow records were reviewed and published by the Survey. Of that total, there were 124 stations classified as primary (long-term hydrologic), 84 as secondary (short-term hydrologic), and 134 as water management (specific purpose).

Ground-Water Records.—There were 330 observation wells where ground-water levels were measured during 1962. Most were in the northeast quarter of the State, about 40 were in or near Alamosa County, and the remainder were east of Pueblo.

Water-Quality Records.—Records of chemical quality of water, suspended-sediment loads, particle-size distribution of fluvial sediments, and water temperature were obtained at 19 sites during 1962.

### Floods and Special Studies

Large floods occurred in 1965 in the Arkansas and South Platte River Basins of eastern Colorado following extremely heavy rains on June 14–17. Rainfall depths of 14 to 15 inches were recorded in large areas of both basins. In the Arkansas River Basin, heavy rains fell on the Fountain Creek Basin near Colorado Springs on June 14. On June 16 and 17, intense rainfall occurred in the upper Fountain Creek Basin and in the southeastern corner of Colorado. In the South Platte River Basin, heavy rainfalls occurred over the Greeley-Sterling area on June 14–15, over the Plum Creek and Cherry Creek Basins on June 16, and over the headwaters of Kiowa and Bijou Creeks on June 17. Hydrologic details of the South Platte River floods were published in WSP 1850–B (1969) and of floods in the Arkansas River Basin of Colorado, in WSP 1850–D (1974).

Increasing urbanization generated a need for peak-flow data on small streams in many areas of the State. In 1962, HA 41, "Floods of Boulder, Colorado," by C.T. Jenkins was published and provided the technical basis for flood-plain zoning by the city of Boulder.

Of the special studies that were conducted all or in part during FY 1958–66, several are considered especially significant because of their application to hydrologic problems or to major water-resources problems that later developed in the area of study. Those in this category are summarized below.

Coffin and Welder studied the water resources of the Piceance Basin to provide the framework for subsequent comprehensive hydrologic investigations of the oil-shale area of the basin. Representative of the reports that resulted from these studies was HA–370 (1971) by Coffin, Welder, and R.K. Glanzman.

Beginning in 1956 and continuing through 1966 and beyond, Boettcher, Chase, Coffin, McGovern, Voegeli, and Weist conducted county-level studies of the Ogallala Formation in Colorado that provided a foundation for subsequent ground-water investigations designed to provide water managers with information applicable to modern management of the Ogallala. Typical of the reports on these studies was WSP 1539–J by W.G. Weist (1964) and Circular 8 by H.E. McGovern and D.L. Coffin published by the Colorado Water Conservation Board (1963).

From 1961 to 1970, Coffin, Hershey, Hurr, Moore, Jenkins, and O. James Taylor conducted a quantitative hydrologic-system study of the Arkansas River Valley from Pueblo, Colo., to the Kansas border. Its purpose was to provide information for planning, managing, and administering the total water supply, taking into account the conjunctive use of ground and surface water. The analog model constructed for the project was the largest built by the WRD at 48 feet long and 6.5 feet high. In 1963, the Colorado Water Conservation Board published preliminary results of the study as its Circular 10, by Moulder, Jenkins, Moore, and Coffin.

Other Investigations.—The GWB staff concentrated most of its efforts on areal investigations that described the geology and ground-water resources of counties or drainage basins. The data that were collected and the concepts that were developed set the stage for the problem-oriented and more detailed studies that began in and after the late 1960's. In addition to county-by-county studies of the Ogallala, the Missouri River Basin program funded ground-water investigations in the South Platte River Valley from Denver to Kersey (WSP 1658, 1964) by R.O. Smith, P.A. Schneider, Jr., and L.R. Petri and in the Cache La Poudre River Valley from Fort Collins to Greeley (WSP 1669–X, 1964) by L.A. Hershey and Schneider. Among the ground-water investigations funded by the cooperative program were Prowers County (WSP 1772, 1965) by P.T. Voegeli, Jr., and Hershey; Otero and southern Crowley Counties (WSP 1799, 1965) by W.G. Weist, Jr., E.D. Jenkins, and C.A. Horr; and Fountain and Jimmy Creek Valleys (WSP 1583, 1964) by Jenkins and R.E. Glover.

## Connecticut

*By* Frederick H. Ruggles, Jr., *and* Robert V. Cushman

Programs were developed, administered, and conducted by the Branches, with coordination by the WRD Council, from 1959 to the end of this 1957–66 period of WRD history.

## Organization and Personnel

### *Surface Water Branch*

The SWB District office was in the old Federal Building on High Street near the railroad station in Hartford. Burke L. Bigwood was District Engineer until June 30, 1959, when he retired after 40 years of service, the last 30 as District Engineer. He was succeeded by John Horton who transferred from the Director's Office in Washington, D.C. Horton also chaired the Connecticut WRD Council. Mendall P. Thomas became the Assistant District Engineer in 1964. Carolyn R. Scarrone served as District Clerk until 1961 when she resigned and was succeeded by Gertrude L. Donahue who resigned in 1965. Donahue was succeeded by Austin D. Dubon.

With the arrival of John Horton, half of the professional staff were sons of retired District Engineers. John was the son of A.H. Horton who led the Maryland District and Miner B. (Jim) Stackpole was the son of Miner B. Stackpole who led the Maine District. The Connecticut SWB District had to lead or the sons would have been led to the woodshed by their fathers.

The staff during this period were pretty much New England born and educated. Mendall P. Thomas, a Connecticut native, spent all of his career in Connecticut; Stackpole came down from Maine and stayed for his entire career except for 2 years in Trenton, N.J.; and Burke came to Connecticut in 1957 from New Hampshire via Boston and Chattanooga and remained in Connecticut until he retired. In 1960, Lawrence A. Weiss, another Connecticut native, joined the staff.

As the workload increased, the staff was also increased. William R. Kaehrle and Henry R. LaRose were hired as engineering technicians in 1962, completed their college work, and were (after 1966) reclassified as hydrologists. In 1964, Michael A. Cervione transferred from New York and in 1965, Frederick H. Ruggles came up from Texas to join the SWB staff of the "Nutmeg" State.

### *Ground Water Branch*

GWB investigations were conducted out of the Subdistrict office on Main Street in Middletown during the entire period of this history. The Middletown staff reported to Mineola, N.Y. which until early 1965 was the GWB District headquarters for operations in New York, Connecticut, and Rhode Island. Robert V. Cushman was Geologist-in-Charge until his transfer to Kentucky in 1961. He was succeeded by John A. Baker. Work continued to be done under the guidance of the Mineola office until February 1965 when Ralph C. Heath became District Chief in Albany, N.Y. Heath relinquished his responsibilities in Connecticut at the time of consolidation of the three Branches in late 1966. During the period 1957 to 1962 the office was manned by three geologists, Cushman, Albert M. LaSala, Jr., and Allan D. Randall. Helena A. Otte was the clerk-stenographer.

Charles W. Spencer joined the group in 1958–59 on detail from Mineola to compile data on buried bedrock valleys in southern Connecticut. The results of this study were published as PP 454–M (Upson and Spencer, 1964).

In 1961, John A. Baker transferred from Boston as Cushman's replacement and began the ambitious program of evaluating the ground-water resources of Connecticut as authorized by the General Assembly in 1959.

In 1962, the Branch staff was increased with the addition of geologists Irving G. Grossman and William E. Wilson and physical-science aid Robert L. Meikle. As the program intensified, geologists Robert B. Ryder and Robert L. Melvin joined the staff along with cartographer Frank G. Boucher. When Helena Otte resigned late in this period of history, she was replaced by Dorothy C. LaBella.

### *Quality of Water Branch*

All water-quality work in Connecticut was handled from the Albany, N.Y., QWB District office, Felix H. Pauszek, District Chemist. Water-quality activities were limited to the collection of data at several surface-water stations and the analyses of samples obtained during the course of ground-water investigations. Most of the field work was done by George J. Conzeri, a hydrologic technician headquartered in Albany. His ability to complete his tasks on time are legendary and the stories of his exploits are always the center of discussion when alumni gather to reminisce. The professional water-quality staff in Albany during much of this period included W. Arthur Beetem, Calvin D. Albert, John A. Shaughnessy, and Chester E. Thomas, Jr. In January 1964, Thomas was transferred to Hartford as the water-quality specialist in Connecticut. His influence on the water-quality program was immediately felt and the program rapidly began to expand.

### *Funding and Cooperation*

As shown in the table below, cooperative (Coop) program funds accounted for the bulk of funding throughout the 1957–66 period—up to 99 percent in 1961. Federal (Fed) funds and funds from other Federal agencies (OFA) provided the remainder. Significant increases began in 1963 as State-cooperator funds became available for basin studies.

Connecticut District funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 95.7 | 99.8 | 94.5 | 110.8 | 148.8 | 209.8 | 240.8 | 242.2 | 285.0 |
| OFA | 4.6 | 5.0 | 4.6 | 0 | 0 | 0 | 0 | 0 | 0 |
| Fed | 5.1 | -- | 18.7 | 8.6 | 4.5 | 4.0 | 6.7 | 7.4 | 10.0 |
| Total | 105.4 | -- | 117.8 | 111.4 | 153.3 | 213.8 | 247.5 | 249.6 | 295.0 |

Source: District program documents except for FY 1959, which is from a Headquarters compilation from unknown sources.

#### *Cooperating Agencies*

The Connecticut Water Resources Commission (CWRC) was the principal cooperator throughout the period for statewide streamflow, ground-water, and water-quality data collection and areal hydrologic studies. William S. Wise and Jack Curry of the CWRC actively supported the cooperative program with the State Legislature.

The Connecticut Department of Transportation supported the collection of flood data on small streams.

The Hartford Flood Commission and the cities of Hartford, Torrington, and New Britain provided support for the operation of gaging stations.

#### *Other Federal Agencies*

The U.S. Army Corps of Engineers provided funds for the collection of streamflow records on streams where records were needed for the operation of flood-control reservoirs.

### Summary of Program

Until 1961, the collection, processing, and publication of water records was the primary focus of the program. Major products were reports on the ground-water resources in north-central Connecticut, several quadrangle ground-water maps, and the ground-water levels of Connecticut. Beginning in 1961, program growth was in interpretive basin studies. By the close of this period, five of the basin studies were essentially completed or well underway.

### Water Records

#### *Streamflow Records*

The number of continuous-record stations ranged from a low of 45 to a high of 87 (1965) and ended the period with 59 stations. Of the 87 stations operated in 1965, 24 were classified as primary, 30 as secondary, and 33 as serving water-management needs. Also in 1965, there were 132 low-flow partial-record stations and 45 crest-stage stations being operated.

#### *Ground-Water Records*

In 1965, there were 30 ground-water observation wells in the State hydrologic evaluation.

#### *Water-Quality Records*

In 1962, records of chemical quality were collected at 15 sites. Miscellaneous records for general hydrologic purposes were obtained at 114 chemical-quality surface-water sites, at 135 chemical-quality wells, and at 34 streamflow sediment sites. As the statewide water-resources investigations by basin began to be implemented, the number of chemical-quality surface-water sites increased to 170, chemical-quality precipitation sites to 11, streamflow sediment sites to 41, and ground-water wells to 420.

### Special Studies

In 1959, the Connecticut General Assembly, on recommendation of the CWRC authorized a "water-resources inventory of Connecticut to be prepared by the Geological Survey to determine the quantity and quality of water available at any location in the State by dividing it into 10 study areas based on major basins." The studies began in 1961 and became a key factor in interbranch coordination leading to Division-level operations.

Ground-Water Mapping Studies.—During the period preceding the initiation of the "basin studies" in 1961, the primary emphasis on the ground-water program was the mapping of ground-water conditions in broad areas such as the entire northern part of the Connecticut River Valley, which was the tobacco-growing area in Connecticut, the Farmington River Valley to the west, and the Bristol-Plainville-Southington area in the Quinnipiac River Valley. This reflected the broader interest of the CWRC with which the cooperation was then carried on vis-a-vis the municipalities, which had been faced with local ground-water problems. The ground-water mapping studies were designed to provide information for locating wells or expanding existing water-supply installations owned by industries, municipalities, and individuals. The products of the studies were reports that provided information on the principal water-bearing formations, their ability to yield water to wells, the quality of the ground water, and the methods for its recovery. Results of studies of the above-listed areas were published as WSP 1752 (Cushman, 1964); WSP 1661 (Randall, 1964); and WSP 1579 (LaSala, 1965). The basic data collected for these investigations, which included records and logs of selected wells and test borings, and chemical analyses, were published by the CWRC as Bull. No. 3 (Randall, 1966); Bull. No. 4 (Cushman, Baker, and Meikle, 1964) and Bull. No. 5 (LaSala and Meikle, 1964).

During the period in which the ground-water mapping studies were carried on, the Connecticut Geological Survey began an extensive program of geologic mapping in cooperation with the USGS. A bedrock geologic map and a surficial geologic map were to be prepared for each topographic quadrangle in the State. GWB personnel participated in this program by mapping in detail the surficial geology of one quadrangle in each of the ground-water study areas. They were published in the Geologic Quadrangle (GQ) series of USGS reports as GQ–146 (LaSala, 1961) and GQ–223 (Cushman, 1963). The surficial map of the Tariffville Quadrangle by Randall was in progress at the close of this period.

(Note by Ralph C. Heath: The ground-water programs in New England went through an interesting evolution during the Leopold years. In the mid-1950's, Joseph E. Upson, II, then District Geologist, GWB, New York District, with the support of Headquarters, insisted that ground-water geologists should be involved in "pure" geologic mapping. The Geologic Division (GD) strongly objected, but an agreement was reached whereby GWB would map one 7.5-minute quadrangle and GD would map three 15-minute quadrangles. With the implementation of this policy, the GWB staffs in Connecticut and Massachusetts, and Rhode Island to a lesser extent, largely switched from ground-water studies to geologic mapping. Most of the GWB studies initiated in these States during this period were on the basis of quadrangles. George Taylor and I succeeded in getting Connecticut and Rhode Island out of "pure" geologic mapping and into comprehensive studies. We also moved away from 7.5-minute quadrangle ground-water reports, which are suitable only for general nonquantitative coverage.)

As a part of both the ground-water mapping and the geologic mapping programs, the USGS published contour maps of the buried bedrock surface under the extensive valley fill in the Broad Brook and the Manchester Quadrangles in its Miscellaneous Investigations Series (I) as I–401 (Cushman and Colton, 1963) and I–402 (Colton and Cushman, 1963).

GWB personnel in Connecticut also participated in a Rhode Island program to prepare a ground-water map of each topographic quadrangle in Rhode Island. The Connecticut part of some of the border quadrangles common to both States were mapped by personnel in Connecticut.

<u>Areal Water-Quality Studies</u>.—A program to appraise the chemical and physical quality of surface and ground waters of Connecticut was underway in 1957 and was designed to provide information on solutes, temperature, and suspended sediment. The first product of this program, published by the CWRC in 1961 as Bulletin No. 1, by F.H. Pauszek, gave a broad-brush review of the quality of the water of Connecticut. The next product, also published by the CWRC as Bulletin No. 6, by Pauszek and R.J. Edmonds, described the water quality of the Housatonic River.

<u>River-Basin Studies</u>.—In 1961, the District began the water-resources inventory by basins that was authorized 2 years earlier. Initiation of the basin studies signaled a change from a program primarily oriented to the collection of basic data to one designed to use the basic data for interpretive reports.

The general objective of the inventory was to determine the quantity and quality of water available at any location in the State. To accomplish this, the State was divided into 10 study areas, based on major drainage basins. By 1966, studies of the Thames, Shetucket, Quinebaug, and Housatonic River Basins and the southwestern coastal river basins were underway. The results of those studies were published by the CWRC in its Bulletin series.

<u>Connecticut River Tidal Study</u>.—In 1965, SWB District personnel installed a gaging station on the tide-affected Connecticut River to determine the tidal interchange that was taking place in the 60-mile-long estuary that entered Long Island Sound. Flow records obtained at the station were used in the design of a nuclear power station, by the Connecticut Department of Fisheries, and for several studies concerning Long Island Sound and were also used in a later open-file report, "Evaluation of flow in tidal reaches of the Connecticut River by mathematical model" by Chintu Lai, Ruggles, and Weiss (1971).

<u>Industrial Area Reports</u>.—In 1959, the Branch Districts began preparing a series of reports on the water resources and water utilization in selected industrial areas of national importance. The reports summarized available information for use by defense and nondefense industries and by municipalities for the preliminary planning of new works or the expansion of

existing facilities. Personnel from the three Branches summarized data and prepared reports on the Hartford-New Britain and the Waterbury-Bristol areas. The cross-fertilization of ideas and data was another step in interbranch coordination leading to Division-level operations. The reports were published as WSP 1499–H (Cushman, Tanski, and M.P. Thomas, 1964) and WSP 1499–J (Cushman, Pauszek, Randall, and M.P. Thomas, 1965).

Hartford Research Center Study.—The Survey was asked by the AEC in 1956 to make field studies of the geology and hydrology at the site of a proposed nuclear engineering laboratory to be located on a high-level terrace adjacent to the Connecticut River southeast of Middletown. Personnel of the three Branches operating in Connecticut determined the source, rate of recharge, movement, and quality of the water in the aquifer underlying the terrace and the eventual movement of a liquid spill anywhere on the surface. Results of the study were published in USGS Bull. 1133–G (Baker, Lang, and M.P. Thomas, 1965).

## Delaware

*By* Donald R. Rima, reviewed *by* Durward H. Boggess, *and* with subsequent assistance from Judith M. Denver

### Organization and Personnel

#### *Surface Water Branch (1957–64)*

During the years 1957–64, the SWB program in Delaware was administered and directed by the College Park, Md., District. John W. Odell was District Engineer until he transferred to Colorado in 1962. He was succeeded by William E. Forrest, who served as District Engineer until 1964 when that position was abolished with the reorganization to a Division operation.

SWB activities in Delaware were under the supervision of the engineer-in-charge of the Subdistrict office located at 604 Fairview Avenue in Dover, Del. In early 1957, Arthur E. Hulme was in charge. Later in the year, he was succeeded by Wilson G. Bonham who, in turn, was succeeded by Philip Pfannebecker in 1961. Others assigned to the Dover office during the period included Marie A. Balda, Wallace M. Bryant, Richard A. Gardner, Charles E. Kobb, Andrew E. Marsh, Marjorie S. Martin, Harry R. Moore, Elizabeth T. Short, Robert H. Simmons, and Wilbert O. Thomas, Jr. The number of people assigned to the Dover office ranged from three to five.

In addition to operating the gaging stations in Delaware, the Dover Subdistrict was also responsible for the stream-gaging work in the adjacent area of Maryland known as the Eastern Shore.

#### *Ground Water Branch (1957–63)*

The GWB program in Delaware was administered and directed from the District office in Newark (emphasis on the last syllable), Del. The office occupied about 1,000 square feet on the ground floor of a one-story annex to a three-story structure fronting on the main street of a small college town in northern Delaware. Entrance to the office was from a side door off an alley leading from the front of the building. The floor plan consisted of one large room with bank-type partial partitions separating the several "stalls" for individual staff members.

The program was under the direction of District Geologist William C. "Wild Bill" Rasmussen who had directed the work in Delaware from an office in Salisbury, Md., prior to moving to Newark. "Wild Bill," so called for his fearless advancement of new and daring explanations of hydrogeologic phenomena, is best known for his water-budget study of Beaverdam Creek Basin (WSP 1472, 1959) and his dissertation on the "Origin of the Carolina Bays and Basins." In 1959, "Wild Bill" was replaced by another controversial character, Donald R. Rima, from the neighboring Harrisburg, Pa., District office. Rima was replaced in July 1962, by Durward H. Boggess, who had contributed significantly to every GWB project undertaken in the Delmarva Peninsula.

A field office under the supervision of the Newark office and staffed by Richard A. Wilkens and Oscar J. Coskery, was located in Georgetown, Del., at the beginning of the period, but it was closed in 1957. Wilkens was transferred to Huron, S. Dak., and Coskery, to Newark.

Several others who contributed to the work of the Delaware District during the 1957–63 period, in order of their appearance, included Betty J. Linehan, Catharina R. Groot (wife of the major State cooperator), Eleanor E. Hartman, Mona W. Dike, Clarence R. Sweetman, Jr., Robert C. Crouch, Lora E. Watson, Mary W. Taylor, Christian F. Davis, Kate D. Rambo, and Joseph R. Cherney. Many of the foregoing individuals served in part-time positions. The size of the staff rarely exceeded six people.

The Newark (Delaware) District office ceased to exist in FY 1963, ending a sometimes stormy relationship between officials of the State and Federal geological surveys. The State officials were dissatisfied with the cost and progress of the projects and the Federal officials were concerned with the State's accounting for direct and reimbursable expenditures. The best solution seemed to be to discontinue the GWB activities, effective by the end of FY 1963.

### *Quality of Water Branch*

QWB operations in Delaware were under the administrative and technical supervision of the QWB District office in Philadelphia, Pa. Norman H. Beamer was District Chemist throughout the period covered by this report. The individuals most closely linked to the work of the QWB in Delaware were Leo T. McCarthy, Bernard Cohen, and Peter W. Anderson.

### *Water Resources Division (1965–66)*

During FY 1965, the Delaware District was merged with the Maryland District and reorganized into a WRD District with headquarters in Towson, Md. The new WRD District was under the direction of John W. Wark. The new organization brought little change in the personnel assigned to the WRD program in Delaware. On the contrary, the only personnel still active and headquartered in the State were the Dover Subdistrict staff. The GWB staff had been reassigned elsewhere following the cut-off of cooperative funds from the Delaware Geological Survey at the end of FY 1963. Durward H. Boggess was the last of the GWB to leave. He was transferred to Salisbury, Md., and later to Florida. The bulk of WRD's work was carried out by the staff of the Dover office under the direction of Philip Pfannebecker, Engineer-in-Charge. He was assisted by Charles E. Kobb, Marjorie S. Martin, Robert H. Simmons, and Wilbert O. Thomas, Jr.

## Funding and Cooperation

The WRD program in Delaware was supported mainly by funds provided under the terms of cooperative (Coop) agreements with State and local government agencies. Small additional sums (usually 5 percent or less) were derived from agreements with other Federal agencies (OFA) and from the Survey's Federal (Fed) program. The source, amount and trends of funding for the Delaware District are shown in the following table.

Funds for Delaware WRD operations, fiscal years 1950–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 78.2 | -- | 74.2 | 86.8 | 89.5 | 81.6 | 39.0 | 43.9 | 51.2 |
| OFA | 4.9 | -- | .7 | .8 | .8 | 1.4 | 4.4 | 4.6 | 4.6 |
| Fed | 11.9 | -- | 4.0 | 3.7 | 3.7 | 4.2 | 4.0 | 4.1 | 3.6 |
| Total | 95.0 | -- | 78.9 | 91.3 | 94.0 | 87.2 | 47.4 | 52.6 | 59.4 |

Source: District program documents (not available for 1959).

### *Cooperating Agenciesa*

The principal State cooperating agency in Delaware during the 1957–66 period was the Delaware Geological Survey (DGS). Other State cooperators included the Delaware Highway Department, the cities of Newark and Seaford, and the Chester County (Pennsylvania) Soil Conservation Department. Although somewhat unusual, a small amount of funding was received from the Pennsylvania Department of Forests and Waters to obtain precipitation records at stations in Delaware. The largest share of the cooperative funding was for areal studies or investigations by the GWB. The next largest share was for the collection of streamflow records by the SWB.

In order to coordinate the efforts of the State and local cooperating agencies, the DGS assumed the role of chief negotiator for the State of Delaware. This arrangement was particularly evident in the program of the GWB. For example, funds provided by the Delaware Highway Department to support the water-table and engineering-soils mapping project were first transferred to the DGS and combined with funds from other sources to make up the State's share of the program costs.

### *Other Federal Agencies*

As shown in the foregoing table, very minor funding was obtained from other Federal agencies. The U.S. Army Corps of Engineers provided a small amount for collecting surface-water data. Likewise, the Air Force provided funds for some quality-of-water work at its base in Dover.

## Summary of Program

At the beginning of the 1957–66 period, the WRD program in Delaware was as diverse as any in the Nation. Funds were allocated among the four Branches as follows: SWB, 27 percent; GWB, 57 percent; QWB, 12 percent; and GHB, 4 percent. About half of the program was devoted to the collection of basic records, 42 percent was for areal investigations and the balance was used to fund a GHB research project. By the end of the period, however, the distribution of funds among the program elements had changed drastically so that nearly three-fourths of the effort was devoted to the collection of water records and the remainder was used for areal studies.

## Water Records

### *Streamflow Records*

Throughout the period, streamflow records were obtained from a network of 15 or 16 stations including 4 long-term hydrologic stations, 5 or 6 short-term hydrologic stations, and 5 to 7 specific-purpose or water-management stations. Three of the long-term stations were part of the Federal program, but the rest of the network was supported by the State cooperative program. Besides the continuous-record stations, periodic records were obtained from about 20 crest-stage gages and about 12 low-flow partial-record stations.

### *Ground-Water Records*

According to program documents for the 1957–66 period, the observation-well network in Delaware consisted of two continuous-record stations and six or eight monthly measurement stations. There was also an extensive state wide network of shallow observation wells that were measured a few times each year as part of the water-table and engineering-soils mapping project. Most of the observation-well network was maintained in cooperation with the DGS prior to 1963. Thereafter, the collection of ground-water records in Delaware was supported solely by the Federal program.

### *Water-Quality Records*

Water-quality data were obtained from 19 sites at the beginning of the period, but by 1964 the number of sites had been reduced to fewer than 10. Additional data were obtained on a reconnaissance basis at numerous sites scattered throughout the State. The type of data collected included chemical and physical quality and suspended-sediment concentrations. The frequency of sampling ranged from continuous to intermittent. The most common frequency of sampling was monthly.

## Areal Studies

In Delaware the traditional county ground-water studies took what was then the uncommon "water-wide" approach in which both surface- and ground-water resources were described. The first of these studies covered northern New Castle County (DGS Bull. 6, 1957). This was followed a few years later by Sussex County (DGS Bull. 8, 1960). The next area in order of priority was southern New Castle County (DGS Bull. 11, 1964), for which only the ground-water resources were included in the study. Kent County, the third and to-be-last of the series, was not completed due to an interruption in the cooperative program.

Rasmussen sought to find an answer to the perplexing question of how the small, shallow, oval-shaped, water-filled depressions that occur commonly in outcrop areas of marine Pleistocene sediments were formed. The origin of the depressions, called "Carolina Bays," has variously been attributed to meteorite scars or possibly to sinkhole collapse. As a result of his research, however, both of these hypotheses had to be vacated and were replaced with a fairly complex explanation. Rasmussen's hypothesis began with what was then a brand new concept, that of transport of colloidal particles through soil pores by infiltrating ground water. The removal of colloids from the surficial soils beneath depressions in the newly emerged land mass and subsequent loss of support caused the surface to subside and create a shallow, undrained depression. The oval shape was explained by the action of the prevailing southeasterly winds creating waves on the surface of the water perched within the depression. The wave action was then credited with eroding the shoreline into an oval shape with the elongation parallel to the wind direction. According the available records, the results of Rasmussen's study were the basis of his dissertation submitted to Bryn Mawr College, possibly in 1958, in partial fulfillment of the requirements for his Ph.D.

A major thrust of the areal-studies program in Delaware during the period of this report was the innovative project to map both the water table and the surface soils throughout the State. The task of mapping of the water table alone proved to be a monumental task. An even greater challenge was the field and laboratory work necessary to determine the engineering properties of soils in sufficient detail to map the soils at a scale of 1:24,000. The project took nearly 10 years to complete and required the services of a dozen people ranging from hourly workers to dig soil-test pits to consultants on the faculty of the University of Delaware.

The results of this monumental effort were published in 1962–65 in more than 30 HA's, from numbers

60 to 141, entitled "Water-table, surface drainage, and engineering soils maps of the (name of 7.5-minute quadrangle) area, Delaware." The senior authorship alternated between the principal investigators: Boggess, who led the hydrologic effort, and John K. Adams, who supervised the preparation of the soils maps.

Experiments were undertaken to determine the feasibility and desirability of using recharge to increase the city of Newark's water supply. The experiments began with infiltrometer tests and graduated to full-scale tests on recharge basins. The infiltrometer tests were conducted and reported on by Catherina Groot (AWWA Jour., v. 52, no. 6, 1960). The recharge basin experiments were directed by Boggess, who reported the results with Rima (WSP 1594–B, 1962).

Results of a study of the relation between the flow of the Delaware River and the position of the saltwater tongue in the estuary were reported by Cohen and McCarthy (WSP 1586–B, 1963).

Rasmussen, Odell, and Beamer coauthored the special report, "Delaware Water" (WSP 1767, 1966). (See Part IV, "Water Resources of States.")

The District's contribution to the Delaware River Basin project dealt with the availability of water supplies from the Coastal Plain sediments. (See Part IV, "Delaware River Basin Project.")

### "Wild Bill" Rasmussen

No account of the Survey's activities in Delaware would be complete without at least some mention of the role played by William C. "Wild Bill" Rasmussen. He was more than the father of the program. He was its heart and soul. Although many stories can be told about him (some might even be true), no one story can capture the true personality and character of the man we all knew as "Wild Bill" Rasmussen. Instead it would take several stories to reflect his wisdom, his resourcefulness, his ambition, and his abilities.

Bill's wisdom can be seen in his many offerings of solutions to the problems of the day. Bill had lots of solutions. For example, as a participant in the Delaware River Basin project, Bill became aware of the many problems involving the quality of the Delaware River water. In typical fashion, he proposed a comprehensive plan for the control and improvement of the quality of the Delaware River. The plan was, to say the least, innovative if not sheer genius. It included a barrier dam to prevent the upriver migration of the saltwater tongue during low flow of the river and the construction of a canal to carry the industrial wastes past the many water-supply intakes along the river. The dam was unusual in that it was not a rigid structure. Rather it was a plastic membrane or sheet that would be placed in the bottom of the river so as to block the upriver intrusion of saltwater. The bottom of the sheetlike dam would be attached to the bed of the river while the top would be allowed to float up or down depending on the pressure of saltwater on the downstream side of the dam. Thus, the lower the flow of the river, the higher the top of the dam would rise to keep the saltwater from moving upstream. The waste canal would, of course, be constructed to discharge below the saltwater dam.

An example of his resourcefulness can be found in his handling of the GWB program in Delaware. Before moving to Delaware, Bill was headquartered in Salisbury, Md., where he directed the Beaverdam Creek project, a landmark water-budget study. He was also responsible for overseeing the ground-water program in Delaware. He saw in Delaware an opportunity for growth if only the State had a suitable cooperating agency. He set about to correct this deficiency. In what seemed like overnight there came into being a Delaware Geological Survey with a mandate to enter into cooperative arrangements with the USGS. With a suitable cooperator to work with and lots of project ideas, it did not take Bill long to put forth a vigorous program of hydrologic studies.

Bill's personal ambition shows up in many ways, not the least of which was his desire to obtain a doctor's degree. He is one of the first males to obtain a doctorate in geology from Bryn Mawr, a previously all-girls school in southeastern Pennsylvania. He was awarded the degree in 1957, after completing his dissertation on the "Carolina Bays." To say that he was proud of this accomplishment would be a mild understatement. A few days after the degree was awarded, Bill had the fact recorded on his office door in big gold lettering which read, "Dr. W.C. Rasmussen." When news of this reached certain quarters, word came back to get a picture of Bill's office door and send it to the staff of the Survey's Pick and Hammer show. That year the show roasted the WRD and its new leaders. Among the songs in the show was one titled "Call Me Doctor" sung to the tune of "Pretty Baby." The program contained a picture of (you guessed it) "Wild Bill's" office door.

Perhaps the best account of Bill's ability as a professional geologist is his accomplishments on behalf of WRD's Radiohydrology Section. After being relieved of his duties as District Geologist in Delaware, Bill was assigned to that Section and given an incredible task. The task—to assess the feasibility of radioactive waste disposal in not one but 18 ground-water provinces—was to be completed in a single calendar year. To get some idea of the monumental size of this job, there were two or three other senior scientists assigned to similar work. The difference was their assignments were for a single ground-water province and they each had 3 years to complete their projects. Believe it or not, Bill rose to the task and finished his job on time. He followed that assignment with several projects to evaluate the effects of subsurface testing of atomic weapons in the desert Southwest.

Bill left the Survey for greener pastures in the consulting field. It was in that capacity that he was working in Vietnam when the jeep in which he was riding struck a land mine, ending the career of one of the Survey's most colorful personalities. We share with his family this tragic loss. Hats off to you Bill, wherever you are.

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## Florida

Based on material provided *by* Roland W. Pride *and* Nevin D. Hoy, assisted *by* retired District personnel Clyde S. Conover, Richard C. Heath, Howard Klein, William F. Lichtler, Frederick W. Meyer, Stanley D. Leach, Horace Sutcliffe, *and* John D. Warren

The Florida District functioned on Branch lines until early 1965. Although many of the programs were carried out under Branch supervision during the period 1957–64, several investigative projects were jointly developed and executed by hydrologists representing each Branch under the technical supervision and coordination of the Florida WRD Council.

In February 1965, Florida was designated a Division District with headquarters in Tallahassee. Transition to the new organization was accomplished with little difficulty because interbranch working relationships had been established through joint investigations prior to 1965, personnel from all three Branches were on duty in Florida, and relatively few personnel moves were required.

### District Organization

#### *Surface Water Branch (1957–64)*

The SWB District office was at Camp Roosevelt, about 3 miles south of Ocala, until May 1961 when it was moved to a new Federal Building in Ocala. Archibald O. Patterson was the District Engineer until he retired in September 1964. Roland W. Pride was the Assistant District Engineer during the entire period covered by this history.

Subdistrict offices were at Miami with James H. Hartwell, Engineer-in-Charge, succeeded in 1963 by Stanley D. Leach; at Sebring with Walter R. Murphy, Engineer-in-Charge, succeeded in 1962 by John D. Warren; and beginning in 1960, at Ocala with Raymond S. Charnley, Technician-in-Charge, succeeded in 1964 by James W. Rabon, Engineer-in-Charge.

#### *Ground Water Branch (1957–64)*

The GWB District headquarters was in the Gunter Building on the campus of Florida State University in Tallahassee. Matthew I. Rorabaugh was the District Engineer until 1961 when he was transferred to the office of the Branch Area Chief, PCA. Clyde S. Conover, formerly Assistant Chief, GWB at the Washington Headquarters, succeeded Rorabaugh in February 1962. Nevin D. Hoy served as administrative geologist during this period. A Subdistrict office with Howard Klein, Geologist-in-Charge, shared offices with the SWB Subdistrict office in Miami.

Field headquarters, generally for the short duration of a project by a small staff, were maintained at various times at Daytona Beach, Gainesville, Jacksonville, Lakeland, Melbourne, Naples, Orlando, Panama City, Pensacola, Pompano Beach, Sarasota, St. Augustine, and Tampa.

#### *Quality of Water Branch (1957–64)*

The QWB District headquarters shared the building at Camp Roosevelt near Ocala with the SWB. James W. Guerin was the District Chemist until 1961, when he moved to St. Louis, Mo., to be Branch Area Chief, MCA. He was succeeded by Kenneth A. MacKichan, who transferred from the GHB, Washington, D.C., to serve as District Engineer. James W. Crooks was the Assistant District Chemist until 1959 and was succeeded by Boyd F. Joyner, who transferred from Raleigh, N.C.

The District water-quality laboratory in Ocala became one of the major District laboratories in the Nation following its move to the new Federal Building in 1961. The laboratory provided water-quality information and services for WRD activities in Florida, Georgia, Alabama, South Carolina, and North Carolina.

***Water Resources Division (1965–66)***

Florida was reorganized as a Division District in early 1965 with headquarters in the Gunter Building in Tallahassee. Conover was named District Chief and Pride transferred from Ocala to be the Assistant District Chief. Leach was reassigned from Miami to the District office as Chief of Operations. Gilbert H. Hughes transferred from Yuma, Ariz. Lawrence M. MacCary transferred from Denver, Colo., to serve as District reports specialist, and Donald F. Tucker, cartographic technician, was hired. Other former GWB staff in Tallahassee remained on the WRD District office staff with added responsibilities.

Subdistrict offices after the reorganization included Miami, with Howard Klein as Hydrologist-in-Charge, and Ocala, with Leonard J. Snell, who transferred from Brazil, as Hydrologist-in-Charge. Tampa was designated a Subdistrict office in 1966 with Joe W. Stewart as Hydrologist-in-Charge and staffed by GWB personnel from the former Tampa field headquarters and by Rodney N. Cherry, James A. Mann, William M. Woodham, and William L. Fletcher, who transferred from Ocala, and Walter R. Murphy, from Sebring. John D. Warren was reassigned from Sebring to Miami, and then Sebring became a field headquarters. The District water-quality laboratory remained in Ocala with Boyd Joyner as Chemist-in-Charge.

***Personnel***

In 1957, the District personnel, including all Branches, consisted of 73 members: 34 engineers, geologists, and chemists; 28 aids and technicians; and 11 clerks and typists. In 1966, the total District personnel was 115, consisting of 53 hydrologists, engineers, geologists, and chemists; 46 aides and technicians; and 16 clerks and typists.

Following are the names, tenures, and Branch affiliations prior to 1965 at each headquarters of the Florida District during the period 1957–66. Additional temporary, short-term employees, who are not listed, served at various times as construction and maintenance workers, draftsmen, and laboratory aides.

At Ocala: Paul R. Adamek (SWB) 1959–61, Helen J. (MacLain) Anderson (SWB, QWB) 1957–66, Warren Anderson (SWB) 1957–66, Priscilla A. Audleman (SWB) 1962–66, Leslie L. Batts (QWB) 1963–66, Michael E. Beard (QWB) 1964–66, James L. Black (SWB) 1960–63, Arthur L. Bonnet (SWB) 1963–66, Wayne C. Bridges (SWB) 1960–66, Robert H. Burch (SWB) 1960–61, Carl J. Cash (SWB) 1961–66, Kenneth W. Causseaux (SWB) 1958–64, Raymond S. Charnley (SWB) 1957–66, Rodney N. Cherry (QWB) 1958–64, James W. Crooks (QWB) 1957–59, Ray E. Cunningham (SWB) 1957–66, Arnold I.B. Davis (SWB) 1957–59, Mary A. Davis (QWB) 1958–60, Catherine L. Cole (QWB) 1958–61, Donald C. Collins (SWB) 1960–66, Robert H. Collins 1965–66, Glenn A. Farmer (SWB) 1957–59, Glen L. Faulkner 1966, Lonny C. Fincher (QWB) 1955–57, William L. Fletcher (SWB) 1964–66, Herbert N. Flippo (SWB) 1964–66, Milton S. Gardner (SWB) 1957–66, Harold L. Gary (SWB) 1962–66, James W. Geurin (QWB) 1957–61, James B. Gore (QWB) 1957–66, Donald A. Goolsby 1965–66, Rodney F. Grantham (QWB) 1960–62, Jack Hardee (QWB) 1961, Mary J. Haugan (QWB) 1963–66, Richard C. Heath (SWB) 1957–66, Justin R. Hodges (SWB) 1961–64, Otis Ted Holly (SWB) 1960–62, Deanne M. Hughes (SWB) 1964–66, and Harold D. Jordan (QWB) 1957.

Also at Ocala: James L. Joslin (SWB) 1959–62, Boyd F. Joyner (QWB) 1959–66, Darwin D. Knochenmus 1965–66, James N. Krider (SWB) 1961–62, Frances P. Leake (SWB) 1957–66, Suzanne C. Lee (SWB) 1963–64, Leonard E. Lindahl 1965–66, Kenneth A. MacKichan (QWB) 1961–65, James A. Mann (SWB) 1960–64, Curtis Lee Martin 1965–66, Paul Meadows (SWB) 1964–66, Clarence C. Menke, (QWB) 1957–61, Edwin W. Meredith (SWB) 1957–63, Alan Lee Messmore (SWB) 1958–62, Donald F. Meyers (QWB) 1960–64, Roland W. Pride (SWB) 1957–65, Rufus H. Musgrove (SWB) 1957–64, Ernest K. Newbern (SWB) 1957–60, James W. Nichols 1965–66, Charles A. Pascale 1965–66, Archibald O. Patterson (SWB) 1957–64, Fred L. Pfischner 1965–66, Eleanor L. Pille 1965–66, Phillip W. Potter (SWB) 1957–66, Alta S. Privett (QWB) 1957–66, James W. Rabon (SWB) 1964–66, Richard D. Ray (SWB) 1958–60, Harry C. Rollins (SWB) 1964–66), William J. Shampine (QWB) 1961–64, Donald E. Shattles (QWB) 1959–64, Donald M. Shaw (SWB) 1963–64, Robert W. Sheets (SWB) 1960–63, Leonard J. Snell 1965–66, Florence D. Speir (SWB) 1957–66, Marvin N. Spinks (QWB) 1964–66, Garnet K. Stack (QWB) 1959–66, Roy B. Stone (SWB) 1957–65, Floyd E. Supianoski (SWB) 1962–66, Louis M. Teboe (QWB) 1957–64, Robert S. Teboe (QWB) 1962–64, Larry G. Toler (QWB) 1961–66, William M. Woodham (SWB) 1957–65, Merle S. Wesley (QWB) 1957–66, William O. White (QWB) 1958–64, and E. Turner Wimberly (SWB) 1964–66.

At Tallahassee: Dorothy I. Barber (GWB) 1957–58, Joseph E. Barclay (GWB) 1957–58, Faye L. Barnette (GWB) 1964–66, Jack T. Barraclough (GWB) 1957–58, Delbert W. Brown (GWB) 1957–63, Robert H. Burch (GWB) 1962–63, Margaret A. Cason (GWB) 1965–66, William E. Clark (GWB) 1963–64, Marilyn Y. Clarke (GWB) 1957–61, Clyde S. Conover (GWB)

1962–66, James H. Criner (GWB) 1959–60, Carl F. Essig (GWB) 1957–66, Lenora C. Finch (GWB) 1959–66, James B. Foster (GWB) 1959, Henry G. Healy (GWB) 1959–66, Martha L. Hall (GWB) 1957–66, Nevin D. Hoy (GWB) 1957–66, Gilbert H. Hughes 1965–66, Luther W. Hyde (GWB) 1960–63, Elizabeth B. Irvine (GWB) 1963–64, Vance C. Kennedy (QWB) 1958–60, William E. Kenner (SWB) 1957–66, Robert T. Kirkland (QWB) 1960–66, Stanley D. Leach 1965–66, Lawrence M. MacCary 1965–66, Jonathan B. Martin (GWB) 1960–66, Henry J. McCoy (GWB) 1957–58, Luther R.E. Mills (GWB) 1957–58, George Ann Osborne (GWB) 1961–63, Roland W. Pride 1965–66, Blanche D. Roache (GWB) 1958–59, Renee H. Roberts (GWB) 1962–63, 1966, Matthew I. Rorabaugh (GWB) 1957–61, Herbert G. Stewart (GWB) 1961; Horace Sutcliffe (GWB) 1959–62; John R. Teel (GWB) 1957–64; Donald F. Tucker 1965–66; and Frank N. Visher (GWB) 1963–66.

At Miami: Charles A. Appel (GWB) 1965–66, Kenneth R. Avery 1965–66, Edmund L. Beaumont (SWB) 1957–66, Morris Bellman (SWB) 1959–66, Martin C. Brooks 1966, Albert G. Carter (SWB) 1957–60, Claiborne F. Galliher (SWB) 1957–66, Jerrold M. Gans 1965–66, Rodney F. Grantham (QWB) 1963–66, David W. Gretzinger 1965–66, Robert V. Hanan (GWB) 1957–63, James H. Hartwell (SWB) 1957–66, Ronald E. Hermance (GWB) 1958–66, Aaron L. Higer (SWB) 1960–66, Jack Hardee (QWB) 1963–66, John E. Hull (GWB) 1957–66, Kenneth L. Jackson (GWB) 1957–64, Antonio Jurado 1965–66, Evans H. Keener 1965–66, Darwin D. Knochenmus (SWB) 1963–65, Howard Klein (GWB) 1957–66, Francis A. Kohout (GWB) 1957–66, Milton C. Kolipinski (QWB) 1963–66, Berton Law (QWB) 1957–60, Stanley D. Leach (SWB) 1957–64, William F. Lichtler (GWB) 1957–60, Doris B. Luethi (SWB) 1957–66, C. Brooks Martin 1965–66, Henry J. McCoy (GWB) 1963–66, Frederick W. Meyer (GWB) 1964–66, Theodore M. Miller (SWB) 1963–66, Laura G. Pollard (GWB) 1957–65, Roger P. Rumenik (SWB) 1963–66, Arthur W. Schnarr 1966, James J. Schneider (SWB) 1960–66, Clarence B. Sherwood (GWB) 1957–66, Henry J. Voegtle (GWB) 1957–66, John D. Warren 1965–66, and Lenore F. Willcox 1965–66.

At Sebring: SWB personnel Allen C. Altvater 1960–63, Robert A. Bird 1957–66, Violet C. Hollingsworth 1957–66, Charles R. Miller 1957–59, Walter R. Murphy 1957–65, Adolph Summerlin 1963–66, Roy B. Stone 1965–66, and John D. Warren 1962–65.

Field headquarters were at the following locations staffed by GWB personnel during the years indicated: Daytona Beach, Granville G. Wyrick 1957–58; Gainesville, Joseph W. Cagle 1958–61, William E. Clark 1959–62, James B. Foster 1960–61, John F. Hoffman 1958–59, and Luther R.E. Mills 1959–62; at Jacksonville, Gilbert W. Leve 1961–66; at Lakeland, George L. Hunt 1957, Frederick W. Meyer 1957–63, Luther R.E. Mills 1963–65, Herbert G. Stewart 1957–60, and Walter S. Wetterhall 1957–66; at Melbourne, James B. Foster 1957; at Naples, Henry J. McCoy 1959–62; at Orlando, William F. Lichtler 1961–66; at Panama City, James B. Foster 1962–66; at Pensacola, Jack T. Barraclough 1958–63, and Owen T. Marsh (GWB), 1958–61; at Sarasota, Horace Sutcliffe 1963–66; at Pompano Beach, George R. Tarver 1961–62; at St. Augustine, Boris J. Bermes 1957–59, 1965–66, Gilbert W. Leve 1957–60, Curtis Lee Martin 1963–65, and George R. Tarver 1957–60).

At Tampa during the years shown were Rodney N. Cherry 1965–66, Norman P. Dion 1965–66, Robert V. Hanan (GWB) 1963–66, Matthew I. Kaufman (GWB) 1963–66, James A. Mann 1965–66, Luther R.E. Mills 1966, Walter R. Murphy 1965–66, Motoko B. Reece 1965–66, Joe W. Stewart (GWB) 1963–66, Martin J. Weitzner 1965–66, Walter S. Wetterhall (GWB) 1964–66, and William M. Woodham 1966.

## Funding and Cooperation

Most of the funds for the District's programs were from the Federal-State cooperative (Coop) program and from other Federal agencies (OFA). Lesser amounts to support a few stream-gaging stations, observation wells, and water-quality analyses were from the Federal (Fed) program. The cost of operating one streamflow station was paid by the Florida Power Corporation, a licensee of the FPC.

Funds for the Florida District, including the consolidated Branch funds prior to 1965 and WRD funds thereafter, are shown in the following table.

Florida District funds, FY 1958–66
[In thousands of dollars]

| Fund Source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 521.7 | * | 680.3 | 703.8 | 771.8 | 810.2 | 1,004.6 | 1,261.1 | 1,266.4 |
| OFA | 28.1 | * | 62.8 | 92.7 | 93.0 | 113.5 | 124.5 | 115.7 | 142.2 |
| Fed | 14.4 | * | 9.4 | 8.2 | 8.4 | 8.0 | 13.9 | 19.6 | 18.2 |
| FPC | 1.8 | * | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| Total | 566.0 | * | 755.0 | 807.2 | 875.7 | 934.2 | 1,145.5 | 1,398.9 | 1,429.3 |

Source: District program documents. *Records not available.

### *Cooperating Agencies*

The Florida Geological Survey (FGS) has been, for many years, the principal Survey cooperator for statewide water-resources programs. Long-term records of streamflow, ground water, and water quality, cooperatively supported by the FGS, have been the basis of many areal studies and of indicators of changes in hydrologic conditions, statewide. The FGS was also the agency responsible for publishing nearly all of the reports on water resources prepared by the WRD in Florida. Robert O. Vernon, Director, an enthusiastic supporter of the cooperative program, assisted in arranging cooperative funding by many counties and municipalities to supplement those of the FGS.

The Florida State Road Department was a long-time cooperator in the stream-gaging program, in flood-frequency studies, and in the preparation of reports on floods at certain stream-highway crossings.

The Florida Trustees of the Internal Improvement Fund (FTIIF) with the financial collaboration of local agencies, cooperated in supporting lake-level monitoring stations and a few discharge stations at lake outlets in central Florida. Local agencies participating with the FTIIF were the Lake Apopka Recreation and Water Conservation Control Authority, Oklawaha Basin Recreation and Water Conservation Control Authority, Tsala Apopka Basin Recreation and Water Conservation Control Authority, West Orange County Conservation District, Winter Haven Lake Region Boat Course District, Highlands County, Hillsborough County, Marion County, Pinellas County, and Polk County. Reports on lake levels and variations from normal were submitted at frequent intervals to each cooperator in this program.

The Central and Southern Florida Flood Control District (CSFFCD), whose District included the upper St. Johns River Basin, the Kissimmee River, Lake Okeechobee, and the area south of Lake Okeechobee, supported extensive networks of stream- and canal-discharge stations, ground-water data stations, and water-quality sampling stations. The program with CSFFCD also included water-resources investigations of Brevard County, ground-water studies of Martin County, studies in several areas to define the surface-water/ground-water relations, a salinity study of the Snake Creek Canal area, and studies in several areas in southeastern Florida to determine the effects of water management.

In 1962, the newly created Southwest Florida Water Management District (SWFWMD) began a cooperative program with the Survey to obtain streamflow data, ground-water and lake levels, and water-quality information needed to plan, develop, and manage the District's water resources. The Green Swamp and the Mid-Gulf areas were the first to be investigated during the period of this history.

The Florida Board of Parks and Historic Memorials supported a hydrologic study of Highland Hammock State Park in Highlands County.

Many local agencies provided cooperative funds for areal studies, for the collection of hydrologic data, and for special studies in support of water-planning and management needs. These included the counties of Brevard, Broward, Collier, Columbia, Dade, Duval, Escambia, Hillsborough, Manatee, Orange, Pinellas, Polk, Sarasota, and Volusia; the cities of Boca Raton, Cocoa, Deerfield Beach, Ft. Lauderdale, Jacksonville, Miami-Miami Beach, Naples, Pensacola, Perry, Pompano Beach, Sarasota, Tallahassee, and Tampa; and the Peace River Valley Water Conservation and Drainage District, Suwannee River Authority, and West Coast Inland Navigation District.

#### *Other Federal Agencies*

The U.S. Army Corps of Engineers, Jacksonville District, paid the costs of operating several gaging stations on streams and lakes in the Florida Peninsula, particularly in the Central and Southern Florida Water Management District, and for investigating levee underseepage from Lake Okeechobee and the conservation areas. Beginning in 1966, the Corps funded an investigation of the geohydrology of the Cross-Florida Barge Canal, construction of which was resumed in 1964 but halted in 1971, and then deauthorized. The Mobile District funded the operation of two stream-gaging stations in the Florida Panhandle.

The U.S. Air Force funded a ground-water surveillance program at its Homestead Base in Dade County and for studies by Florida District personnel of ground-water supplies at down-range guided-missile stations in the British West Indies. The U.S. Navy provided funds for a water-resources study of its base at Guantanamo Bay, Cuba, in 1960–61, that involved personnel from the Florida District. The Navy also furnished partial support in 1965 and 1966 for an evaluation of the effects of water management in southeastern Florida and for data collection in southern Dade County.

The Fish and Wildlife Service provided funds to study the salinity of estuaries of the Everglades National Park, to obtain water-quality data at fish hatcheries in southeastern Florida, and to make a reconnaissance of the water resources in the Loxahatchee National Wildlife Refuge and adjacent areas of Palm Beach County.

The National Park Service funded studies of the water resources of the Everglades National Park, and the AEC financed the cost of a ground-water study of the Cape Canaveral area in 1963–64. The Area

Redevelopment Administration furnished funds in 1964 for partial support of a program to evaluate the hydrology of the Deadening Lake area in southeastern Washington County.

## Summary of Program

### *Water Records*

The collection of surface-water records was directed by Richard C. Heath, ground-water records by Henry G. Healy, and water-quality records by Boyd F. Joyner.

Data activities are summarized as of 1961, about the midyear of this period of WRD history, from "Water-Resources Investigations in Florida, 1961." However, there was significant expansion in the hydrologic data program through 1966 and beyond.

Streamflow Records.—There were 166 streamflow stations being operated in Florida in 1961, of which 56 were classified as primary (long-term hydrologic), 29 as secondary (short-term hydrologic), and 81 as serving water-mamagement needs. In addition, 168 stations were operated to obtain records of water levels only on streams and lakes. (By 1969, the station network had grown to 203 for streamflow, 244 for stage only, and 112, newly established, for partial-records.)

Ground-Water Records.—Water levels were measured in 670 observation wells in Florida in 1961, increasing to 908 in 1969. In 1962, emphasis was given to annual synoptic measurements of ground-water levels in observation wells statewide in May or June when levels are generally lowest. Records during that period provided a base for year-to-year comparison and preparation of periodic statewide assessments.

Conover and Healy were largely responsible for inspiring the punch-card system for the storage and retrieval of ground-water data. Conover was a member of the committee, chaired by Solomon M. Lang, that developed the punch-card system and manual of instructions. (See Part VII, "Function and influence of the computer in WRD.") The system was initiated in Florida in 1962–63. The Florida District was unique in applying the surface-water classification system to its observation-well network.

Water-Quality Records.—During 1961, there were four surface-water stations from which daily samples were given complete analyses, 99 from which periodic samples were given complete or partial analyses, and 8 stations where continuous conductance records were obtained. The total doubled by 1969. About 160 water samples from wells were analyzed in 1961; about 720 in 1969.

In 1966, a statewide annual water-quality sampling program of surface water began that emphasized physical and major inorganic parameters during May (normal low-flow conditions) at approximately 500 sites.

### *Hydrologic Investigations, Special Studies, and Reports*

The major growth in WRD programs in Florida during 1957–66 was in areal investigations and interpretive studies required to meet the demands for hydrologic information by cities, counties, water-management districts, State agencies, and other Federal agencies as the population of the State grew from 4.2 million in 1957 to 6.2 million in 1966. The percentage of the program budget for investigations and special studies increased from 41 in FY 1958 to 49 in FY 1966.

During the period 1957–66, about 50 water-resources investigations were initiated or being continued. Approximately half of the investigations were made to obtain knowledge of the quantity and quality of water in specific geographic areas, usually counties. Other investigations were of topical subjects such as water management, water use, floods, droughts, modeling, saltwater encroachment and the hydrology of springs and lakes.

The hydrologic investigations included those of the water resources of the counties of Alachua, Bradford, Clay and Union; St. Johns, Putnam, and Flagler; Escambia and Santa Rosa; Brevard; Hillsborough; Orange; Duval; Broward; Dade County (Area B); Lee; and of the Green Swamp, Tampa Bay, and Mid-Gulf areas; Boca Raton-Deerfield Beach and of the Myakka River and Econfina Creek basins. Studies of the ground-water resources were made of the counties of Glades and Hendry; Martin; Polk; Columbia; Collier; (central) Broward; Volusia; Seminole; Indian River; Marion; and of the Pompano Beach and Naples areas. There was a study of Florida springs and of saltwater encroachment in Dade and Pinellas Counties. Special hydrologic studies were made of the Florida cross-barge canal, the upper Old Tampa Bay, the Everglades National Park, the Venice well field, and of the Snapper Creek Canal area. In addition there was a saltwater study of the Snake Creek Canal and studies made of the low-flow characteristics of Florida streams, of water-management effects in southeast Florida, of the Hillsborough River floods at Tampa and of lake hydrology. An analog model of the Biscayne aquifer was built and water-atlas maps were prepared. Important research in the Miami area by Francis A. Kohout established the principle of cyclic flow whereby saltwater invades the lower part of the Biscayne aquifer, mixes with the inland fresher water, flows upward, and becomes part of the ground-water flow to Biscayne Bay.

Representative reports that resulted from these studies, alphabetically by principal investigator, date of publication, area or topic, and type of publication were: Anderson, Lichtler, and Joyner (1965), control of lake levels in Orange County, FGS Circular 47; Bermes, Leve, and Tarver (1963), Flagler, Putnam, and St. Johns Counties, FGS Rept. 32; Brown, Kenner, Crooks, and Foster (1962), Brevard County, FGS Rept. 28; Clark (1964), Venice well field, FGS Rept. 38; Flippo and Joyner (1968), low streamflow in the Myakka River Basin, FGS Rept. 53; Hughes (1967), Lake Jackson fluctuations, FGS Circ. 48; Hyde (1965), aquifers in Florida, Florida Bureau of Geology Map 16; Kenner (1966), runoff in Florida: Florida Bureau of Geology Map 22; Kohout (1964), flow of the Biscayne aquifer of the Miami area, WSP 1613–C; Pride (1958), floods in Florida, magnitude and frequency, Open-File Rept. FL–58002; Pride, Meyer, and Cherry (1966), Green Swamp area, FGS Rept. 42; and Sherwood and Leach (1962), Snapper Creek Canal area, FGS Rept. 24. A complete list of Florida water-resources reports by the Survey are in "Bibliography of U.S. Geological Survey Reports on the Water Resources of Florida, 1886–1986," Open-File Report 85–424.

### Other District Activities

A long-range plan for WRD activities in Florida, prepared by Conover, MacKichan, and Pride entitled "The water mapping, monitoring, and research program in Florida, 1965" was published by the FGS as Special Bulletin 13.

Water-use data from Florida were compiled in 1960 and 1965 as part of the 5-year national reports. James H. Criner directed the 1960 compilation and Pride, the 1965 compilation. Beginning in 1965, a special effort was made to improve water-use estimates by setting up procedures for measuring pump discharge and power use at key wells.

Ray E. Cunningham headed a unit to redefine the boundaries of drainage basins and to recompute drainage areas at gaging stations and at other specified locations using newly available USGS 7.5-minute quadrangle maps with 5-foot contours.

Many gaging stations were installed in canals and tidal streams in southern Florida; however, no conventional stage-discharge relations could be developed at these stations because of tidal effect or regulation by gated structures or pumps. It was therefore necessary to develop an alternate method for rating the stations. The Florida-type deflection meter, pioneered by James H. Hartwell and Stanley D. Leach of the Miami Subdistrict during this period, permitted defining the stage-discharge ratings. Although the deflection meter provided reliable field data for rating each station, the manual procedure for computing the mean daily discharge was prohibitively time consuming. Charles A. Appel and John D. Warren of the Miami Subdistrict made use of a digitizer, an electronic device that transforms graphic data to magnetic tapes, that was purchased by the WRD and assigned to the Miami Subdistrict. The use of the deflection meter and the digitizer in conjunction with a computer provided a practical method of obtaining streamflow data at sites otherwise impractical to gage.

### Vignettes

In 1957, William F. Lichtler was assigned to a project in Martin County which had started in 1955 as a 1-year study of the Stuart area and was expanded in 1956 to include the entire county. In those days, detailed instructions were given on how to pursue an investigation. For the Stuart area study, Nevin Hoy's instructions were to prepare a water-table contour map, a chloride contour map, run a pumping test, and write a report. For the 3-year Martin County study, the instructions given by Howard Klein were much more detailed: "Bill, do the rest of the county!" Those were the "good old days."

In the early 1960's at the request of the U.S. Navy, a study was made to determine the availability of fresh ground-water supplies at the Guantanamo Naval Base, Cuba. The mode of transportation from the States to the base was a 6-hour flight by military aircraft. On one of these flights, Horace Sutcliffe, Del Brown, and Willis Hyde had a somewhat upsetting experience. After 5 hours into the flight, it was discovered that the autopilot was malfunctioning and the plane was still several hours from the base and could not make it without refueling. But fortunately, a short time later they were able to land on a Bahama island and, after refueling, proceeded to their destination only 6 hours late.

Increased need for water-resources data in The Everglades led to an expanded program of data collection, analysis, and interpretation. Routine visits to remote locations in The Everglades were major challenges and sometimes adventures to hydrologists of the Miami Subdistrict. Travel to these remote locations was only by airboat, motorboat, or helicopter.

Stan Leach, accompanied by Paul Kiel, an employee of the city of Miami, was returning from one such trip to service water-level recorders when their airboat broke down about midafternoon. They were still a long distance from where they had launched the boat that morning and had no means of calling for help. So, with the prospect of spending the night, they pushed the airboat through the swamp looking for a dry place to set up camp. Nearby, they found a small island that was high and dry, and the wild oranges and grapes growing on the island were an added bonus. As night approached, they built a huge bonfire using dry wood that was also plentiful on the island. The fire served as a distress signal as well as a deterrent to the multitude of mosquitoes. They set up their jungle hammocks and mosquito nets and after foraging the island for something to eat, they settled down close to the fire for protection from the mosquitoes and slept soundly during the night. Early the next morning, they were spotted by a search plane and were soon rescued by the Coast Guard and taken to the Tamiami Trail, where they had parked their truck the previous morning. Thus ended an event that could have been an ordeal but turned out to be an interesting experience for the hydrologists.

As part of a multicounty water-resources investigation in northeastern Florida, a test-well drilling program was carried out to obtain supplemental data on the hydrologic characteristics of the shallow aquifers (0–250 feet).

James Foster, who was in charge of this phase of the investigation, experienced a tragic accident during the drilling of one of these test wells. Operations were going smoothly one afternoon at the drilling site adjacent to a State highway as Foster, the driller, and the driller's helper were engaged in their respective duties. Without warning, the land surface dropped in an area about 15 to 20 feet surrounding the well. The driller's helper, standing near the well, went down about 20 feet with the collapsing land surface and was immediately covered by several feet of soil. Foster, standing near the perimeter of the collapse, was carried laterally and downward into the sink, and was buried up to his armpits by the time the collapsing material had stabilized. The driller, standing in front of the partially submerged drilling rig, was not injured.

A sheriff's deputy drove by a short time later, saw the accident, and radioed for help, then he and the driller began rescue operations. The drilling rig was first secured to keep it from sinking further into the collapsed area. Then volunteer workers, attached by ropes, began the slow process of freeing Foster, imprisoned near the center of the collapse. After 2 or 3 hours, he was safely freed in a semistate of shock and with multiple contusions, but recovered quite rapidly. The rescue operation to free the driller's helper was a much slower and difficult process, and his body was not recovered until the next day.

Foster, recounting the details of this event, always closed his story by expressing his unhappiness at Washington for denying his claim for a new pair of boots he had been wearing for the first time and which remained behind when he was extricated.

## Georgia

*By* Albert N. Cameron *and* Harlan B. Counts, assisted *by* current Georgia District staff *and* reviewed *by* retirees Robert L. Wait *and* Robert F. Carter

### Organization and Personnel

Programs were developed, administered, and executed by the Branches until late 1965, when Georgia was designated a Division District. The District did not function on a Division-level basis until the end of FY 1966. Therefore, most personnel and programs operated as separate Branches, coordinated by the Georgia WRD Council, through this period of WRD history.

#### *Surface Water Branch*

The SWB District headquarters was in Atlanta at 795 Peachtree Street in 1957, moved to 805 Peachtree Street in 1958, and to Peachtree-Seventh Building in 1962. All office locations were near the Georgia Institute of Technology (Georgia Tech) which was desirable because the Institute furnished most of the District's coop and part-time personnel, and there was a close relationship between the District staff and the Georgia Tech Civil Engineering Department faculty.

Operations in the Georgia District would have been much more difficult without an excellent co-op and part-time student program. Many co-op students from Georgia Tech found careers in the Geological Survey as did others from Abraham Baldwin College at Tifton and the University of Georgia at Athens. Those who worked for WRD in Georgia during the period and remained with the Survey after graduation included Billy E. Colson, Timothy W. Hale, David W. Hicks, Ernest J. Inman, Frederick A. Kilpatrick, Miguel A. Lopez, Curtis L. Sanders, Jr., William R. Stokes, III, Gary D. Tasker, and Ezra J. Tharpe, Jr.

Medford T. Thomson was District Engineer until he transferred to Arlington, Va., in November 1960. Albert N. Cameron transferred from SWB headquarters in Washington to succeed Thompson in September 1961. Cameron was District Engineer until the reorganization in July 1965, when he became District Chief.

The Assistant District Engineer at the beginning of this period was Cameron, who transferred to SWB headquarters in October 1957. He was succeeded by

Harold H. Odell, who served as the assistant until the 1965 reorganization. Other technical members of the District staff who served during all or part of this period were Earnest C. Baxter, Clyde M. Bunch, William C. Carr, Philip H. Carrigan (transferred from SWB Research Section, Atlanta, 1959), Robert F. Carter, Samuel P. Clemence, Billy E. Colson, Oliver J. Cosner, William M. Coyle, Jr., Thomas R. Dyar, Marvin A. Franklin, William B. Gannon (transferred from Boston, Mass. in 1959), Rodney Grantham, Charles S. Hedges, Arlen Q. Hess, Joe C. Hickman, Ernest J. Inman, David L. Kennison, (Georgia Tech Professor) Kenneth C. Kindsvater (1958-60), Joseph C. Mehrhoff, L. Grady Moore, Lawrence E. Newcomb (transferred to Washington, D.C., September 1958), William H. Norris, Gary M. Potter, McGlone Price (transferred from Nashville, Tenn., December 1958), James W. Rabon, William M. Sloan, William R. Stokes, III, Roger J. Sundy, Gary Tasker, Ezra J. Tharpe, Charles H. Tibbals, Robert W. White, Jimmy L. Woods, and Robert R. Wright.

Problems that arose during project studies including those following the 1954 drought convinced Thomson that the District needed a "surface-water geologist," and he requested one. After many discouraging episodes, Headquarters agreed to transfer Cosner, formerly of GWB, to SWB in Atlanta.

The SWB District Clerk was A. Lucille Cain. Other clerical staff were Mary Jo Ayers, Mary M. Bennet, Dorothea Davidian, Ruth Ellis, Janet K. Groseclose, and Lottie H. Pamplin.

The District Research Section was headed by Robert F. Carter, succeeded by William B. Gannon in 1959. Assistance was furnished at various times by Carrigan, Cosner, Goodrich, Newcomb, Norris, Price, Rabon, and others.

The Atlanta Subdistrict was headed by George T. Condrey, Jr., until he moved to the District headquarters in 1965. He was succeeded by Roy A. Whatley. Other members of the Subdistrict staff at some time during the period 1957 to 1966 were T. Lee Bowen, Jr., Audie J. Bradley, Samuel P. Clemence, Billy E. Colson, Robert W. Crisp, Donnie K. Gay, William R. Goodrich, Timothy W. Hale, Arlen Q. Hess, R. Bruce MacGregor, Reuben J. Nicholson, Frank H. Posey, Gary M. Potter, Greg A. Potter, Jerry C. Raper, Harold F. Reheis, Curtis L. Sanders, Robert E. Smith, Walter M. Stinnett, William R. Stokes, III, Ezra J. Tharpe, and Harold R. Wetmore.

The Tifton Subdistrict Office at 1203 North College Avenue was supervised by Harry A. Carlson until he transferred to Columbus, Ohio, in November 1958. Robert E. Smith replaced Carlson and was in charge until he transferred to Houston, Tex., in 1962. Smith was replaced by Luther R. Mills, Jr. Also on the Subdistrict staff at times were T. Lee Bowen, Robert L. Coleman, Tommy Condrey, Bobby E. Cox, Darrell D. Dorminey, Fred D. Hilliard, Robert W. James, William H. Norris, James L. Pearman, Harold F. Reheis, Curtis L. Sanders, Clyde E. Simmons, William R. Stokes, III, Gary D. Tasker, and Robert W. White. D.B. Cowart and Charles W. Sever, Jr., were assigned to Tifton after reorganization.

The Toccoa Subdistrict Office at 108 West Currahee Street had Miguel A. Lopez as Engineer-in-Charge until August 1961 when he was replaced by William R. Stokes, III. The office was moved to 1021 Baxter Street in Athens in 1964 and headed by Ezra J. Tharpe. Dyar, Inman, Hilliard, and David W. Hicks assisted Tharpe at Athens. Fred L. Williams served at both locations.

The SWB Research Section at Atlanta was placed under the administrative supervision of the District in 1963. Its personnel and functions are described in Part III, "Surface Water Branch."

#### *Ground Water Branch*

The GWB District headquarters was in the Agricultural Building at the State Capitol in Atlanta. Joseph T. Callahan was District Geologist until mid-1961, when he was transferred to Washington, D.C., as Assistant Branch Chief. In late 1961, Harlan B. Counts transferred from the Savannah Subdistrict to become District Engineer and remained in that position until the District reorganization.

Other District headquarters staff included Joe W. Stewart, until he transferred to Tampa, Fla., in 1963, Harry E. Blanchard, Stephen M. Herrick, Willis G. Hester, Charles W. Sever, until 1961, and Elmer S. Santos, until he transferred to the Geologic Division in late 1958. Robert C. Vorhis joined the staff in 1960. Morris J. McCollum transferred from the Savannah Subdistrict in 1963 and remained until 1965.

Sandra S. Gipson was District Clerk until 1959 and was succeeded by Gertrude L. Stern. Other members of the clerical staff were Mary E. Bevers, 1959–63; Lenore I. Wilcox, 1960–65; and Hannah J. Reid, 1965 through the end of the period.

A Branch Subdistrict office was in Savannah until 1963 when it became a field headquarters. Field headquarters was established at Fort Oglethorpe in 1958, Rome in 1963, Calhoun in 1965, Albany in 1957, Brunswick in 1959 (changed to a subdistrict in 1962), Bainbridge in 1961, and Quitman in 1963.

In the Savannah Subdistrict, Counts was Engineer-in-Charge until late 1961. Morris J. McCollum was Geologist-in-Charge until his transfer to the

District office in 1963 and the Savannah office was changed to a field headquarters. Other personnel were Ellis Donsky, until his transfer to Trenton, N.J., in 1959, Julian H. McKenzie, until 1957, and Ollie B. Odom, during this entire period.

The Brunswick Subdistrict was established by Robert L. Wait as a field headquarters in 1959. It became a Subdistrict in 1962. Other personnel were Dean O. Gregg, 1963–66; Jerry C. Rice, 1960–64; and Charles N. Joiner, 1965–66.

The Albany field headquarters was established by Wait in 1957, and he remained there until 1959, when he opened the Brunswick office. Vaux Owen, Jr., who started with Wait in 1957, closed the Albany office and opened a field headquarters at Bainbridge in 1960. Owen transferred to the District office in 1961. Other Bainbridge personnel were Charles W. Sever, 1961–63; and D.B. Cowart in 1963. A field headquarters was opened at Ft. Oglethorpe by Charles W. Cressler in 1958. Mack G. Croft was assigned there until he transferred to California in late 1960. The office was closed in 1963. A field headquarters in Rome was opened by Cressler in 1963 and closed in 1965. Cressler then opened a field headquarters in Calhoun where he remained through the end of this period. At Quitman, a field headquarters was established by Sever and Cowart in 1963 and both remained there until the office was closed in late 1965.

#### *Quality of Water Branch*

The QWB District headquarters at Ocala, Fla., provided water-quality services to the Georgia District through most of the period. Sediment and water-quality samples for projects were collected by Georgia personnel and analyzed by the Ocala laboratory. Florida District personnel collected certain other water samples. Temperatures were measured at several stations by the Georgia District staff. At the end of the period, all water-quality field work was being done by the Georgia WRD staff, and Rodney G. Grantham, who transferred from Miami, Fla., in 1966, was selected as Chief of the Water Quality Section of the reorganized District. The Ocala laboratory continued to provide analytical services.

#### *Water Resources Division 1965–66*

In July 1965, Georgia was designated a Division District with Albert N. Cameron, District Chief and Harlan B. Counts, Assistant District Chief. The surface-, ground-, and quality-of-water programs continued without significant change through FY 1966.

### Funding and Cooperation

Funds for the District's programs were largely from the cooperative program (Coop) and other Federal agencies (OFA). Federal program (Fed) funds provided support for a few gaging stations including construction and operation of hydrologic benchmark stations, compilation of streamflow records, network evaluations, the operation of several observation wells, and some water-quality analyses. Minor funding was received from licensees of the FPC.

The following table shows combined total funds for the WRD Districts for years indicated:

Georgia District funds, fiscal years 1958, 1960–66

[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 286 | - | 349 | 369 | 376 | 398 | 439 | 448 | 432 |
| OFA | 35 | - | 71 | 55 | 52 | 63 | 60 | 74 | 78 |
| Fed | 36 | - | 15 | 13 | 18 | 10 | 32 | 19 | 51 |
| FPC | 3 | - | 3 | 3 | 3 | 4 | 4 | 4 | 5 |
| Total | 360 | - | 438 | 440 | 449 | 475 | 535 | 546 | 566 |

Source: Consolidated work plans. Figures for 1959 are not available.

#### *Cooperating Agencies*

The Georgia Department of Mines, Mining and Geology (DMM&G) was the principal cooperator for statewide water-resources activities—the streamflow and ground-water data programs, areal hydrologic studies, and some geologic studies related to the occurrence of ground water. The local governments of East Point, Savannah, Chatham, Brunswick, Glynn, and Cook Counties contributed funds through the DMM&G for water-resources studies. The Georgia Highway Department cooperated in flood studies to support drainage-structure design.

#### *Other Federal Agencies*

The U.S. Army Corps of Engineers, Mobile and Savannah Districts, funded the collection and publication of streamflow records. Included in the program were funds for the SWB District to review and publish some streamflow records furnished by the Corps; to develop a flood profile for Peachtree Creek; and to do a flood-plain study in DeKalb County.

The SCS provided funds to collect data to be used by the SCS to evaluate flood-detention reservoir design and sediment-trap efficiency in northeastern Georgia.

The TVA funded the operation of several streamgaging stations in the Tennessee River area of northern Georgia. The Tennessee and North Carolina SWB Districts did the field work and prepared the records for publication until late in this period of WRD history when the Georgia District took over this operation.

The U.S. Study Commission, Southeast River Basins, reimbursed the Survey for compilations of water-resources data and special studies made for the Commission. The primary objective of the Commission was to "prepare a comprehensive plan for the conservation, utilization, and development of the land and water resources of the designated Southeast area" covering 88,000 square miles in South Carolina, Georgia, Florida, and Alabama. The Georgia District's contribution to its 13-volume report, published in 1963, was to seven of the eight basin reports and to the hydrology volume. (See "Special Studies," below.)

In 1956, the AEC requested a water-resources investigation at the Georgia Nuclear Laboratory site near Dawsonville, and the work was done early in this period of history. The National Park Service was provided assistance on ground-water problems in several parks during the period.

## Summary of Program

Collecting, processing, and publishing water records were strong components of the District's program; however, program growth was mostly in interpretive studies. Emphasis shifted during the period from data collection and traditional hydrologic areal and site studies to studies needed for water-management and for assessing environmental impacts.

### *Water Records*

Streamflow Records.—As of November 1965, a total of 127 continuous-record stations were being operated, consisting of 62 primary (long-term hydrologic), 26 secondary (short-term hydrologic) and 39 serving water-management (specific-purpose) needs.

Georgia is the largest State east of the Mississippi River, yet the number of continuous-record streamflow stations operated in the State was one of the lowest. Its streamflow program was augmented at low cost by the operation of partial-record stations to collect low-flow and flood data. About 300 partial-record stations were in operation at the end of the period.

After 1961, when the change was made to State-level data reports, the Georgia SWB District was the first in the Nation to release its annual reports. The goal for publishing data was not more than 3 months after the end of the water year. Rabon and Condrey provided the leadership to meet this goal.

Ground-Water Records.—The GWB District reported 72 key wells in the observation-well network in 1963. By November 1965 there were 92 wells in the network, about 20 of which were equipped with continuously recording gages. About 46 observation wells that had adequate records for general hydrologic purposes had been discontinued.

Statewide collection of subsurface information—geologic, geophysical, and hydrologic—related to principal aquifers and in support of active or planned ground-water investigations continued throughout the period. This information was generally open-filed on a current basis and used in subsequent reports and maps.

Water-Quality Records.—In 1965, the District collected records of temperature at 275 surface-water stations and chemical-quality samples at 16 stations. Well-discharge temperatures were measured at 39 wells and chemical-quality samples were collected at 25 wells.

### *Special Studies*

A number of principal studies were conducted, all or in part, within fiscal years 1957–66. A study of weathered crystalline rocks at the Georgia Nuclear Laboratory in Dawson County by Stewart and others in 1957–59 provided information on the potential of the rocks for radioactive-waste disposal and for water yield (USGS Bull. 1133–D and 1133–F, 1964, and PP 450–B, 1962). Herrick compiled well logs of the coastal plain of Georgia obtained during the years 1949–60 [Georgia Geological Survey (GGS) Bull. 70, 1961]. The impact of saltwater encroachment from planned increased pumpage of ground water in the Savannah area of Georgia and South Carolina was investigated by Counts, Donsky, and McCollum during the years 1954–65 (WSP 1611, 1963, and WSP 1613–D, 1964).

Also in Glynn County, Wait and Gregg in 1959–65 studied the problem of saltwater entering wells (WSP 1613–E, 1965, and Georgia Department of Natural Resources Hydrologic Rept. 1, 1973). The yield of sedimentary aquifers in the coastal plain was investigated by Callahan and Sever in 1959–62 for the U.S. Study Commission, Southeast River Basins (WSP 1669–W, 1964).

The geology and ground-water resources of many counties in Georgia were investigated and reported on during this period. By county name, investigator, publication, and date of publication, they were: Dougherty, by Wait, WSP 1539–P, 1963; Lee and Sumter, by Owen, WSP 1666, 1963; Bartow, by Croft, WSP 1619–FF, 1963; Catoosa, by Cressler, GGS Circ. 28, 1963; Mitchell, by Owen, GGS Circ. 24, 1964; Dade, by Croft, GGS Circ. 26, 1964; Chattooga, by Cressler, GGS Circ. 27, 1964; Dawson by Sever, GGS Circ. 30, 1964; Walker by Cressler, GGS Circ. 29, 1964; Seminole, Decatur, and Grady, by Sever, WSP 1809–Q, 1965; Rockdale, by McCollum, GGS Circ. 33, 1966; Thomas, by Sever, GGS Circ. 34, 1966; Floyd and Polk, by Cressler, GGS Circ. 39, 1970; Cook, by Sever, open-file report, 1972; Sumter, Dooly, Pulaski, Lee, and Wilcox by Vorhis, HA–435, 1973; and Gordon, Whitfield, and Murry, by Cressler, GGS Circ. 47, 1974.

The Alaska earthquake of 1964 affected water levels in wells and streams in Georgia. The water-level records were analyzed and reported by Vorhis in PP 544–C (1967) and by McGarr and Vorhis in PP 544–E (1968). (See Part X, "Alaska.")

A reconnaissance study of the chemical quality of Georgia streams was made by Cherry in 1957–58 (DMM&G Bull. 69, 1961), supplanting William L. Lamar's work in the 1940's.

A significant contribution to the hydrology volume of the series of publications of the U.S. Study Commission, Southeast River Basins, was that on the hydrologic characteristics of the southeast river basins, released by the Commission in 1960. The work was done by Robert F. Carter.

Determining the hydrologic and hydraulic characteristics of floodflows at bridge sites, begun in Georgia in 1947, was the first project of its type in the Nation. About 200 bridge-site reports had been prepared by the end of this period of history. Circular 100, "Floods in Georgia, frequency and magnitude," by Rolland W. Carter (1951), that had been used as a model for similar reports in other Districts, was updated by Bunch and Price (open-file rept., 1962). In further support of highway drainage design on small streams, Cameron was influential in arranging BPR funding through State highway departments to develop and operate networks of flood-hydrograph recorders throughout the Southeastern States.

Gannon and Norris developed inexpensive low-flow gages to obtain minimum stages. A description of the "Minimum Stage Indicator," by Gannon was published in the February 1963, WRD Bulletin. Norris received an incentive award for his development of a later version of the minimum-stage indicator.

The surface-water resources of the Yellow River Basin in Gwinnett County were investigated by R.F. Carter and Gannon (DMM&G Circ. 22, 1962).

Reports on drainage-area data for Georgia streams by R.F. Carter (1959) and on the flow-duration of streams in Georgia by Rabon (1961) were open-filed. Streamflow maps of Georgia's major rivers by Thomson were published as DMM&G Circular 21, in 1960.

### Other District Activities

District conferences were held at various times by GWB and SWB and later by the WRD District. The meetings were attended by all personnel. They were primarily technical in content, but provided the opportunity for Divisionwide team efforts.

Hurricane Betsy hit Baton Rouge, La., September 9–10, 1965, causing a barge containing 600 tons of liquid chloride to capsize in the Mississippi River. Cameron arranged for the shipment, from Atlanta to Baton Rouge by military aircraft, of 2,500 pounds of Rhodamine-B dye urgently needed for a time-of-travel study of the Mississippi River from Baton Rouge to New Orleans. (See Part IV, "Tracers in Hydrology" and Part X, "Louisiana.")

## Hawaii

*By* Hugh H. Hudson *and* Frank N. Visher *and* reviewed *by* Dan A. Davis, Charles J. Ewart, III, Mearle M. Miller, *and* Benjamin L. Jones

Programs were developed, administered, and conducted by the GWB and the SWB until early 1966 when the Branch activities in Hawaii and other Pacific Islands were integrated into a Division District. Prior to reorganization, the WRD activities in Hawaii were coordinated by a two-Branch WRD Council. The QWB had no staff in Hawaii during this period and was intermittently represented on the Council by visiting regional QWB staff members.

The District headquarters offices of GWB and SWB were in the Federal Building in downtown Honolulu until 1960. The GWB office was on the third floor and those of SWB on the second floor. In 1960, both moved to the Home (later, First) Insurance Building, 1100 Ward Avenue.

Although the administration and management of GWB and SWB were independent of each other until integrated, liaison with the principal cooperator was accomplished by highly unorthodox means. This unusual liaison resulted from the dual role of the SWB District Engineer who was also ex officio the Chief Hydrographer of the Territory, later State. Howard S. Leak was the last to wear both hats. He described a fictional meeting in which he, as Chief Hydrographer, proposed the cooperative program for the coming year involving both ground- and surface-water investigations with, of course, considerable input from the District Geologist. "Then I got up, walked around the table, put on my other hat and, as Council Chairman or as District Engineer, offered local acceptance of the Chief Hydrographer's proposal."

This unique arrangement ended on January 1, 1961, with the appointment of Robert H. Chuck as Manager-Chief Engineer of the newly created Division of Land and Water Development, Department of Land and Natural Resources (DLNR). Chuck became the Chief Hydrographer and the principal cooperator with the Survey.

## Organization and Personnel

### *Surface Water Branch*

Streamflow investigations were conducted during the entire period in Hawaii on the islands of Oahu, Kauai, Hawaii, Maui, and Molokai; on Guam; and on the island of Tutuila in American Samoa. In 1963, operation of gaging stations began in Okinawa that included collecting data on sediment, chemical quality of water, and rainfall. There were field headquarters or subdistrict offices on Kauai, Maui, and Guam. Beginning in 1962, an office was established on Hawaii and in 1963, on Okinawa. After reconnaissance surveys of Yap, Saipan, Truk, and Ponape in 1965–66, a streamgaging program began in cooperation with the Trust Territory of the Pacific Islands in 1966. Trust Territory employees, trained by District staff, performed much of the routine field work under the supervision of the Guam Subdistrict staff.

The general functions and principal staff of each office were as follows:

Honolulu.—The District office in Honolulu provided technical and administrative direction for SWB programs in Hawaii, American Samoa, Guam, Okinawa, and the Trust Territory. Field work on the islands of Oahu and Molokai was performed by members of the Honolulu staff and, until 1962 when the Hilo office was established, on the island of Hawaii. Members of the Honolulu staff visited American Samoa once or twice each year to advise and review the work of Government of American Samoa employees who maintained the gaging stations and did the routine streamgaging.

Howard S. Leak was District Engineer until his retirement in 1962. Hugh H. Hudson was the Assistant District Engineer until June 1961 when he was transferred to Washington, D.C. Mearle M. Miller was then transferred from Menlo Park, Calif., to Honolulu as Hudson's replacement. Miller was named District Engineer when Leak retired and became Hawaii's first District Chief with the change to Division operations in February 1966.

George T. Hirashima was the "office engineer" for many years prior to the beginning of this period of history. He had a long and unrequited interest in streamflow characteristics other than basic streamflow records and in 1959 was relieved of routine office duties in order to research the more arcane aspects of Hawaii streams. A Hydrologic Studies Section was established in 1961 with Hirashima in charge.

Daniel E. Havelka transferred to Honolulu in 1959 as Hirashima's replacement. In May 1962, Havelka was transferred to Kathmandu, Nepal. His replacement was Wallace A. Brownlie from Portland, Oreg. Brownlie was placed in charge of the Hydrologic Records Section when that unit was created. George Yamanaga had been a senior member of the Honolulu staff until 1961 when he transferred to Menlo Park and was a storehouse of valuable but unrecorded Hawaii District program details. He transferred back to Honolulu to be the Assistant District Engineer after Miller was promoted to District Engineer in 1962.

Santos Valenciano, a long-time member of the Honolulu staff, was transferred to Guam in 1955 and returned to Honolulu in 1960. Increases in program and staff led to formation of a Honolulu Subdistrict in 1961 and Valenciano became the Subdistrict Chief. Subdistricts were also established on the islands of Hawaii, Maui, Kauai, Guam, and Okinawa during this period of WRD history with Otto Van Der Brug, Kenzo Takumi, Frank O. Morris, Stuart H. Hoffard and Salwyn S.W. Chinn in charge, respectively.

Other members of the Honolulu staff who transferred in or out during this period include Walter C. Vaudrey, Morris, Hoffard, and Elmer G. Pearson. Vaudrey reported for duty in Honolulu from Denver, Colo., in 1960. Morris was on duty in Honolulu at the beginning of this period, then transferred to Kauai in 1958 and to Alaska in 1962. Kenneth H. Fowler transferred to Kauai in 1962 as Morris' replacement. Hoffard transferred to Honolulu in 1962 from Agana, Guam, and remained in Hawaii for the remainder of this period. Pearson, formerly of Tacoma, Wash., transferred to Honolulu in 1959, then was reassigned to Los Angeles, Calif., in 1962.

New staff were added in Honolulu when Chinn was hired in 1959, Reuben Lee in 1960, Iwoa Matsuoka in 1961, William C. F. Chang in 1962, and Thomas Ushijima in 1963. Stanley H.S. Wong was hired in 1956 but by 1960 had resigned. Richard H. Nakahara, a student and part-time subprofessional employee at the beginning of this period, was assigned to California for a couple of years, returned as an engineer in

1963, and remained on duty in Honolulu for the remainder of this period.

Honolulu office and field operations would have been extremely difficult without the cadre of dedicated technicians and aids who served during all or part of this period. Among this group were Stephen Bowles, Donald V. Cameron, David Dang, Aloysius Ho, Eugene L. Hogue, Hisashi Kanno, Mae Kuboi, James H.S. Lee, Hajime Matsuura, Frank M. Romualdo, Richard A. Saltwich, Charing A. Seehaas, Richard Takaesu, Akiko Tanaka, Grace A. Tateishi, Katherine L. Wong, and Clayton A. Wyse.

Although the District Clerk was a SWB employee, she served both Branches. Anna S. Homer was District Clerk at the beginning of this period. Her husband was a Treasury Department employee who was able to effect very rapid turnaround in such crucial matters as the overnight issuance of expense checks to the District staff. Homer left in 1958 when her husband was transferred and was succeeded by Daisy S. Reelitz. Reelitz served as District Clerk for the remainder of this period, assisted by Amy H. Watanabe and Louise Kabasawa.

Lihue, Kauai.—In 1957, Charles H. Tate was Engineer-in-Charge of operations on Kauai. Worthy of mention was his assistant, Noriaki E. Kojiri, who may have been the only GS–1 on Survey rolls in 1957. His star rose rapidly, and in 1969, Kojiri was placed in charge of operations on Kauai.

In February 1958, Tate transferred to Indianapolis, Ind., and was succeeded by Frank O. Morris, who reported to Lihue in April 1958 from Honolulu. The Lihue office, in 1961, became a Subdistrict office. In 1962, Morris was transferred to Alaska. His replacement was Kenneth H. Fowler, who remained Engineer-in-Charge of Kauai operations for the remainder of this period. Noriaki Kojiri and Kenneth Konishi were assigned most of the field work.

Kahalui, Maui.—SWB operations on the Island of Maui consisted largely of the operation of gaging stations to provide streamflow records for the administration by the State of leases of water to sugar plantations. Kenzo Takumi was in charge during the entire period. In 1957, he was assisted by George Gohara, technician. In 1966, after a near decade of steady program growth, Takumi and Gohara had the assistance of two additional technicians, Robert Sugimoto and Raymond Otsubo. In 1957, the office was a field headquarters located in Paia. It was moved to Kahalui in August 1960 and upgraded to Subdistrict status in 1961.

Hilo, Hawaii.—The Hilo office was established in 1962 as a field headquarters with Otto Van Der Brug, engineer-technician, formerly of Salinas, Calif., in charge. Van Der Brug opened the office with Isami Ogi as his assistant. They were later joined by an engineer, Stephen Ching, and technicians John Janssen, from the Spokane, Wash., Subdistrict, and Isao Yamashiro. The Hilo office became a Subdistrict office in 1965 with Van Der Brug remaining in charge through this period of history.

Agana, Guam.—Santos Valenciano was Engineer-in-Charge of the SWB operations on Guam at the beginning of the period and remained in that position until 1960 when he returned to Honolulu. His replacement was Stuart H. Hoffard, who transferred to Guam from Tacoma, Wash. Hoffard served as Engineer-in-Charge until 1962 when he transferred to Honolulu. Valenciano and Hoffard were assisted by technician Jose S. Quinata. With Hoffard's departure, Quinata was placed in charge of day-to-day operations.

Camp Hue, Okinawa.—At the request of the Okinawa District, U.S. Army Corps of Engineers, Miller made a reconnaissance survey of Okinawa in April 1963, and the construction of gaging stations began in July 1963. Station operations began in Okinawa in 1964 with Salwynn Chinn from the Honolulu staff as Engineer-in-Charge and Hisashi Kanno, a career technician and long-time member of the Honolulu staff, as his assistant. In 1965, they were joined by Iwao Matsuoka, an engineer from the Honolulu office. Several Okinawans were hired and trained to do field work.

#### *Ground Water Branch*

During the period 1957 to 1966, the ground-water work in Hawaii and in other Pacific Ocean islands, where there was a U.S. Government interest, was under the direction of District Geologist Dan A. Davis. Davis' professional staff in 1957 consisted of Frank N. Visher, Kiyoshi J. Takasaki, John F. Mink, and Porter E. Ward. Ward was geologist-in-charge of the Guam office. Mink left WRD to work for the Honolulu Board of Water Supply in 1960. In 1961, Christe P. Zones moved to Hawaii from Nevada, and Ronald E. Lubke transferred from Mineola, N.Y. Jack C. Rosenau also joined the staff in 1961 and served as assistant to Davis. Ward transferred to Norman, Okla., in 1958. Visher moved to Florida in September 1963 and was replaced by Robert H. Dale, who transferred from Sacramento, Calif., in 1964. Also in 1963, Zones moved to Santa Barbara, Calif., and in 1965, Lubke took an overseas position with the U.S. Army Corps of Engineers.

Others who worked in the District included Eugene H. Herrick, who worked on Okinawa from July 1958 until his sudden death in February 1959, and Dagfin J. Cederstrom, who worked in the Kadeno-Tengan area of Okinawa from March 1964 to May 1965. The professional staff was ably supported during this period by James Y. Nitta, cartographic draftsman for both Branches, Rose M. Maruoka, and Joan A. Hirai. Most of the routine observation-well measurements were made by Sam Wong, a State employee permanently assigned to the WRD. After Wong retired, he was replaced by K.Y. Chang, also a State employee.

## Funding and Cooperation

Funds for the Hawaii District's programs were largely from the cooperative program (Coop) and other Federal agencies (OFA). The Federal program (Fed) provided funds for operating the Waialeale rain gage and a few gaging stations and observation wells. As shown in the following table, total funds nearly doubled from FY 1957 to FY 1966. The increase reflected programs that began in American Samoa, Okinawa, and the Trust Territory during this period and the need, principally in Hawaii, for more comprehensive hydrologic investigations.

Hawaii District funds, Intermittent fiscal years, 1957–66
[In thousands of dollars]

| Source | 1957 | 1959 | 1961 | 1963 | 1965 | 1966 |
|---|---|---|---|---|---|---|
| Coop | 343.0 | 341 | 456 | 482 | 496.6 | 509.1 |
| OFA | 4.6 | 27 | 5 | 31 | 73.9 | 63.0 |
| Fed | 11.3 | - | - | - | 20.5 | 17.7 |
| Total | 358.9 | - | - | - | 591.0 | 589.9 |

Source: Figures for 1957, 1965, and 1966 are from District program documents and are reliable. Those for other years are from Headquarters compilations of unknown reliability.

### *Cooperating Agencies*

The principal cooperating agency in Hawaii for both the GWB and SWB was the Division of Land and Water Development, Department of Land and Natural Resources (DLNR). Cooperative programs with the DLNR supported most of the water-resources investigations on the islands of Oahu, Kauai, Maui, Hawaii, and Molokai. The DLNR provided cooperative support not only for the collection of basic hydrologic data statewide but also for areal geologic and ground-water studies, multidiscipline hydrologic investigations of selected areas, and topical studies such as those of floods in Hawaii. The city and county of Honolulu was also a cooperator on the Island of Oahu for areal hydrologic studies, some with major emphasis on ground water, and in the program of special flood-data collection and interpretation.

In American Samoa, the cooperator was the Government of American Samoa and in Guam, the Government of Guam. The Trust Territory of the Pacific cooperated in work on Saipan, Palau, Yap, Truk, and Ponape.

### *Other Federal Agencies*

The Honolulu District of the U.S. Army Corps of Engineers funded the operation of several gaging stations in Hawaii where flood records were needed for the design and maintenance of flood-control structures. The Okinawa District of the Corps requested Survey assistance in establishing and operating the islandwide network of streamflow, sediment, and water-quality stations and in conducting a ground-water study of part of Okinawa.

The Weather Service, U.S. Department of Commerce, provided partial support for the operation of the Waialeale rain gage. The U.S. Navy provided funds for obtaining reservoir records and some streamflow records in Guam.

## Summary of Program

For the SWB, collecting, processing, and publishing streamflow records was the most stable component of the program throughout most of the period. Principal program growth that occurred during the latter part of the period was in interpretive studies. During the final several years of the period, water-resources investigations were planned, executed, and reported jointly by the two Branches.

For the GWB, program growth consisted of increases in areal ground-water studies and in hydrologic investigations conducted jointly with SWB, not only in Hawaii, but throughout the District.

### *Water Records*

Data activities are summarized from information contained in "Water Resources Investigations in Hawaii and other Pacific Islands, 1966."

Streamflow Records.—The number of streamflow stations operated by the District in Hawaii, Guam, American Samoa, and Okinawa was 121, 11, 9, and 20, respectively. Stations operated for water-management purposes made up about 40 percent of the total. The remainder were approximately evenly divided between primary and secondary stations. Peak-flow data were collected at 81 crest-stage stations, all of which were in Hawaii.

Ground-Water Records.—Water-level records were obtained from 169 observation wells in 1966, of which 15 were equipped with continuous recorders. The remainder were measured manually at intervals ranging from weekly to annually. All but 50 were on Oahu Island.

Water-Quality Records.—In Hawaii, ground-water samples for chloride content were taken at monthly or less-frequent intervals at 153 sites of which 130 were on Oahu. Temperatures were measured intermittently at 17 observation wells. In Okinawa, chemical-quality samples were taken intermittently at 3 streamflow-measuring sites, temperatures were measured daily at 3 sites, and samples for suspended sediment were taken daily at 3 sites and intermittently at 11 sites.

Other Data Activities.—The District maintained numerous rain gages in Hawaii, American Samoa, and Guam, largely in support of project activities. Of special importance was the continuously recording rain gage on Mount Waialeale. It was destroyed by a hurricane in August 1959 and resumed recording rainfall in May 1962. A streamflow-measuring station with a drainage area of 0.16 acre was established in December 1963 adjacent to the Waialeale rain gage.

In the early 1960's, the SWB installed and operated three specialized water-level recording gages in Hilo Harbor, Hawaii, for the Corps of Engineers, Honolulu District, to provide detailed water-level changes resulting from tsunamis or major windstorms.

Low-flow, duration-of-flow, and flood-flow summaries of streamflow records provided the basis for the report "Flow characteristics of streams in Hawaii," by George T. Hirashima (DLNR Report R–27).

### *Special Studies*

Several studies that were begun before 1957 were finished during the 1957–66 period, including a report on the geology and ground-water resources of the Island of Kauai by Gordon A. MacDonald, Dan A. Davis, and Doak C. Cox, published by the Hawaii Division of Hydrography (Bull. 13, 1960).

A study by Visher and Mink of the geology and ground-water resources in southern Oahu Island began in July 1956. Their reports included Visher's "Qualitative hydrodynamics within an oceanic island," (IASH Committee of Subterranean Waters, publication 52, 1961), and Mink's "Some geochemical aspects of sea-water intrusion in an island aquifer," also in the foregoing publication. A summary of preliminary findings was published as Circ. 435 (1960) and the final report was WSP 1778 (1964).

Takasaki and Valenciano studied the water resources of the Truk Islands from June to December 1957. Their report to the U.S. Army was completed in 1960. Davis did a reconnaissance of the ground-water resources of Saipan which was completed in 1959 with a report to the U.S. Army. Davis also completed a reconnaissance of Ishigaki and Iromate Islands in 1960.

Takasaki and Yamanaga, later joined by Lubke, began an investigation of the water resources of windward Oahu in 1959. A preliminary report was published as DLNR Circ. 10 (1962). This study was followed in 1962 by an investigation of the water resources of the Kahuku area, which abuts the windward Oahu study area on the north. This study, by Takasaki, Valenciano, and Ho, produced a preliminary report, DLNR Circ. 39 (1966) which, combined with the windward Oahu area, was published as WSP 1894 (1969).

A study was begun in 1960 of the ground-water resources of the Waianae area of Oahu by Zones in 1960 and was continued by Takasaki in 1965. A preliminary report by Zones was published as DLNR Circ. 16 (1963). After further work in the area, the final report by Takasaki was published as HA–358 (1971).

Studies of the basal water systems in southern Oahu were continued by Visher until he left Hawaii in 1963, then by Dale (HA–267, 1967). A study of the water resources of north-central Oahu by Rosenau, Lubke, and Nakahara was begun in the early 1960's (WSP 1899–D, 1971).

Davis and Yamanaga studied the water resources of Kohala Mountain and Mauna Kea on the Island of Hawaii (DLNR Circ. 14, 1963) and did a preliminary study of the Kau District of Hawaii from July 1963 to June 1966 (DLNR Circ. 27, 1966).

Freshwater springs of the entire shoreline of the Island of Hawaii were studied by W.A. Fischer, D.A. Davis, and T.M. Sousa, utilizing infrared images of temperature differentials to locate and to some extent quantify the flow of freshwater into the ocean (HA–218, 1966).

Davis completed a reconnaissance of the water resources of American Samoa (WSP 1608–C, 1963). His was the first formal report following the beginning of water-resources studies in American Samoa that were begun in 1958 by Hudson and Takasaki.

(Author's note: Investigations of the water resources of several islands in the western Pacific were made by Ted Arnow during the period January 1951 to June 1954. Accounts of his work and of much of the work of the Hawaii District staff on Guam were inadvertently omitted from Volume V of this series. The following several paragraphs that describe WRD activities on Guam, Palau, and Ifaluk Atoll during those earlier years are based on information supplied by Arnow.)

In 1951, the Military Geology Branch (GD) began a study of the geology and hydrology of Guam. The ground-water work was begun by Joseph W. Brookhart, who transferred from Grand Forks, N. Dak.; continued in 1954–55 by Ernest W. Bishop, who transferred from Florida; and by Kiyoshi J. Takasaki. The work was further continued in 1955–58 by Porter E. Ward, all under the supervision of Dan A. Davis.

Stream-gaging installations were made by Raymond K. Chun of the Honolulu office, assisted by Jose S. Quinata, Ben Santos, and Ben Santiago, all of Guam. Studies of streamflows were made by Chun, Hudson, Valenciano, Hoffard, and Quinata. All surface-water work was under the supervision of Max H. Carson and later, Leak and Miller.

From 1951 to 1953, the work was supported in part by the Pacific Geological Mapping Program of the U.S. Army Corps of Engineers. Beginning in 1953 the work continued under a cooperative program with the Government of Guam.

The reports on the work on Guam included "Water in Guam" by Ward (The Military Engineer, July-August, 1961) and "Hydrology of Guam" by Ward, Hoffard, and Davis (PP 403–H, 1965).

In the very early 1950's, the High Commissioner of the Trust Territory of the Pacific Islands requested an investigation of the effects of phosphate mining on the ground water in Angaur, Palau Islands. Theodore Arnow, then working in Mineola, N.Y., was assigned to the project. The original intent was that Arnow would be headquartered on Anguar; but because of the Korean War, the headquarters was moved to Guam, which was considered to be safer.

In January 1951, Arnow and his wife arrived in Honolulu and Arnow continued on to Angaur while his wife, who was pregnant, remained in Honolulu. On June 2, the Arnow family (which had doubled with the birth of twin boys in Honolulu) arrived on Guam to take up residence in a quonset hut provided by the Government of Guam.

For the next 3 years, Arnow continued the work on Angaur and submitted 15 administrative reports to the High Commissioner's office during January 1951 to March 1955. The first 11 reports were prepared by Arnow and the last 4 by Ernest W. Bishop. Arnow summarized his work on Anguar in WSP 1608–A (1961).

Arnow also carried out hydrologic investigations throughout the Trust Territory of the Pacific Islands. He participated in a Pacific Science Board expedition to Ifaluk Atoll, the results of which were published in the Pacific Science Board Atoll Research Bulletin and in the Bulletin of the Bernice P. Bishop Museum of Honolulu. Results of investigations in the Marshall Islands were published in the Atoll Research Bulletin and by the U.S. Army. A summary of the Atoll studies was published in the proceedings of the Eighth Pacific Science Congress, Philippine Islands.

In June 1954, Arnow left Guam for Austin, Tex., and was replaced by Ernest W. Bishop, from Florida, and he in turn, in 1955, by Porter E. Ward who transferred from Indianapolis, Ind.

In September 1964, Miller met with the High Commissioner of the Trust Territory to visit Saipan and explore the possibility of cooperative water-resources investigations in the various Trust Territory Districts. As a result, Arnow (then in the Utah District) and Miller during September 1965 reevaluated water-supply conditions on Saipan and Yap. Miller and Edward A. Moulder made a similar study on Truk and Ponape in March 1966. Results were presented in administrative reports to the High Commissioner.

## Idaho

Condensed from material provided *by* Wayne I. Travis that was written with the assistance of retired personnel Emerson G. Crosthwaite, Maurice J. Mundorff, Arthur L. Larson, *and* Alfred Clebsch, Jr., *and* Linda K. Channel *and* other members of the current Idaho District staff

The Idaho WRD program continued to be administered by the Branches throughout this period.

### Organization and Personnel

#### *Surface Water Branch*

There were two SWB Districts in Idaho through December 1958—one headquartered at Boise and the other at Idaho Falls.

The Boise office was at 429 Federal Building at Eighth and Bannock Streets until 1957 when it was moved to 914 Jefferson Street. Thomas R. Newell was District Engineer until he retired on October 31, 1958. Wayne I. Travis served as Assistant District Engineer prior to Newell's retirement, succeeded Newell as District Engineer on February 22, 1959, and remained in that position until July 1, 1966, when the Branch Districts were reorganized into a Division District. Sherman O. Decker transferred from the New Mexico District in September 1959 and became the Assistant District Engineer. The SWB staff in Boise numbered about 20 in 1957, was down to 15 in 1964, and increased to 19 in 1966. Senior staff members in 1957 included Carl L. Lawrence, who transferred to the Illinois District in 1958; Gordon E. Lokke, who transferred to the California District in 1958; John E. Cummans, who transferred to the Washington District in 1960; and Cecil A. Thomas and James R. Spofford, both of whom remained on duty in Boise through the end of the period. Others on the staff included Leonard Koski and Stewart A. Gutenberger, who remained through the period; Seldon C. Cordes, who transferred to the GWB in 1961 and returned to the SWB in 1962; Ruth S. Thornton, who transferred to another Federal agency in 1959; and Tom M. Lethlean, who retired in 1963. Doris C. Randall, District Clerk through the period, also provided accounting services to the GWB office in Boise.

Those who moved into or from the District during the period included Harold J. McDowell, from the New Mexico District in 1959; Kenneth H. Fowler, from the GWB office in Boise in 1958, moved on to the Hawaii District in 1962; George T. Higgins, to the Washington District in about 1963; Robert W. Harper, to Idaho Falls in 1960 and transferred to the Current Records Center in Portland, Oreg., in 1966; Henry C. Broom, on temporary assignment from the Washington District in 1960; Ralph A. Shelton; Ruth C. Murphy; Raymond S. George, to the Alaska District about 1964; Edward L. Young; Harold J. Seitz; Michael C. Bennett; Alfred E. Jansen; William A. Harenberg; Michael L. Jones; and Robert W. Luscombe, from the Boise GWB office in 1965.

The north Idaho field headquarters, which was located at Bonners Ferry for many years, was moved to Sandpoint in 1962 and accorded Subdistrict status in 1963. Elmer H. Likes, Engineer-in-Charge, was assisted by Stewart A. Gutenberger.

Field units, answering to the Branch Area Chief in Menlo Park, were maintained at Boise and Idaho Falls and staffed, respectively, by Lynn Crandall during 1960 and Thomas R. Newell during 1960–67. Newell was the Federal representative on the Columbia River Interstate Commission for interstate compact negotiations. Crandall was generally considered to be the foremost authority on irrigation in Idaho.

The Idaho Falls office remained at 204 Federal Building throughout the period. Lynn Crandall was District Engineer until he retired on December 31, 1958, at which time the Idaho Falls District became a subdistrict of the Boise District with Henry C. Eagle as Engineer-in-Charge. Charlotte E. Elg (Wood), engineering aid, handled the clerical duties and assisted with technical work. She, Crandall, and Eagle made up the complement of full-time Federal employees at the start of the period. Arthur L. Larson was reassigned to Idaho Falls from Boise in March 1959 as was Robert W. Harper in June 1960. The dual-duty status of the head position at Idaho Falls has been covered in an earlier volume of the WRD history. The watermaster responsibility passed to Eagle and later to Larson.

#### *Ground Water Branch*

The GWB District headquarters office was moved from the Fidelity Building to 914 Jefferson Street in Boise in 1957. Maurice J. Mundorff was District Geologist until July 1962 when he was transferred to Pakistan. His successor was Herbert A. Waite, who served as District Geologist until the reorganization of the District and then, he too, transferred to Pakistan. The GWB District headquarters staff numbered 18 in 1957 and was gradually reduced to a low of 7 in 1964 as personnel were moved to other assignments.

Other senior District staff at the beginning of the period were Eugene H. Walker and Emerson G. Crosthwaite, who remained throughout the period; William C. Walton, who resigned in September 1958, and Robert C. Scott, who transferred to the Colorado District in about 1958. Others who remained with GWB through the period were Harold C. Sisco and Richard L. Whitehead. Robert W. Luscombe transferred to SWB, Boise, in 1965 as did Kenneth N. Fowler in 1958. Emma V. Hanson (Lowery) remained as District Clerk through the period, with Rachael M. Clemens and Vivien S. McDowell assisting during the early years. Others on the staff at the end of the period or who served for shorter terms at Boise or Idaho Falls were Glenmore M. Hogenson, Rodger G. Jensen, Chabot Kilburn, Harold Meisler, Ralph F. Norvitch, Alan E. Peckham, Eugene Shuter, Peter R. Stevens, and Warren E. Teasdale.

A field unit was maintained at the National Reactor Testing Station (NRTS) near Idaho Falls from the beginning of the period until September 1959 to supervise test drilling and for monitoring operations. Key personnel included Florian J. Frank, Alan E. Peckham, and Don A. Ralston. In September 1959, the unit was upgraded to a field headquarters with Paul H. Jones as Geologist-in-Charge. In 1963, Jones was succeeded by Donald A. Morris, George H. Chase, and Jack T. Barraclough, in that order, during the remaining years covered by this history. The Idaho Falls operation was under the general and administrative supervision of the District Geologist at Boise.

#### *Quality of Water Branch*

Quality-of-water studies in Idaho were under the general supervision of the Portland QWB District throughout the period, and water samples were sent to the Portland laboratory for analyses. During the early years of this period, water-quality data collection was limited to three or four stations; however, beginning with the 1965–66 biennium, the cooperative agreement with the IDR provided funds for increasing the quality-of-water program in Idaho.

## Funding and Cooperation

The Idaho Department of Reclamation (IDR) continued to be the principal State cooperator during the years covered by this history. The Idaho Department of Highways, and to a much smaller extent, the Idaho Department of Fish and Game also participated as did water-user organizations, particularly Water District No. 36. Total funding for all the State-agency cooperative programs in FY 1957 was about $120,000 for both Branches and generally trended upward during the next 8 years to well over $200,000 in FY 1965 and approximately $280,000 in FY 1966. In general, the data-collection programs were relatively stable during the period. The increases in funds, starting with FY 1959, resulted mostly from a greater number of areal interpretive studies and to a significant rise in the collection of chemical-quality data.

Federal program funds fluctuated considerably but provided a substantial level of support throughout the period.

Funds from other Federal agencies ranged from about $100,000 to $220,000 annually during the period. A detailed breakdown of these funds is not available; however, major amounts were provided by the U.S. Army Corps of Engineers, the BOR, and the Department of State. Other agencies participating at various levels and times were the AEC, Forest Service, Bureau of Public Roads, Fish and Wildlife Service, Bonneville Power Administration, and the SCS. Funds amounting from about $4,300 to $9,700 annually were paid by permittees of the FPC.

## Summary of Program

Collecting, processing, and publishing surface- and ground-water records continued to be an important part of the program of the Idaho District, particularly the surface-water records. GWB personnel became increasingly involved with interpretive studies to meet the demand for development of ground-water sources to supplement the traditional use of surface water for irrigation. The interest in quality-of-water information picked up rapidly by the middle 1960's.

### *Water Records*

Data-collection activities summarized herein are from information reported by the Districts to the IDR for its biennial reports.

Surface-Water Records.—A total of 183 continuous-record stations on streams and 31 on lakes and reservoirs were being operated in June 1958 by the Idaho SWB District. Also, seasonal records of daily discharge were being collected at 21 canals and 9 groups of diversions, principally by the Idaho Falls staff. Five streamflow and one lake-level station in Yellowstone National Park were operated by the Boise staff through 1959, then those stations were transferred to the Montana District. The Logan, Utah, staff collected streamflow records at 18 stations in the Bear River Basin in Idaho. By June 1966, 150 continuous-record and 24 lake and reservoir water-level stations were operated. The reductions were largely due to network evaluations that were made to achieve better coverage at lower costs.

A network of partial-record (crest-stage only) stations was started in about 1960 to obtain flood data, particularly on small streams. By June 1966, there were approximately 100 crest-stage stations in operation.

Ground-Water Records.—In 1958, water levels were measured periodically at 337 sites and continuously at 42 sites. Of these, 284 sites were in the cooperative programs. By 1966 a reevaluation of the observation-well network had reduced the number to 115 sites, and an additional 168 wells were measured for special studies. Of the total, 50 were continuously recorded and 233 were measured periodically.

Water-Quality Records.—For the analyses of water supplies for Air Force bases and the study of waste disposal at the NRTS, 22 ground-water samples were analyzed during FY 1963 and 22 ground-water and 22 surface-water samples during FY 1964. Chemical analyses of surface- and ground-water samples at miscellaneous sites totaled 109 in 1966. In 1966, 29 daily, monthly, or intermittent chemical-quality stations were operated. Sediment records were collected at 3 sites and water temperatures at 14 sites. Additionally, many samples were taken of wells, springs, and surface-water sources to determine water quality for specific uses.

## Special Studies

The use of ground water to irrigate additional lands adjacent to established irrigation projects increased rapidly during the 1950's in areas along the Snake River extending from Mud Lake downstream to

Rupert. An investigation of the potential ground-water supply of the Snake River Plain was begun in 1956 in cooperation with the BOR. As a part of the study, reconnaissance investigations were made in the Bonanza Lake area of Power and Blaine Counties (open-file rept., 1958), Salmon Falls Creek area (Circ. 436, 1960), Camas Prairie area of Camas and Elmore Counties (WSP 1609, 1962), and Teton Basin (WSP 1789, 1964). Studies of the ground-water resources in the Big Wood River Basin were made by Rex O. Smith (WSP 1478, 1959). He also made a geohydrologic evaluation of streamflow records in that basin (WSP 1479, 1960). The results of the overall Snake River Basin project were published in 1964 as WSP 1654, "Ground water for irrigation in the Snake River basin, Idaho," by Mundorff, Croswaithe, and Hilburn.

An intensive quantitative study of the Mud Lake area included evaluation of the hydrologic characteristics of the aquifers, sources and amounts of recharge, magnitude of ground-water withdrawals, the effect of pumping on water levels, and an estimate of underflow. Data collection and quantitative studies were completed by 1962 and a preliminary report drafted, but no final report was published. Ralston and Chapman compiled a report on water-level changes from 1958 to 1968 (IDR Water Info. Bull. 7, 1969).

A brief quantitative appraisal of the water resources of the Little Lost River Basin, taking into account the ground-water supplies and relationship to peripheral surface inflow, was started in 1959. The report by Mundorff, Broom, and Kilburn was published in 1963 (WSP 1539–Q).

A brief ground-water reconnaissance in the Sailor Creek area south of Glenns Ferry was financed by the Bureau of Land Management (open-file rept., 1963).

A study of the water resources of the Goose Creek-Rock Creek area south of Murtaugh was later expanded to include lower Goose Creek Basin. Results of the study by Crosthwaite, scheduled for completion in 1966, were to aid in ground-water development and to assist the IDR in administering ground-water use (IDR Water Info. Bull. 8, 1969).

Herbert E. Skibitzke and Jose A. da Costa of the Phoenix Research Unit, GWB, worked with the District in constructing an electrical analog model of the Snake River aquifer (WSP 1536–D, 1962).

Leslie B. Laird of the Portland QWB District documented the quality of the surface water of the Snake River Basin from July 1958 to June 1960 (PP 417–D, 1964).

Preliminary work was started in 1960 to determine the feasibility of recharging the Snake River Plain by using surface water during times of surplus flows. After a brief interruption, the study was resumed in July 1965 and continued through the end of this period of history. Norvich, Thomas, and Madison evaluated the potential and effect of recharging the Plain (IDR Water Info. Bull. 12, 1969).

The Raft River Valley has possibly the most critical water shortage of any developed area in Idaho. Raymond L. Nace and others reported the results of their ground-water investigation made during the period 1948–55 (WSP 1587, 1961). A reappraisal of the water resources of the basin was made by Mundorff and Sisco (WSP 1619–CC, 1963).

Documenting, compiling, and analyzing flood data was a major activity of the SWB during the period 1957 to 1966. Flood records were used to determine the magnitude and frequency of floods in Idaho by major drainage basins [WSP 1684 (1966); WSP 1687 (1964); and WSP 1688 (1964)].

The cloudburst floods of August 20 and September 22, 26, 1959, at Boise were documented by Thomas (open-file rept., 1963). The severe floods of February 1962, the highest known on many streams, were reported by Thomas and Lamke (Circ. 467, 1962).

Members of SWB and GWB collaborated in preparing the water resources part of the report on the mineral and water resources of Idaho, written at the request of Senator Church (see Part IV, "Water Resources of States").

In the spring of 1965, a study was undertaken to determine the presence of pesticides in Boise River and its tributaries, principally through the irrigated area downstream from Lucky Peak Dam (open-file rept., 1966).

The results of the study of the subsurface geology of the NRTS by Walker were published in Bulletin 1133–E (1964).

Other studies reported on during this period included those by Stevens of the ground-water problems in the vicinity of Moscow (WSP 1460–H, 1960) and the effect of irrigation on ground water in southern Canyon County (WSP 1585, 1962). Also, Sisco and Luscombe reported on inflow to the Rathdrum Prairie-Spokane Valley aquifer (open-file rept., 1963). Ground water for irrigation in part of the Fort Hall Indian Reservation was studied and reported on by West and Kilburn (WSP 1576–D, 1963); ground water in the Sandpoint region, Bonner County, by Walker (WSP 1779–I, 1964); ground water in the Midvale and Council areas, upper Weiser River Basin, by Walker and Sisco (WSP 1779–Q, 1964); and ground-water resources of the upper Star Valley, Wyoming-Idaho, by Walker (WSP 1809-C, 1965).

## Illinois

*By* Warren S. Daniels with the assistance of G. Wayne Curtis of the Illinois District *and* retirees Lyle C. Brook, Theron R. Dosch, James B. Hood, John P. Monis, Allen W. Noehre, *and* Richard L. Stahl

The Illinois District program traditionally had been oriented toward surface-water activities and it continued so during this period of history. The Illinois State Water Survey, a major cooperator, continued its in-house program of ground-water studies. Ground-water well records at a few locations were collected by the Indiana GWB staff, and a ground-water study at Argonne National Laboratory was conducted by the Wisconsin GWB staff.

### Surface Water Branch

The SWB District was headquartered in Champaign at 605 South Neil Street. J. Holloway Morgan was District Engineer until he retired on July 31, 1959, after about 45 years of service with the Geological Survey, 29 of which were as District Engineer in Illinois. He was succeeded by William D. Mitchell, who for many years had been in charge of hydraulic and hydrologic studies and since 1955 had been Chief of the Hydrologic Unit. Warren S. Daniels was Chief of Operations in charge of the basic-data collection program until 1959, when he became the Assistant District Engineer. Daniels was temporarily assigned to the WRD Planning Section at Washington, D.C., in May 1963 and in the following November was transferred to that office. In May 1964, John P. Monis transferred from the Tennessee District and served as Assistant District Engineer through 1966. Dora K. Clifford was the District Clerk and later was head of Administrative Services Section, assisted by Helen L. Larson and Mary L. Garrelts.

The staff of the Basic Operations Section (later Unit) included Clark H. Benson, Gordon D. Booz, Lyle G. Brooks, Jack M. Carns, James B. Hood, Jr., Charles C. Huffer, Oscar G. Lara, John W. Lawrence, Delbert A. Morgan, Kent M. Ogata, Marvin W. Pilgrim, John W. Skinner, Richard L. Stahl, and Delbert E. Winget. Hood transferred to New York in March 1961 and Benson transferred to Alaska in 1962. Additions to the staff included Vincent D. Herreid, 1961 and 1962, Albert J. Heinitz, 1962 to 1965, and Danny L. Hare, in 1961. University of Illinois engineering students were employed on a part-time basis throughout the period.

A field headquarters was continued in Peoria, manned by Chester W. Sandifar until he retired in 1965. Brooks transferred from Champaign in September 1965 as Sandifer's successor.

The Hydrologic Unit staff included, at various times during this period, Richard G. Godfrey, until he transferred to SWB headquarters in September 1957, Loren E. Young, until he transferred to California in July 1958, Carl L. Lawrence, Oscar G. Lara, Howard L. Allen, Jr., George W. Curtis, and Danny L. Hare.

In September 1961, a Subdistrict office was established in the Chicago suburb of Oak Park to conduct flood-inundation mapping in Cook County and to operate the basic-data collection program in the area. Davis W. Ellis was the Engineer-in-Charge, assisted at first by Howard E. Allen, Jr., David Lafont, Dean E. Long, and Allen W. Noehre. Later the staff included Vester J. May, Roman T. Mycyk, Ruth Romine, Andrew M. Spieker, Leo L. Tolia, Gerald L. Walter, and Theodore A. Wyman. Ellis moved to the District office in June 1966 to head the Hydrologic Unit and Noehre succeeded him as Engineer-in-Charge.

A field office was opened in Mount Vernon in 1966 with Marvin W. Pilgrim in charge of field work in that area. Records continued to be processed for publication in the District office.

### Funding and Cooperation

As shown in the table below, cooperative (Coop) program funds continued to be the major source of financing of the District, increasing from about 63 percent of total funding in FY 1957 to 78 percent in FY 1966. The other principal source of funding was from other Federal agencies (OFA) at about 22 percent in FY 1958–60, then decreasing to about 15 percent. Federal (Fed) program funds supported wholly or in part the operation of key stream-gaging stations.

Illinois District funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Fed | 33.7 | -- | -- | -- | -- | -- | -- | 13.4 | 13.2 |
| Coop | 159.6 | 189.5 | 180.3 | 216.9 | 278.9 | 252.9 | 306.0 | 319.4 | 372.4 |
| OFA | 53.2 | 60.1 | 62.6 | 58.9 | 56.5 | 67.2 | 55.2 | 67.2 | 79.4 |
| Total | 246.5 | 249.6 | 242.9 | 275.8 | 335.4 | 320.1 | 361.2 | 400.0 | 474.5 |

Source: Figures for Federal funds from District-program documents and are reliable. Those for OFA and Coop funds are from Headquarters compilations of unknown reliability.

Although OFA funds varied considerably, dropping about to 1958 levels in 1964, the trend was upward with an increase of 53 percent during this period. Growth of the cooperative program was not only more consistent, but it amounted to a 133-percent increase.

### Cooperating Agencies

The Illinois Department of Public Works and Buildings was the principal cooperator throughout the period. Its Division of Waterways supported the collection of streamflow records and, beginning in 1959, cooperatively funded a statewide low-flow frequency study. Its Division of Highways continued to support investigations of floods from small drainage areas.

The Illinois Department of Registration and Education, State Water Survey Division, also continued strong support of the collection of streamflow records including records of low flows.

The Metropolitan Sanitary District of Greater Chicago became a cooperating agency for the collection of streamflow records in 1961. At about the same time, the Cook County Highway Department's support of the program was shifted to the Northwestern Illinois Area Planning Commission with initiation of the flood-mapping program for Cook County.

As noted above, the Northeastern Illinois Metropolitan Area Planning Commission became a major cooperator in the six-county area including and surrounding Chicago.

The U.S. Army Corps of Engineers was the primary OFA source of funding for the collection of surface-water records.

### Program

In 1958, 75 percent of the Illinois District program consisted of collecting, processing, and publishing surface-water records. Research and interpretive studies were a strong 25 percent of the total. During this period, program growth was in interpretive studies which by 1967 had increased to 38 percent of the total. Completing and publishing statewide reports on unit hydrographs, water-supply characteristics of Illinois streams, magnitude and frequency of floods in Illinois, and flow-duration of Illinois streams during the previous decade led to further detailed research and application of the results to specific water problems.

#### *Water Records*

In 1957 the District was operating 158 continuous-record gaging stations: 56 were classified as primary (long-term hydrologic), 85 as secondary (short-term hydrologic), and 17 as serving water-management needs. By 1962 peak-stage data were also being collected at 96 crest-stage stations, and low flows were being measured at 39 partial-record stations in northeastern Illinois.

Although the GWB and the QWB had no formal programs in Illinois, by 1967 the District was collecting ground-water data from four observation wells, temperature records at seven stations, daily water samples for chemical analyses at two stations, and monthly water samples at 24 gaging stations.

#### *Special Studies*

In 1956 a program of hydrologic and hydraulic analyses at highway-stream crossings was begun at the request of the Division of Highways. Through 1962, 33 reports had been prepared and the project continued, although at a slower pace, through the remainder of this period of history.

The first publication from the flood-inundation mapping project in northeastern Illinois was an open-file report in 1962: "Floods in the Arlington Heights Quadrangle, Illinois," by Ellis, Allen, and Noehre. The map, showing limits of actual and potential flooding in a highly urbanized area, was well received. In 1966, the project was expanded to cover not only Cook County, but all or parts of Will, DuPage, Kane, McHenry, and Lake Counties. By 1967, 48 HA's had been published under the general heading of "Floods in northeastern Illinois" and specifically as HA's 39, 67–71, 85–90, 145–154, 202–211, 226–254, "Floods in [----] Quadrangle, Illinois." An additional 21 quadrangles were in press or planned.

In 1965, an areal hydrology project was initiated, headed by Andrew M. Spieker, on the application of hydrologic data to land-use planning. The project, cooperatively funded with the Northeastern Illinois Metropolitan Area Planning Commission, was completed after 1966 (WSP 2002, 1970).

## Indiana

*By* Malcolm D. Hale with the assistance of Charles G. Crawford, Richard E. Hoggatt, Archie McCollum, Claude M. Roberts, *and* Frank A. Watkins, Jr.

Programs were developed, administered, and executed by the Branches until April 1965. Coordination was accomplished through the Indiana WRD Council consisting of the District Engineer, SWB, the District Geologist, GWB, and the District Chemist of the Ohio District QWB. In early 1965, Indiana was designated as and began functioning as a Division-level District.

## Organization and Personnel

### *Surface Water Branch (1957–65)*

The District office was located at 611 North Park Avenue in Indianapolis. Don M. Corbett was District Engineer until September 1960 when he was assigned a special project under the Branch Area Chief, MCA. He remained headquartered in Indianapolis until he retired in 1961. Corbett was succeeded by Malcolm D. Hale, who had been serving as his assistant. In 1961 Mack R. Stewart was reassigned from the SWB Floods Section, Arlington, Va., to be the Assistant District Engineer until he transferred to Louisiana as District Engineer in December 1963. George W. Edelen then transferred from the Floods Section to be the Assistant District Engineer. Mary F. Miller was the Chief Clerk of the Administrative Services Section, which served both the SWB and GWB. She was assisted by Barbara L. Gallagher.

A Hydrological Unit under the direction of A. Rice Green, until his transfer to the SWB Floods Section in 1958, was responsible for special investigations such as flood reports and indirect measurements of peak discharges. Richard E. Hoggatt succeeded Green as head of the unit. The Lake Mapping Section, with Don C. Perkins as chief and Robert L. Stewart as assistant, was assigned to this unit.

One-man field headquarters were in Bloomington and Carlisle. Robert S. Hammond operated out of Bloomington and L. Wayne Carrico, out of Carlisle. Each operated and maintained gaging stations in his area of the State.

During the summers, a full-time construction crew, headed by Carl L. Alderson and assisted by Carrico and part-time college students, constructed and provided major maintenance of gaging stations.

It was District practice to employ college students, majoring in engineering or science, on a part-time basis during the summer and during school holidays. Also, three mathematics and physics teachers from the Indianapolis schools were employed part-time to compute streamflow records.

Charles E. Schoppenhorst was the office engineer from 1957 until his transfer to the Kentucky District in 1963. He was succeeded by Archie A. McCollum, who transferred from North Dakota in 1960.

As the program grew, it became necessary, in 1964, to divide the responsibilities for the stream-gaging program. The responsibilities were assigned by dividing the State into three areas. The Basic Operations Section was reorganized into Basic Operations Sections 1, 2, and 3, each Section corresponding to and responsible for an area of the State. Charles H. Tate (transferred from Hawaii in February 1958) was in charge of Area 1; James B. Swing was in charge of Area 2; and Walter S. Bush (transferred from West Virginia in 1964) was in charge of Area 3. Each Section, housed in the District office, was responsible for operating and maintaining the gaging stations in its assigned area and for preparing for publication the streamflow records from its area. Personnel from the original Basic Operations Section became staff for the area operations. Archie McCollum was the Engineer-in-Charge of the overall District Operation Section.

In 1962 a field unit was established at the Indiana Institute of Technology in Fort Wayne to conduct research at Pretty Lake. John F. Ficke was reassigned from the SWB Research Section in Washington to the unit, and in 1963 Robert L. Lipscomb was reassigned from the Indiana District to the unit. The unit was under the administrative supervision of the District and under the technical supervision, initially, of the SWB Research Section, and later of the GHB.

Others assigned to the District for all or part of the period included Ronald Beam, Donald D. Beck, Billie G. Blumenshine, Patricia Bruce, Nancy Bulthaup, Patricia Campbell, Edwin L. Cardwell, Jack B. Deeter, Lana J. Eisele, Harry D. Gallman, William F. Hadley, Lewis D. Jay, Mildred N. Lambermont, Constance Nagle, Graham E. Nell, Ruth C. Plummer, Warren J. Rice, Tom Richards, Mary L. Ringwald, Ruth M. Romine, James M. Royce, William A. Skinner, Shirley Spradlay, Justine S. Springer, Johnna R. Thiest, Richard L. Thompson, and Jimmy W. Tucker (transferred from Alabama).

### *Ground Water Branch (1957–65)*

The GWB District office was also located at 611 North Park Avenue in Indianapolis. Claude M. Roberts was the District Geologist during the entire period. His professional staff for all or part of the period were Louis W. Cable, Richard D. Duryea, James D. Hunn, Donald G. Jordan (transferred to Puerto Rico in 1962), Terrence J. McGurk, Tully M. Robison (transferred from Puerto Rico in 1963), Joseph S. Rosenshein (to graduate school in August 1960, University of Illinois, then to the Florida District, November 1964), Rubin J. Vig (resigned in November 1959), William H. Walker, Frank A. Watkins, Jr., and Ronald J. Wolf. Administrative or clerical staff were Emma Lee Beagle, Eulalah E. Dain, Geraldine M. Litteral, Naomi J. Stultz, Elmira (Ducheneax) Vig, and Mary Jane Wilson. The technicians on the staff included John H. Broglin, John W. Hawley, and Robert J. Southwood.

Prior to 1961, the Indiana District Geologist served as ground-water consultant to the Illinois District.

### *Quality of Water Branch (1957–65)*

The QWB maintained neither staff nor office in Indiana; however, QWB District staff and laboratory at Columbus, Ohio, provided water-quality assistance to WRD operations in Indiana.

### *Water Resources Division (1965–66)*

Indiana was designated a Division-level District in February 1965 with Hale as District Chief and Roberts as Assistant District Chief. With both former Branches headquartered at the same address, the problem of physically combining operations on a Division level was minimal. No transfers of personnel were required.

Additions to the staff after reorganization and during the remainder of this period were James F. Daniel (transferred from California in 1966), Phillip R. Egan, James E. Heisel, Charles R. Keeton, Mildred I. LaLond, Elwood C. Ludwick, Dale J. Nyman (transferred from Tennessee, June 1965), Thomas E. Richards, and Richard V. Swisshelm, Jr.

## Funding and Cooperation

Funds for the District's programs came primarily from the cooperative program (Coop) and from other Federal agencies (OFA). A small amount of Federal program (Fed) funds supported the operation of selected stream-gaging stations and observation wells. During the period 1960–66, the U.S. Army Corps of Engineers constructed a number of flood-control reservoirs in the State. Gaging stations were constructed and operated to measure inflow and outflow at those reservoirs, the costs of which were paid by the Corps. The following table illustrates the dynamic nature of the program. Funds increased from a low of $375,200 in FY 1958 to $723,200 in FY 1966. Federal program funds for the Pretty Lake project were transferred to the District by the SWB Research Section or by the GHB in FY 1963 and account for the large increase in that program.

Indiana District funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 335.3 | 366.0 | 407.6 | 428.6 | 402.3 | 421.1 | 444.4 | 486.4 | 536.2 |
| OFA | 26.2 | 37.1 | 44.0 | 69.9 | 59.2 | 40.5 | 50.9 | 65.4 | 110.0 |
| Fed * | 13.7 | 13.7 | 12.2 | 10.8 | 11.0 | 75.4 | 81.9 | 84.9 | 81.2 |
| Total | 375.2 | 416.8 | 463.8 | 509.3 | 472.5 | 537.0 | 577.2 | 636.7 | 727.4 |

* Partly estimated. Source: District program documents.

### *The Cooperative Program*

The Indiana Department of Conservation through its Division of Water Resources (DWR) was the cooperator for ground-water investigations and the lake-level and lake-mapping programs. The Indiana Flood Control and Water Resources Commission (FC&WRC) was the principal cooperator for the stream-gaging program. Effective July 1, 1965, the Department of Conservation and the FC&WRC were combined into the Department of Natural Resources (DNR), after which DNR was the cooperator for most statewide water-resources investigations.

The Indiana Department of Health cooperated in operating a number of stream-gaging stations to obtain flow data to be used in its chemical-quality sampling program. Also, starting in July 1965, the Department cooperated in a time-of-travel study.

The Indiana State Highway Department shared the costs of operating several stream-gaging stations and the costs of preparing reports on the hydrology and hydraulics of floods at specific bridge sites.

Municipalities and some industries collaborated in funding the cost of operating several stream-gaging stations required by State laws regarding dilution of waste effluent or in the interest of future water needs. The cooperation was handled through the appropriate State agency.

### *Other Federal Agencies*

The principal OFA was the U.S. Army Corps of Engineers, which through its Louisville, Ky., Chicago, Ill., and Detroit, Mich., Districts, funded the costs of operating several stream-gaging stations. The Louisville District provided the costs of a study of the ground-water resources of the Wabash River Basin that began in 1963. The SCS and the FWPCA funded several water-resources investigations.

In 1959–60, the U.S. Air Force funded a ground-water investigation at Bunker Hill Air Force Base at Peru, Ind.

## Summary of Program

Collecting, processing, and publishing water records was a major District activity during much of the period. The introduction of the digital recorder at stream-gaging stations, and to some extent at ground-water observation wells, improved the timeliness of processing and publishing data. Ground-water areal investigations were by county or region for the most part and were largely qualitative in order to build a background of geologic and hydrologic data concerning the State's aquifers. During this period of history, studies were made and reports were prepared on the statewide frequency of floods and of low-flow characteristics of streams. In 1963, the State Legislature passed a 1-percent sales tax on cigarettes and earmarked a portion of the monies raised to the Indiana Flood Control and Water Resources Commission. Subsequently, new interpretive and research programs were begun.

### *Water Records*

Data activities are summarized from District Annual Program, Part II—Water Records Schedule, dated October 1, 1966. Additional information may be obtained from "Water Resources Investigations in Indiana, 1962."

Streamflow Records.—A total of 169 continuous-record stations were operated on October 1, 1965, consisting of 44 classified as primary, 43 as secondary, and 82 as water management. In addition, 65 stations were included in a low-flow network where flow was measured periodically. Daily stages were obtained at 146 lakes and reservoirs and daily precipitation was obtained from 15 recording rain gages.

Ground-Water Records.—As of October 1, 1965, there were 143 wells in the observation-well program, of which 86 were equipped with continuous recorders and 57 were measured periodically. Starting October 1, 1965, the District began a well-drilling program to provide more information about the aquifers being monitored through accurate well logs and to obtain quantitative data through pumping tests.

Water-Quality Records.—The Indiana Department of Health, as its preferred policy, collected and published records of the chemical quality of streams in Indiana. The District furnished the Department with stream-discharge values corresponding to the times of sampling. The District obtained water-temperature data on a periodic basis at 237 stream sites and continuously at 8 sites. Sediment discharge was obtained at 11 stations periodically and at 2 stations on a daily basis. Russell F. Flint of the Ohio District gave technical direction to the design and operation of the sediment program and the laboratory in Columbus, Ohio, analyzed the samples. Ground-water samples were obtained in the course of project investigations, analyzed in the Columbus laboratory, and published in ground-water project reports.

Other Data Activities.—The District assisted in the compilation of surface-water records for Parts 3A, 4, and 5 of the United States for the period 1951–60. "Floods In Indiana, Magnitude and Frequency" by Green and Hoggatt was open-filed in 1960. In the early 1960's, streamflow records were computer processed to obtain summaries of low flows, duration of flows, and floodflows, thus providing the basis for the report "Low-flow characteristics of Indiana streams" by Hoggatt, 1962 (Indiana Stream Pollution Control Board report).

Depth-contour maps of most lakes in northern Indiana were published as part of the cooperative program.

The outstanding floods of June–July 1957 and January–February 1959 were documented by Schoppenhorst in Circular 407 (1958) and by Hale and Hoggatt in Circular 440 (1961), respectively. The District also furnished information for WSP 1750–A (1964) "Floods of January–February 1959 in Ohio and adjacent States" and for WSP 1840–A, (1965) "Floods of March 1964 along the Ohio River."

The District collected and catalogued information applicable to the geology and hydrology of ground-water resources, such as: well and test-hole records, including water levels, yields, and drilling logs; sample cuttings; pumping tests; and pumpage and water use. These data provided the essential materials for the reports published in the Bulletins of the State cooperator.

### *Special Studies*

Among the special studies that were conducted, all or in part, within FY 1958–66 were those of the geology and ground-water resources of 20 counties of west-central and northwestern Indiana. Ten west-central counties were studied during 1950–61 (Watkins and Jordan) and ten northwestern counties, during 1954–61 (Rosenshein and Hunn). The overall objective was to obtain basic ground-water information on a county-by-county basis, preliminary to preparing interpretive reports defining location, extent, quality of water, and the potential for developing the principal aquifers in the region. The basic information was published on a county basis in the Bulletins of the Indiana Department of Conservation, DWR. Information contained in these preliminary reports include selected well logs, chemical analyses of water from selected wells, population figures, and water-use figures. The west-central counties, the dates of publication of the Bulletin, and the Bulletin numbers were: Greene, 1961, 11; Sullivan, 1962, 14; Clay, 1962, 16; Vigo, 1963, 17; Owen, 1963, 18; Putnam, 1964, 21; Parke, 1964, 23; Montgomery, 1964, 27; Fountain, 1964, 28; and Vermillion, 1964, 29. For the northwestern counties, publication dates and Bulletin numbers were: Lake, 1961, 10; Porter, 1962, 12; LaPorte, 1962, 13; St. Joseph, 1962, 15; Marshall, 1964, 19; Fulton, 1964, 20; Starke, 1964, 22; Pulaski, 1964, 24; Jasper, 1964, 25; and Newton, 1964, 26. After the preliminary studies were completed, interpretive reports were prepared and published for six areas that included nine counties. By county name, date of publication, and Bulletin number, these were: Lake, 1968, 31; Porter and Laporte, 1968, 32; St. Joseph, 1969, 33; Vigo and Clay, 1971, 34; Sullivan and Greene, 1973, 35; and Montgomery, 1974, 36.

The ground-water resources of Tippecanoe County were investigated by Rosenshein in 1952–58 and of Adams County by Watkins and Ward (Indiana Dept. Conserv., Div. Water Resources Bull. 8, 1958, and Bull. 9, 1962). The ground-water resources at Bunker Hill Air Force Base were investigated by Watkins and Rosenshein in 1959–60 (WSP 1619–B, 1963).

A report on continuing sediment investigations in Indiana covering this period of history and more was prepared by Johnson (open-file rept., 1971).

A report on the ground-water resources of the Wabash River Basin was being prepared by Watkins as this period of history ended. The report was requested and funded by the Corps of Engineers as the lead agency of an interagency study charged by the U.S. Water Resources Council to develop a comprehensive plan for the development of the land and water resources of the basin.

A comprehensive study of the water resources of Delaware County was made in 1963–65 by a multidisciplinary team made up of R.E. Hoggatt (SWB), J.D. Hunn (GWB), and W.J. Steen of the State Department of Conservation (Indiana Dept. Conserv., Div. Water Resources Bull. 37, 1968). This was the first time in the State that a Federal-State team was used in one project. The work was under the guidance of the Indiana WRD Council.

The ground-water resources of Vanderburgh County were studied by Cable and Wolf in 1964–66 (Indiana Dept. Conserv., Div. of Water Resources Bull. 38, 1977) and the ground-water resources of Posey County, by Robison in 1965–66 (Indiana Dept. Conserv., Div. Water Resources Bull. 39, 1977). A ground-water reconnaissance of a proposed industrial corridor in Harrison County was made by Hunn in 1965 (open-file rept., 1968).

After the Topographic Division completed mapping the State on 7.5-minute quadrangles during the 1960's, the District began delineating drainage boundaries on the quadrangles of all basins of more than 5 square miles and determining the drainage areas above gaging stations, dams, sewage outfalls, water-treatment plant intakes, and major State and Federal highway crossings. The project, begun in 1965, was under the supervision of Hoggatt.

Evaporation losses from lakes were studied by Heisel in 1965 in an attempt to determine monthly evaporation losses and to develop coefficients for use, statewide. The basis for determining losses was the energy-budget method using methodology and instrumentation developed by the research staff in Denver (see Part IV, "Evaporation Studies").

Time-of-travel studies, under Hoggatt's leadership, began in 1965 to determine the traveltime of water particles (as opposed to traveltime of the energy wave) in selected streams at various rates of flow. A report was planned that would contain actual results and regionalized formulas to allow traveltimes to be estimated on streams, statewide. The fluorometer and Rhodamine-B dye were used. Because tracing each dye injection involved a 24-hour vigil, considerable manpower was needed for each "run." Soon after the program began, a train accident on a bridge over a major stream spilled a large quantity of toxic materials upstream from a city's water-supply intakes. The District was asked to estimate the number of hours before the toxic materials would reach the city. The District's estimate of 96 hours for the leading edge of the spill to reach the city's water-supply intakes was within 4 hours of the actual time, as determined by Board of Health samples.

A study of channel meander, under Daniel's leadership, was begun in 1966 on the White River downstream from Indianapolis in an attempt to develop an empirical method of predicting channel meander.

A study of the water resources of the city of Columbus by Watkins was begun in 1966, at the request of the State cooperator, to provide information on the availability of ground water needed by the city.

### Other District Activities

The District prepared long-range plans for the systemic investigation of the State's water resources.

Annual technical conferences, involving outside experts as well as District specialists and attended by all personnel were held most years during the period. District management was very conscious of the need for training. Personnel, both administrative and technical, attended numerous formal training sessions. These sessions were both in-house and those offered by the Branches or Division. Twice during the period, the District Engineers of the Indiana, Illinois, Ohio, and Michigan SWB Districts arranged inter-District seminars, one for professional personnel and the other for technicians.

## Iowa

*By* Walter L. Steinhilber assisted *by* Sulo W. Wiitala, Ivan L. Burmeister, *and* Samuel Mummey, Jr.

Water-resource programs were developed, administered, and executed by the Branches throughout the years 1957–66. Integration as a Division-level District was in February 1967.

### Organization and Personnel

#### *Surface Water Branch*

The District office remained in the Hydraulic Laboratory at the University of Iowa throughout the period. Vernal R. Bennion, who had been the District Engineer since 1949, continued in that position until his death in September 1964. He was succeeded by Sulo W. Wiitala, who was reassigned from the Michigan District in 1965. George Anthony was the Assistant District Engineer from 1957 to 1959. He was succeeded by Ivan L. Burmeister, who transferred from the North Carolina District. (Burmeister was enrolled at the University of Iowa in 1964–65, under the auspices of the Government Employees Training Act, where he earned an M.S. degree in Water-Resources Engineering). Claire E. Putz was the District Clerk until she transferred to the Social Security Administration in October 1957. Elaine M. Field was transferred from the Council Bluffs Subdistrict in 1958 to become District Clerk (later Administrative Assistant). Elaine A. Rohret Gockel succeeded Field in 1964.

Hydraulic and hydrologic research was conducted in the District under the auspices of the SWB Research Section. Herman J. Koloseus (1957–61) and Jacob Davidian (1958–61) conducted hydraulic research in the Hydraulic Laboratory. Ernest C. Pogge, who was a SWB engineer in the Council Bluffs and Iowa City offices from 1956 to 1960, went on WAE status and initiated a research project (also to be the subject of his Ph.D. dissertation at the University of Iowa) on the mechanics of base flow. He continued this project beyond this period. George R. Kunkle conducted and completed a research project on base flows in the Four Mile Creek Basin in east-central Iowa during 1962–65. Leon E. Betts, engineering aid, assisted Pogge and Kunkle from 1962 to 1965 and was then transferred to the Ft. Dodge Subdistrict.

From 1957 to 1960, all SWB field and office work was carried out by the Iowa City District office and the Council Bluffs Subdistrict and the Ft. Dodge Subdistrict (established in 1958). By 1961, when the District office was reorganized, collecting and processing streamflow data was assigned to the newly established Iowa City Subdistrict. Also established with the reorganization were the Hydraulic and Hydrologic (H&H) Section and the Sediment Data Section, although both types of work were conducted and reported on for years before the reorganization. The staff of each of the Subdistricts or Sections during this period were:

Iowa City Subdistrict.—Robert J. Longfield was in charge until 1962 when he transferred to the California District. He was succeeded by Richard E. Myers. Others on the staff were Errol M. Alexander (who worked in both the Council Bluffs and Ft. Dodge offices before being transferred to Iowa City Subdistrict in 1962); Phillip J. Carpenter (until reassigned as Engineer-in-Charge of the Ft. Dodge Subdistrict in 1963); Shirley A. Dvorak (1959–61); Phyllis E. Hahn (1962–64); Josephene C. Kulik (1964–66); Wilbur J. Mathes, Jr.; Myron P. Molnau; Samuel Mummey, Jr. (from the H&H section in 1963 until he was placed in charge of the Sediment Data Section in 1965); Gerald G. Plantz; Robert J. Polman (1964–66); Theodore Sieger, Jr.; and Charles H. Swift (until he transferred to H&H Section in 1961).

Council Bluffs Subdistrict.—Charles W. Sullivan was in charge until he transferred to the Oklahoma District in 1958. He was succeeded by Orlando J. Ramsvick. Others on staff were Raymond A. Boster (1962–64); Raymond D. Burkey; Mary D. Kilday; Frank E. Lindstrom; Errol McAlexander (1959–60); David A. Schaull; Eugene D. Stenstadvold; Viola Taylor (replaced Kilday in 1962); and Richard H. Thompson (1957 to the winter of 1964, when he drowned while measuring the Missouri River at Sioux City).

Ft. Dodge Subdistrict.—James L. Cook, who transferred from the Iowa City District office in 1958 to establish and head the Subdistrict office, was reassigned to the California District in 1963. He was succeeded by Carpenter from the Iowa City Subdistrict. Carpenter transferred to the H&H Section in Iowa City in late 1965). Others were Richard A. Bair, who succeeded Carpenter as Engineer-in-Charge in early 1966; Leon E. Betts (from the Iowa City Research Section in 1965); John H. Hanneman; Genevieve R. Knudson (clerk-typist from 1959–62); Carrol W. Saboe (1958 to 1963, when he transferred to H&H Section in Iowa City); and Katherine M. Svaleson (succeeded Knudson).

Hydraulic and Hydrologic Section.—Harlan H. Schwob, the Engineer-in-Charge, was the consummate hydrologist—analyzing and publishing on floods and low flows of Iowa streams for years before and after this period. Others on the H&H staff were David H. Appel (1965–66); Jack T. Freshwaters; Daniel J. Gockel (transferred to the Post Office Department in 1962 and returned to the District in 1966); Mummey; Donald J. Riddle; Donald W. Spencer (1959 to 1963, when he transferred to the Missouri District); Swift (from the Iowa City Subdistrict in 1961 until he was reassigned in 1965); Duane E. Wheat (1965–66); and John D. Winslow (1960–1961).

Sediment Data Section.—Owen J. Larimer was in charge until he transferred to the South Dakota District in 1964. Myron Molnau moved from the Iowa City Subdistrict in 1964 to succeed Larimer. Molnau resigned in the fall of 1965 to attend the University of Idaho and was succeeded by Mummey, who transferred from H&H. Others were Ambrose E. Cooper (1957–62) and Plantz, who moved from the Iowa City Subdistrict in 1962).

### *Ground Water Branch*

The GWB District remained headquartered in the Geology Annex of the University of Iowa with personnel of the Iowa Geological Survey (IGS). Walter L. Steinhilber, who was appointed District Geologist in March 1957, continued to serve in that capacity throughout the period. At the beginning of the period, the staff numbered three because of the transfers prior to 1957 of such District mainstays as William E. Hale, R.J. Jeffords, C. Richard Murray, Charles W. Lane, H. Garland Hershey, who was the District Geologist and the Director of IGS, James B. Cooper, and Eugene H. Walker. However, as the program grew, the staff reached a maximum of eight by the early 1960's. In addition, three to five IGS personnel were assigned to the cooperative GWB program.

Other personnel assigned to the District during all or part of this period were Donald B. Aaronson (appointed in 1965), Joseph W. Cagle (arrived from the Florida District in 1961), Ronald W. Coble (appointed in 1962), Robert E. Hansen (appointed in 1957), Hans M. Jensen (1957–59), Leon L. Steele, and Floyd R. Twenter (transferred from the Arizona District in 1962). The District Clerk throughout the period was Olatha M. Tweedy. IGS personnel assigned to the program were Russell Campbell, Paul J. Horick, Richard A. Northrup, Mary Parker, and various draftspersons.

### *Quality of Water Branch*

The quality-of-water program in Iowa was operated out of QWB headquarters in Lincoln, Nebr.; however, they did little work in Iowa. The SWB District collected sediment and temperature data from Iowa streams; the GWB District collected ground-water samples that were analyzed by the Iowa State Hygienic Laboratories.

## Funding and Cooperation

Funds for the District's programs were principally from the cooperative program (Coop) and from other Federal agencies (OFA). The Federal program (Fed) added support to the Federal base-station and observation-well networks and supported special reports, such as that for the Upper Mississippi River flood of 1965. As the following table indicates, total funds show a persistent rise from $277,900 in 1958 to $530,700 in 1966, most of which reflected significant increases in the SWB program. The GWB program was fairly level at $30,000 to $35,000 from 1957 to 1962, at which time the Director, IGS, and principal cooperator convinced the Iowa Legislature that additional funds would be needed for increased ground-water studies to meet the State's current and future water needs.

Iowa District funds, fiscal years 1958, 1965, and 1966
[In thousands of dollars]

| Fund source | 1958 | | 1965 | | 1966 | |
|---|---|---|---|---|---|---|
| | GWB | SWB | GWB | SWB | GWB | SWB |
| Coop | 38.0 | 128.6 | 103.0 | 224.5 | 110.3 | 241.8 |
| OFA | 0 | 81.2 | 0 | 124.5 | 0 | 138.2 |
| Fed | .7 | 29.4 | 0 | 36.6 | 2.2 | 38.2 |
| Total | 38.7 | 239.2 | 103.0 | 385.6 | 112.5 | 418.2 |
| Total, WRD | 277.9 | | 488.6 | | 530.7 | |

Source: District program documents; figures for FY 1959–64 are not available.

### *Cooperating Agencies*

The IGS continued to be the principal cooperator of both the SWB and GWB by contributing about 70 percent of total Coop offerings during this period for statewide water-resources activities—streamflow and ground-water data networks, areal and topical hydrologic studies, and hydrologic and geologic mapping.

Other State organizations that assisted in the collection and publication of water records of the SWB, only, included State University of Iowa through Iowa Institute of Hydraulic Research, Iowa State University and its affiliated Agricultural Experiment Station, Iowa Natural Resources Council, Iowa State Highway Commission, and Iowa State Conservation Commission.

The Conservation Commission funded the collection and publication of water levels at 10 Iowa lakes. Financial support of the Natural Resources Council was limited principally to the maintenance and operation of an extensive network of low-flow partial-record stations and to low-flow studies. The Highway Commission supported the operation of a network of crest-stage stations, studies of the flood hydrology of various drainage basins, and flood-frequency studies.

Additional funding or services and use of facilities in the surface-water data-collection program were provided by Linn County, Union Electric Company, Des Moines Waterworks, and 12 of the major cities in the State.

### *Other Federal Agencies*

The U.S. Army Corps of Engineers, through four of its Districts (Omaha, Kansas City, Rock Island, and St. Paul) funded a large share of the streamflow-data program. Their support increased from about $75,000 in FY 1958 to more than $133,000 in FY 1966, when there were 62 gaging stations funded by the Corps.

The SCS provided funds to support one gaging station and the U.S. Weather Bureau provided assistance in the form of services or use of facilities.

## Summary of Program

Collecting, processing, and publishing water records continued to be a very strong component of the District program, varying from about 77 percent to 82 percent during this period.

Moderate but significant program growth occurred in interpretive studies. The increasing use of statistical methods in conjunction with computer technology enhanced the timeliness and usefulness of flood and low-flow reports. Areal water-resources studies, integrating surface- and ground-water data, were initiated by 1962. Also, an increasing emphasis on the areal studies was beginning to change from descriptive hydrologic conditions to determinations of the impacts of water development on the environment.

### *Water Records*

Streamflow Records.—The number of continuous-record stations varied from 106 in 1958 to 121 in 1966. Some stations, mostly for general hydrologic purposes, were discontinued and a number of new stations were added to the network during this period. As of January 1966, there were 75 primary (long-term), 38 secondary (short-term), and 8 water-management (special-purpose) stations. It was also during this period that the analog recorders were gradually being replaced by the new analog-to-digital recorders. The number of partial-record stations also varied somewhat during this period; but by 1966 there were 124 crest-stage stations and 425 low-flow stations in the program.

Lake-Stage Records.—Continuous water-level records were obtained at 10 lakes in Iowa throughout the period and were published with the streamflow records.

Ground-Water Records.—In 1958, water-level data were collected at 148 observation wells—18 measured continuously and 130 periodically. By 1966, water levels were measured continuously at 18 wells and periodically at 180 wells. The observation-well program was continually being reevaluated and revised in order to establish a viable network. Conclusions drawn from areal studies dictated the need for establishing observation wells in areas of heavy industrial and municipal pumpage to monitor water-level and chemical-quality changes. Additionally, short-term observation wells were established in areas of future hydrologic studies.

Statewide Collection of Subsurface Information.—This activity was a strong element in the cooperative ground-water studies. The IGS and GWB District personnel maintained liaison with Iowa water-well drillers and taught geologic and hydrologic courses at their annual conventions. Consequently, the drillers voluntarily saved drill cuttings, recorded water-level and performance-test data, and collected water samples for chemical analyses. IGS subsurface specialists studied the drill cuttings and produced strip logs. Thousands of strip logs were filed and, with the hydrologic data collected by drillers and Survey hydrologists, provided the backbone of the areal studies.

Water-Quality Records.—By 1966, sediment discharge and temperature data were collected daily at 11 streamflow stations and periodically at 9 stations.

Other Data Activities.—Throughout the period, the SWB District gave priority attention to the measurement and documentation of notable floods. Many indirect measurements were made at regular and crest-stage gages and miscellaneous sites whenever a sizable flood occurred. The Upper Mississippi River flood of

March-May 1965 was reported in WSP 1850-A (1970) by Anderson and Burmeister. Other outstanding floods of the period were summarized in the Survey's annual WSP flood series entitled "Summary of floods in the United States, during [dates]."

#### *Special Studies*

Among the principal areal, topical, and site studies that were conducted, all or in part, within this period was the determination of drainage areas of Iowa streams by Larimer in 1956–57 (Iowa Highway Research Board Bull. 7, 1957). The low-flow characteristics of Iowa streams, investigated by Schwob in the early 1950's, was continued through this period (Iowa Natural Resources Council Bull. 9, 1958).

The geology and ground-water resources of Clayton County were studied by Steinhilber, Van Eck, and Feulner during 1956–60 (IGS Water Supply Bull. 7, 1961). The availability of ground water in Decatur County, investigated by Cagle and Steinhilber beginning in 1962, was continued through this period. The report (IGS Water Atlas No. 2, 1967) was the first in an ongoing contractual test-drilling program to locate water-bearing sands in the glacial drift in south-central Iowa, an area noted for having poor water supplies.

A hydrogeologic study of the ground-water reservoirs contributing to the base flow of Four Mile Creek in east-central Iowa was made by Kunkle in 1962-65 (WSP 1839–O, 1968).

In 1962, Twenter and Coble began working on the first report of "The water story in central Iowa," a multiyear program to define, describe, and quantify the total water-resources potential in nine regions in Iowa (IGS Water Atlas No. 1, 1965).

Summer base-flow recession curves were prepared for Iowa streams by Saboe in 1966 (available from Iowa WRD District office).

Reporting the hydrologic and hydraulic characteristics of floods in Iowa was a major activity of the District. Schwob reported on the "Magnitude and frequency of Iowa floods, parts 1 and 2" (Iowa Highway Research Board Bull. 28, 1966). Numerous reports on the hydrology and hydraulics of floods at highway-stream crossings were prepared as requested by the Highway Commission. Floods at Des Moines were documented by Myers (HA–53, 1963) and the Cedar River Basin floods by Schwob (Iowa Highway Research Board Bull. 27, 1963).

Other ongoing studies, completed and published soon after this period ended, were of ground-water studies in Linn and Cerro Gordo Counties and the definition and description of Iowa's ground-water reservoirs, the first of which was a study of the Mississippian aquifer. Flood profiles and flood-plain information for Linn County were being prepared.

## Kansas

*By* Edward J. Kennedy, John D. Winslow, Arthur M. Diaz, *and* Jesse M. McNellis

Programs were developed, administered, and executed by the Branches, with planning coordinated by the Kansas WRD Council, during the entire 1957–66 period.

### Organization and Personnel

#### *Surface Water Branch*

*By* Edward J. Kennedy

The SWB District headquarters was in the Post Office Building in Topeka. Elwood Leeson was the District Engineer until his reassignment to Washington, D.C., as Assistant Division Chief in October 1961. Edward J. Kennedy, previously the Assistant District Engineer, was appointed to succeed Leeson and Hal K. Hall was transferred from Houston, Tex., as the Assistant District Engineer. Both served for the remainder of the 1957–66 period. The District Clerk was James D. Rose until 1960 when he was succeeded by Grace C. Kreipe, previously the District secretary. Anna Belle Holston succeeded Kreipe as secretary. Eleanor L. Gulley became District Clerk in 1965.

The District was reorganized in 1957 into a District office, Hydrologic Studies Section, and Subdistrict office, all in Topeka, and with Subdistrict offices in Ellinwood and Stockton.

Lawton W. Furness was in charge of the Hydrologic Studies Section. His staff included Gerald W. Armentrout (1961–63), Clarence V. Burns, Mark W. Busby (1961–), George W. Edelen (1957–59), Davis W. Ellis (1957–61), Thomas J. Irza, Ivan C. James (1963–66), Carroll M. Kilgore (1961–64), Kenneth L. Lindskov (1960–66), and David V. Maddy (1965–).

Melvin L. Thompson was reassigned from the Nebraska QWB District as Engineer-in-Charge of the newly established Topeka Subdistrict. Later, his office was moved from the Federal Building to a suburban location. The staff included at various times: Dorothy Bates (1959–63), Stephen V. Bond (1965–), James S. Carpenter (1957–58), William J. Carswell Jr. (1965–), Robert T. Coomes (1960–62), James D. Craig, Russell E. Curtis Jr., Claude O. Geiger (1960–63), Charles W. Kennedy (1963–65), Anthony T. Klamm, Glenn C.

Quy, Carroll V. Schroer (1957–58), Neil W. Schild (1960–63), and Lloyd E. Stullken (1958, 1963–).

Leo A. Bohner established the Ellinwood Subdistrict as its Engineer-in-Charge. The staff at various times included Larry L. Jones, Frank P. Kipple, DeAlton H. Lewis, Paul S. Marshall, and R. Dale Thomas.

The Nebraska QWB Subdistrict office in Norton, Kans., operated some northwestern Kansas gaging stations that also involved sediment and chemical quality, on a reimbursable basis. When the water-quality work was completed in 1957, the Norton office was closed. Carroll V. Schroer established a Subdistrict office in Stockton to operate the former Norton stations and some others. His staff, at various times, included Stephen V. Bond (1962–65), Claude O. Geiger (1963–65), and Lloyd E. Stullken (1958–63).

The Ellinwood and Stockton Subdistrict offices were closed in 1965 and replaced with offices at Wichita and Hays. Leo A. Bohner, the Engineer-in-Charge at Wichita, was aided at various times during the period by Claude O. Geiger, Kenneth L. Lindskov, Paul Marshall, Richard D. Thomas, James A. Kimble, and Joyce M. Lee. Charles W. Kennedy (1965–) headed the Hays office, aided by Dennis L. Lacock and Diane M. Waldschmidt. Larry L. Jones operated out of the Colby GWB field headquarters.

#### Ground Water Branch

*By* John D. Winslow *and* Jesse M. McNellis

The GWB District headquarters, which also served as the headquarters for field projects in the central and eastern parts of the State, was in Lindley Hall at the University of Kansas, in Lawrence. Office facilities and activities were shared with the staff of the Division of Ground Water, Kansas Geological Survey (KGS). Vinton C. Fishel was the District Engineer until he transferred to the Foreign Hydrology Section in July 1963. Robert J. Dingman, previously in Chile, was then appointed District Geologist. Charles W. Lane was Assistant District Geologist until 1962 when he moved to Billings, Mont., to be the Montana GWB District Geologist. John D. Winslow, reassigned from Albany, N.Y., then became Assistant District Geologist. Betty Lee G. Henderson was District Clerk until 1958 when Eleanor L. Gulley took the position and served until 1965 when she was reassigned to the SWB in Topeka. Janet K. Kerr succeeded Gulley.

Other District staff, at various times during this period included (generally in the order of their assignment to the Kansas District): Carlton R. Johnson, Gilbert J. Stramel, Bernita K. Mansfield, Audry J. Lavely, Betty J. Mason, Lorraine L. Gross, Edyth L. Godwin, Ralph H. King, Kenneth L. Walters, Warren G. Hodson, Leslie E. Mack, Kenneth D. Wahl, Barbara B. Daly, Marilyn L. Eaton, Dorothy J. Hayes, Nancy L. Roofe, Lottie I. Rodenhaus, Charlotte A. Bayne, Jesse M. McNellis, William K. Johnson, Nancy R. Chamney, Margaret E. Broeker, Melvin H. Franz, Mary J. Kummer, Dorothy J. Hayes, Larry Shelton, Judy M. Crissler, Richard H. Benson, Charles O. Morgan, Betty S. Allen, Jeanette H. Jones, Donald W. Layton, Carrie L. Reavis, Brent H. Lowell, and Glenda F. Richardson.

The field headquarters in Garden City was opened in 1959, first under the direction of Stuart W. Fader, and later, successively, under Walter R. Meyer and Harold E. McGovern. It served projects in southwestern Kansas. The staff, at various times during the period, also included Lee C. Burton, Edwin D. Gutentag, Donald W. Layton, William N. Lockwood, David H. Lobmeyer, William A. Long, Robert C. Prill, Larry Shelton, and Ethel A. Waddell.

Edward D. Jenkins established the field headquarters in Colby in 1964 to serve projects in northwestern Kansas. His staff included, at various times, Alan W. Burns, Larry L. Jones, Marilyn Pabst, Richard H. Pearl, and Robert Roberts.

The primary role of the Garden City and Colby field offices was to conduct areal aquifer investigations in southwestern and northwestern Kansas to provide information on the ground-water problems developing in those areas owing to the great excess of ground water withdrawn as compared to the very limited recharge.

Henry V. Beck (WAE) was the sole staff member of a field headquarters in Manhattan, for the full period.

#### Quality of Water Branch

*By* Arthur M. Diaz

Until 1957, practically all of the quality-of-water investigations in Kansas were carried out by Nebraska QWB personnel headquartered in Norton, Kans. The investigations were in support of the multi-State Missouri River Basin program (see Part IV, "Missouri River Basin program") and were directed by Paul C. Benedict, Regional Engineer, QWB, Lincoln, Nebr., succeeded by Donald M. Culbertson. Substantial completion of those investigations led to the closing of the Norton office in 1957. The few remaining operations in Kansas were handled by Lincoln, Nebr., QWB District personnel until 1958 when the Kansas QWB cooperative program was started.

A statewide program of fluvial-sediment investigations began in 1958 with the establishment of a Subdistrict office and sediment laboratory in Salina, Kans. Calvin D. Albert was named Soil Scientist-in-Charge, reporting to the Lincoln, Nebr., Regional Engineer. The staff included at various times Clarence Frederick, James P. Marshall, Joseph T. Religa, David R. Selleck, Willis Waterman, and Larry Watts.

A statewide program of chemical-quality investigations began in October 1961 with the establishment of a QWB Subdistrict office in Topeka. Arthur M. Diaz was transferred from Salt Lake City, Utah, to be Chemist-in-Charge. His staff included Saundra Clinkenbeard, Lyle Davis, Lloyd Gavin (WAE), Robert B. Leonard, and various technicians and support personnel from the State cooperating agency. Reorganization of the Nebraska QWB District in May 1965 led to the designation of the Topeka QWB office as a project office, with the Salina office reporting to it. The project office was placed under the direction of the Area Hydrologist, RMA, pending the scheduled reorganization of the Kansas District.

### Funding and Cooperation

Funds for District operations were largely from the cooperative (Coop) program and from other Federal agencies (OFA). Federal (Fed) program funds provided support for a few gaging stations, selected water-quality stations, part of the observation-well measurement program, and some miscellaneous items of work.

Kansas District funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 222.8 | *258 | *268 | 386.4 | 501.8 | 511.7 | 621.2 | 643.6 | .700.6 |
| OFA | 144.6 | *136 | *155 | *121 | 149.8 | 172.2 | 174.0 | 174.5 | 173.3 |
| Fed | 13.1 | *12.1 | *11.0 | 12.2 | 15.3 | 14.7 | 11.8 | 13.6 | 17.1 |
| Total | 380.5 | *406.1 | *434.0 | 519.6 | 666.9 | 698.6 | 807.0 | 831.7 | 891.0 |

* Partially estimated from a Headquarters-prepared compilation by States of total WRD expenditures that include those of the District, plus a prorated portion of the cost of Headquarters-staff work related to District programs. The prorated portions were estimated, subtracted from the compiled figures, and the resulting amounts were entered in the above table. All other figures were obtained directly from available District-prepared tables of annual expenditures.

#### *Cooperating Agencies*

The Kansas Water Resources Board (KWRB) was the principal cooperator for operation of the streamflow-data network, surface-water hydrologic studies, sediment-data network, and fluvial-sediment studies.

The Kansas Geological Survey (KGS), Division of Ground Water, was the principal cooperator for the observation-well program, for studies of the geology and ground-water resources of individual counties, for valley aquifer studies, and for regional studies in areas where ground water was the principal source of irrigation water. Certain KGS personnel were assigned to the District for project activities similar to those of District staff.

The Kansas Department of Health and Environment (KDHE), Division of Environment, was principal cooperator for the water-quality data network and quality-of-water investigations and also cooperated in the monitoring of water quality in a selected statewide network of nearly 300 observation wells.

The Kansas Department of Transportation supported the statewide network of crest-stage gages and flood-runoff recorders, preparation of reports on flood characteristics at specific stream sites, and small-area flood-frequency studies.

The Kansas State Board of Agriculture, Division of Water Resources, cooperated in collecting hydrologic data by furnishing experienced personnel for streamflow measurements of floods and low flows, making periodic discharge measurements at gaging stations on streams used for irrigation, and by assisting in ground-water studies in areas where irrigation water was obtained from wells.

The city of Wichita provided funds and services for gaging-station operation and other flood-control-related investigations in the Wichita area and cooperated in the operation of an observation-well network to obtain information on water levels and quality trends in an extensive well-field area northwest of Wichita.

#### *Other Federal Agencies*

The U.S. Army Corps of Engineers and the BOR provided funds and services for the operation of numerous gaging stations and observation wells in their project areas, and the FWPCA (later the EPA) also provided funds for the operation of selected water-quality stations.

### Summary of Program

The collection, processing, and publication of water records in keeping with the application of network concepts, continued as the largest component of the surface-water program and as a less significant part of the ground-water and water-quality programs. Hydrologic and areal investigations, and appraisals of water resources were the major parts of the ground-water and water-quality programs.

### *Water Records*

Surface-Water Records.—In 1956 there were about 107 regular gaging stations and 5 reservoir or lake stations in the program. By 1966 the program had grown to 152 regular gaging stations, 15 reservoir or lake stations, and 101 crest-stage partial-record stations.

The advent of the digital water-stage recorder, with its need for accurate and reasonably complete registration of the gage-height record on a recorder tape, mandated the complete restructuring of Kansas stream-gaging procedures. Most Kansas streams flow in unstable alluvial beds whose channels move horizontally as well as vertically during both high- and low-water periods. Prior to 1955, a typical Kansas gaging station consisted of a graphical recorder over a stilling well that was connected to the stream by an intake pipe. The intake end was often buried under the shifting sand in the streambed and periodically, in large rivers, was inaccessible and inoperative for a year or more. Much of the gage-height record was based on graphs based on observer's gage readings. These stations were inherently labor intensive and totally unsuited to digital-recorder operation.

The then-newly developed gas manometers (bubble gages) promised only a partial solution to the problem. A few bubble gages, installed with their orifices well above the sandy streambeds, furnished a good record for all but very low stages. Digital recorders could be used with those bubble gages, but nonrecording supplemental equipment was still necessary. Then, an informal suggestion by Guy Vincent, a State (DWR) engineer and stream gager, led to the eventual development, mainly by James D. Craig and Melvin L. Thompson, of well-point orifices that enabled bubble gages to register complete and reliable gage-height records at nearly all Kansas gage sites. Prefabricated bubble-gage shelters, and equipment for their rapid installation, were developed. The old gages were replaced by the new at a rate of about 20 or 30 each year until practically all of the District's regular gaging stations were bubble gages driving digital recorders.

Most of the crest-stage stations were installed on small streams to collect data for a planned small-area flood frequency report. Semiportable stage-rainfall recorders (SR gages), eventually replaced with pairs of digital recorders, were operated at each small-area crest-stage gage site until enough rainfall and stage hydrographs of flood events had been recorded at that site to define an adequate runoff model. Then the equipment was moved to a different site and the process was repeated until runoff models for all of the small-area sites had been calibrated.

Ground-Water Records.—Records of water levels—continuous, monthly, quarterly, annual, occasional, or miscellaneous—were collected in about 900 observation wells distributed over the State. The records of water levels in the statewide network of about 500 observation wells with descriptions of the wells were published annually by the KGS. The chemical analyses of water from observation wells in the State were published periodically by the KDHE.

Quality-of-Water Records.—In 1957, seven chemical-quality and five sediment stations were operated continuously, and periodic records were collected from four reservoirs and five sediment-station sites. All were for stations in the Missouri River Basin program. By 1966, because of the establishment of a statewide cooperative program, the work expanded to 65 chemical-quality stations, 31 sediment stations, 13 water-temperature stations, about 100 periodic sampling sites, and numerous sites that were selected to support areal investigations.

### *Special Studies*

Surface water.—The long-range plan of Leeson and Robert L. Smith (Executive Secretary of the KWRB, principal cooperator as well as an outstanding hydrologist, planner, and manager) that led to the formation of the Hydrologic Studies Section of the District, was fully implemented by 1957 and work continued or was begun on a series of planning, areal, and site studies, the first of which was "Development of a balanced stream-gaging program for Kansas" by Furness (KWRB, Bull. 4, 1957). This was followed by reports by Furness on flow duration (KWRB Tech. Rept. 1, 1959), on low-flow frequency (KWRB Tech. Rept. 2, 1960), on storage requirements to sustain gross reservoir outflow (KWRB Tech. Rept. 4, 1962), and by Furness, Burns, and Busby on storage requirements to control high flow (KWRB Tech. Rept. 5, 1964) and on base-flow distribution (KWRB Tech. Rept. 6B, 1966). Furness and Busby also investigated two methods of estimating base flow at ungaged stream sites in Kansas and adjacent States (PP 475–C, 1967). Base flows of Kansas streams were also investigated and reported on by Busby and Armentrout (KWRB Tech. Rept. 6A, 1965).

Ellis and Edelen prepared a report on the magnitude and frequency of floods in Kansas (KWRB Tech. Rept. 3, 1960) and Ellis and others documented the floods that had occurred at Wichita from 1942 to 1960 (HA–63, 1963). Additional flood data from small streams permitted the preparation of a report by Irza on preliminary flood-frequency relations for small streams in Kansas (open-file rept., 1966). A project in cooperation with the city of Wichita on effect of urbanization on flood runoff was started in 1963 and an analysis of initial conditions was made by James (open-file rept., 1967).

Ground water.—The principal GWB project activities were studies of the geology and ground water of individual counties, which were completed at the rate of about five each year. There were also areal ground-water investigations in southwestern and northwestern Kansas and valley aquifer studies. The results were generally published by the KGS.

A series of short reports was published annually as KGS bulletins that showed the rapid decline of water levels in the major aquifers serving as sources of agricultural irrigation water.

Research was conducted by Prill and Meyer on the quantitative determination of ground-water recharge in the Kansas high plains by using a neutron probe to study the soil moisture and mechanics of ground-water recharge to depths exceeding 500 feet (PP 600–B and D, 1968).

In 1963, John Winslow established an electric-analog model laboratory where he and State-cooperator staff modeled a number of complicated aquifer situations to analyze ground-water/surface-water interrelations.

Also in 1963, Jesse McNellis started a program to develop digital computer programs to assist in the collection, tabulation, and analysis of ground-water and quality-of-water data. He was joined by Charles Morgan and Brent Lowell. They rapidly built up an extensive group of computer programs that greatly facilitated the work of project personnel. In 1964, SWB and QWB personnel started using the computer facilities available through the KGS and the University of Kansas to develop ADP programs to facilitate surface-water and water-quality data processing and analysis. As the importance of this new use of computers in the collection, tabulation, and analysis of hydrologic data was recognized, a series of computer short courses was given in Lawrence and in other districts for WRD personnel. Many of the computer programs were adapted to run on the ADP system at national headquarters.

Representative reports on other-than-county or areal appraisals of geology and ground-water resources were "Water-level changes in Grant and Stanton Counties, Kansas, 1939–1964," by Winslow, Nuzman, and Fader (KGS Special Pub. 10, 1964); "Logs of wells and test holes in Sedgwick County, Kansas," by Lane and Miller (KGS Special Pub. 22, 1965); "Application of pattern analysis to the classification of oil-field brines," by Angino and Morgan (KGS Computer Contrib. 7, 1966); "Electronic simulation of ground-water hydrology in the Kansas River valley near Topeka, Kansas," by Winslow and Nuzman (KGS Special Pub. 29, 1966); and "Ground water in Kansas—Bibliography and subject index," by Roberts and Hodson (KGS Bull. 182, 1966). An interdisciplinary team made up of Petri (QWB, Lincoln, Nebr.), Lane (GWB, Lawrence), and Furness (SWB, Topeka) investigated and reported on the "Water resources of the Wichita area, Kansas" (WSP 1499–I, 1964).

Quality of water.—Reports on special studies by the staff of QWB from Kansas or from Nebraska were generally published by the Kansas cooperating agency or by the USGS. Some of the studies and their reports were "A program of fluvial sediment investigations in Kansas," by Mundorff (QWB, Lincoln, Nebr., KWRB Bull. 6, 1961); "Brine in surface water of the Little Arkansas basin, Kansas," by Albert (KDHE, Bull. 1–5, 1964); "Results of four chemical-quality surveys of the Walnut River basin, Kansas, December 1961 to October 1963," by Leonard (KDHE Bull. 1–3, 1964); "A method of evaluating oil-field-brine pollution of the Walnut River basin, Kansas," by Leonard (PP 501–B, 1964); "Chemical quality of surface waters in Kansas, 1963 water year," by Mayes and Diaz (KDHE Bull. 1–8, 1965); "Fluvial sediment in the lower Kansas River basin—A progress report 1957–60," by Mundorff and Scott (KWRB Bull. 7, 1964); "A general classification of source areas of fluvial sediment in Kansas," by Collins (KWRB Bull. 8, 1965); and "Fluvial sediment in the Little Arkansas River basin, Kansas," by Albert and Stramel (WSP 1798–B, 1966).

## Kentucky

*By* Robert V. Cushman *and* reviewed *by* Marion S. Hines

Water-resource investigations in Kentucky were carried out by the Branches throughout the period 1957–66 with planning and coordinating of the work of the three Branches by the Kentucky WRD Council. The Council functioned well as the District offices of two of the three Branches, Surface Water and Ground Water, had office space together. They were at 830 West Broadway, Louisville, in 1957, but moved in 1958 to the Center Building, 522 West Jefferson Street, for the rest of this period. Consolidated annual proposed programs and progress reports had been submitted to the principal cooperator since before the start of this period.

## Organization and Personnel

### *Surface Water Branch*

Floyd F. Schrader was the District Engineer throughout the period and Nathan O. Thomas was the Assistant District Engineer until his transfer to North Carolina in 1963, after which John A. McCabe served as the Assistant. Others assigned to the Louisville office for all or part of the period included Howard C. Beaber, Lamar E. Carroon until 1958, Curtis H. Hannum, W. Howard Jackson, George A. Kirkpatrick until 1961, William B. Mann beginning in 1959, Thomas R. Oglesby beginning in 1958, Sterling R. Osborne until 1958, Billy L. Raney, John L. Spillman, and Robert E. Steacy until 1958. Irene A. Fraser, the District Clerk, also did the bookkeeping for the GWB District for part of the period. Elizabeth A. Aboud and Mary P. Hays handled the secretarial work.

Field personnel from the District office serviced gaging stations and computed streamflow records for the central part of the State under the supervision of Howard C. Beaber. Subdistrict offices were maintained at Paducah and Williamsburg to perform field and office work in western and eastern Kentucky, respectively. Personnel assigned to Paducah included Arthur S. Curtis, Engineer-in-Charge, assisted by Raymond L. Bailey, Marion S. Hines until 1962, and Bob L. Miles. The Williamsburg staff were Chester H. Minehan, Engineer-in-Charge, assisted by Vernon T. Bird, William H. Dykes until 1962, Rufus S. Siler, and Rosella Shaw.

### *Ground Water Branch*

Gerth E. Hendrickson was the District Geologist until 1961 when he transferred to the Lower Colorado River project at Yuma, Ariz. He was replaced by Robert V. Cushman, who transferred from Connecticut. Edwin A. Bell was his assistant until 1963 when he was transferred to Memphis, Tenn. Other members of the Louisville District office included Richmond F. Brown until 1958 when he transferred to Washington, D.C., Hayes F. Grubb hired in 1965, Herbert T. Hopkins (previously assigned to the Louisville field unit of the Denver Hydrologic Laboratory in 1957–59), Willis K. Kulp until 1959 when he was transferred to Sacramento, Calif., Donald S. Mull until 1958 when he set up a field unit at Lexington, Ky., Wilbur N. Palmquist until December 1957 when he was transferred to Denver, Colo., William E. Price until 1963 when he resumed his studies at the University of Arizona, Paul D. Ryder hired in 1965, Harley L. Young until 1960, John A. VanCouvering hired in 1960, moved to Henderson field headquarters in 1961, resigned in 1962 to return to school, and Douglas V. Whitesides. Edith S. Nichols was cartographic draftsman throughout the period and also did drafting for the SWB. Maxine Catlett was fiscal clerk and Alene C. Byers, Hazel C. Douthitt, and Echo I. Elliott were clerk-typists.

Field headquarters were maintained in Henderson and Paducah to further the regional ground-water investigations. Personnel assigned to the Henderson field unit were Robert W. Devaul until he took an assignment in Santiago, Chile, John T. Gallaher until 1961 when he was moved to the Louisville headquarters office, and John VanCouvering from 1961 to 1962. Staff of the Paducah office were Lawrence M. MacCary, Geologist-in-Charge throughout the period, Robert W. Davis who was transferred from Huron, S.Dak., in 1959, John H. Morgan from 1960 to 1964, T. William Lambert, and Arnold J. Hansen, hired in 1965.

A field headquarters, staffed by Mull, was established at the University of Kentucky in Lexington in 1958 to carry out the Area Redevelopment study of the water resources of eastern Kentucky. The office occupied one end of a wood-frame building known as the Euclid Avenue Classroom Building. The Survey's office was separated by a stage from a large, open room used by classes in modern dance and as an indoor drill hall for the ROTC unit. The dance classes provided eye-catching entertainment. However, the presence of the ROTC, besides being distracting, was used as the excuse by campus radicals of the mid-1960's to set fire to the building. The flames were extinguished before the building was demolished but the Survey lost numerous recorder charts from observation wells and two recorders.

### *Quality of Water Branch*

No QWB personnel were stationed in Kentucky. All water-quality operations in the State were under the administrative and technical supervision of the Branch District office and laboratory in Columbus, Ohio. Field work was done by the Columbus staff.

## Funding and Cooperation

Accurate figures of annual program funds for the District have not survived over the years. In the following table, funds shown for fiscal years 1958, 1965, and 1966 are believed to be accurate. For the intervening years, funds for the cooperative program (Coop) and FPC are reasonably accurate. The figures serve to show that the Kentucky program increased in funding by 20 percent during this period, but there were some lean years midway in the period.

Kentucky District funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 325.6 | 330.8 | 331.4 | 293.6 | 334.2 | 329.4 | 316.7 | 317.7 | 327.7 |
| OFA | 84.9 | 57.4 | 103.1 | 109.7 | 79.1 | 92.3 | 89.2 | 147.2 | 157.7 |
| Fed | 25.3 | - | - | - | - | - | - | 36.6 | 39.8 |
| FPC | 1.0 | 1.0 | 1.0 | 1.0 | 1.2 | 1.2 | 2.1 | 2.2 | 2.2 |
| Total | 436.8 | | | | | | | 503.7 | 527.4 |

Note: Funding figures for 1958, 1965, and 1966 are from District program documents and are considered reliable. Those for other years are from Headquarters compilations from unknown sources and are probably accurate to within 10 or 15 percent.

### *Cooperating Agencies*

The Kentucky Department of Economic Development (later named Department of Commerce) was the principal cooperator at the beginning of the period, and since 1949, for statewide water-resources investigations. This Department also administered Kentucky Department of Highway funds allocated to the water-resource investigations to finance interpretation and application of flood data to specific highway bridge sites. Since the mid-1950's the Highway Department had an internal requirement that all highway bridges planned to cost more than $100,000 should have a hydraulic sufficiency report from the USGS.

In 1958, the entire program administered by the Department of Economic Development was transferred to the Kentucky Geological Survey (KGS). The KGS remained the principal cooperator throughout the period. Its Director, also the State Geologist, Dr. Wallace W. Hagan, a valued friend of the USGS, also commenced a landmark cooperative program with the Geologic Division to map the areal geology of the entire State on 7.5-minute quadrangles, at a scale of 1:24,000. These maps were invaluable to the water-resources investigations.

The Ohio River Valley Sanitation Commission (ORSANCO), an interstate regulatory agency established by a compact between Kentucky and seven other States to promote pollution control on a regional basis, funded water-quality sampling at six locations in Kentucky for part of the period.

### *Other Federal Agencies*

Among the Federal agencies giving financial support, the U.S. Army Corps of Engineers, through its Louisville, Nashville, and Huntington District offices, was the largest supporter. Streamflow records, including copies of all rating curves and related information, for practically all gaging stations in Kentucky were furnished to those Corps offices.

The TVA funded the costs of operating two gaging stations in the lower Tennessee River Basin. The National Park Service furnished funds, beginning in 1958, to provide data to evaluate the present and future water supply for Mammoth Cave National Park. The support at first was for stream gaging but was expanded later for a study of the hydrology of the Mammoth Cave area.

The SCS provided financial support for stream gaging and sediment studies in four small pilot watersheds. Later the funding included support for the interagency study on the effects of strip mining on the hydrology of the Beaver Creek Basin in south-central Kentucky, which was also funded in part throughout the period by the U.S. Forest Service.

The FPC, through its licensees, the Kentucky Utilities Company and the Public Service Company of Indiana, provided support for stream gaging.

### Summary of Program

Early in this period, the Kentucky WRD Council developed a long-range plan to obtain water data for all the multipurpose needs of State and Federal agencies and the general public. The plan, accepted by the cooperators, placed emphasis on interpretive programs while maintaining the established strong program of collecting and interpreting basic water records. Topical hydrologic studies, such as those of flood and low-flow frequency and sediment-yield rates, stressed analysis of existing water records to improve their usefulness for design and water-management needs. The statewide reconnaissance of ground water in the five major physiographic regions and the Ohio River alluvial valley in Kentucky was completed by the beginning of the period and emphasis shifted to areal and site studies and studies of special problems, such as pollution by oil-field brines and acidic mine drainage. Data obtained in the statewide reconnaissance were published during the period (1960–62) in a WSP and several HA's for each physiographic region. The atlases presented factual information on the geology of aquifers, locations of selected wells, depths to water, and water quality. These data were summarized and interpreted for planning purposes in each of the WSP's. Near the end of the period, the entire District program and its findings were summarized as part of a useful report entitled "Kentucky Water Resources—1965" published by the Kentucky Department of Natural Resources. The report stressed the importance of water-resource investigations and their value to the State, particularly in solving water problems.

### *Water Records*

The value of collecting, processing, and publishing water records was highlighted in Kentucky by several extreme hydrologic events during the period. These included an unusual flash flood in eastern Kentucky in July 1961, an major flood in the entire southeastern Appalachian region in March 1963 followed by a severe 6-month drought in Kentucky in September 1963 through February 1964, and a major flood along the Ohio River in March 1964.

Streamflow Records.—In FY 1958 the Kentucky District operated 123 continuous-record stations and 29 crest-stage gages on streams. A total of 127 continuous-record stations were being operated in FY 1966, consisting of 48 long-term hydrologic stations, 34 short-term stations, and 45 water-management stations. In addition, peak-discharge data were obtained at 29 stations, low-flow data at 40 stations, and 12 stations were equipped with crest-stage gages.

SWB personnel compiled and analyzed data on the magnitude and frequency of floods for publication in WSP's. McCabe prepared a report on the magnitude and frequency of floods in Kentucky (KGS Information Circ. 9, 1962). Special reports on the floods of 1957 (WSP 1652–A, 1964) and 1964 (WSP 1840–A, Beaber and Rostvedt, 1965) were published. Flow records for all major rivers flowing to the Ohio River were compared and analyzed by Howard Jackson in order to arrive at the best figures of flow of the Ohio River in its several segments and at its mouth. This comparison was useful because a number of major streams in Kentucky feeding the Ohio had flat water-surface slopes near their mouths. Gaging stations in these areas had "three-dimensional ratings" and a few recorded negative flows.

Ground-Water Records.—The size of the observation-well network varied during the period because of short-term networks established for areal ground-water studies. The permanent network increased in size from 69 wells to 80 wells equipped with continuous water-level recorders. Wells measured periodically were 163 in FY 1958 and 110 in FY 1966. In addition the flows of 31 large springs were measured periodically during part of the period for a special project on the hydrology of these potential water sources for municipal and industrial supply (KGS Information Circ. 8, VanCouvering, 1962). Records of ground-water levels in the permanent network were published in WSP 1568 (1956–58), WSP 1803 (1959–63), and WSP 1978 (1964–68). The records for the period 1948-60 were published by the KGS (Information Circ. 7, Whitesides and Nichols, 1961).

Water-Quality Records.—A systematic study of the quality of surface waters, begun in 1949, was continued through the period by personnel from the Columbus, Ohio, QWB District. Daily water-sampling stations for chemical quality were maintained at 13 sites in FY 1958 but reduced to 7 sites by FY 1966. At other sites, samples were collected less frequently at low and high water and at the 31 large springs mentioned above. Personnel of the Kentucky GWB collected samples periodically from wells for quality-of-water data; 66 wells were sampled in FY 1966.

Temperature data were collected at surface-water stations, springs, and observation wells throughout the period. In 1965 they were obtained daily at 24 gaging stations and at less frequent intervals at 44 gaging stations, 9 springs, and 26 wells.

The measurement of suspended sediment and sediment particle size, a program begun in 1951, was done daily during low and normal flows at 12 gaging stations. Samples were collected more frequently at these sites during rapidly changing discharge.

Data on the quality of surface water were published annually in the WSP series "Quality of surface waters of the United States." Beginning in 1964 these data for Kentucky were released annually as open-file reports. Data on the chemical quality of ground water generally were published as part of project reports.

Other Water-Records Activities.—SWB personnel processed streamflow records on the Headquarters computer to obtain low- and flood-flow frequencies and flow duration. These summaries were open-filed or compiled for publication at a later date. McCabe prepared low-flow data for inclusion in a report on low-flow characteristics of streams in the Mississippi Embayment (PP 448–H, 1965).

Information on the public and industrial water supplies of Kentucky were compiled and published by the KGS as Information Circular 4 (Kulp and Hopkins, 1960). This compilation updated two reports published in the 1950's.

Drainage-area figures for all river basins were revised and updated by Beaber as the latest topographic maps became available.

Reports on the hydraulics of bridge sites were prepared by Hannum for the Highway Department as requested.

In 1965 the District measured base flow and collected water-quality samples in support of the Division's regional assessment of the effects of acidic mine drainage on stream quality in Appalachia (Circ. 526, 1966).

A project of controlled-rate pumping tests and specific-capacity test of wells in individual bedrock aquifers began in 1964 to obtain reliable information on the maximum yield of aquifers. Whitesides assembled a trailer-mounted pumping rig for this purpose.

#### *Areal and Site Investigations*

Areal and site investigations were carried out during the period to provide up-to-date and reliable hydrologic data and analysis for regions or sites, such as a community. Many were spin-offs from the earlier reconnaissance studies, which indicated the need for more intensive coverage in certain areas of Kentucky or a more refined analysis of existing data.

Included in the principal areal and site investigations was the study of the subsurface geology and ground-water resources of the Jackson Purchase region by Davis, Lambert, MacCary, and others. The results were published in 32 HA's, and a summary report was published as WSP 1987 (Davis, Lambert, and Hansen, 1973). The hydrology of the alluvial deposits in the Ohio River Valley in Kentucky was investigated by Gallaher and Price. The project, completed in 1965, resulted in 25 HA's and a summary report (WSP 1818, Gallaher and Price, 1966).

The ground-water resources of the Louisville area were investigated by Bell and Kulp. Two summary reports were published (WSP 1579, Bell, Kellogg, and Kulp, 1963; and WSP 1819–C, Bell, 1966). Records of ground-water levels in the Louisville area for the period 1935–60 were published by the KGS (Information Circ. 6, Whiteside and Nichols, 1961).

Hendrickson and Robert A. Krieger reported on the geochemistry of natural waters of the Blue Grass region (WSP 1700, 1964). A study of the hydrology of the cavernous limestones of the Mammoth Cave area by Brown, Cushman, and others began in 1953 for the National Park Service, was intensified in 1961, and is continuing. The hydrology of the area was described in WSP 1837 (Brown, 1966), and the present and future sources were described and related to future use in WSP 1475–Q (Cushman, Krieger, and McCabe, 1965).

The influences of strip mining on the hydrologic environment of parts of the Beaver Creek Basin were investigated by Collier, Musser, McCabe, Cushman, and others. Reports on this study include PP 427–A (Musser, 1963), PP 427–B (Collier and others, 1964), and PP 427–C (edited by Collier, Pickering, and Musser, 1970). The effects of coal mining on the water resources of the Tradewater River Basin were studied by Grubb and Ryder, beginning in 1965, to augment in part the Beaver Creek study (WSP 1940, 1970).

A program was begun in 1959 to provide a data base for long-range action programs to stimulate the economy in the Jenkins-Whitesburg and the Middlesboro areas of eastern Kentucky. A study of the ground-water resources of the Jenkins-Whitesburg area was begun in 1962 (WSP 1809–A, Mull, 1965), and a study of the water resources of the Middlesboro area was begun in 1965 by Mull and Pickering and was continuing at the close of this period of history.

#### *Special Investigations*

The District investigated sedimentation in Plum Creek Subwatershed No. 4 from April 1, 1956, to September 30, 1964, as part of a nationwide study of the trap efficiency of small detention reservoirs constructed by the SCS (WSP 1798–G, Anttila, 1970).

The effects of Greensburg oil-field brines on the streams and potable ground water in the upper Green River Basin were investigated by Krieger, Hendrickson, and Hopkins from 1959 to 1963 in cooperation with the Kentucky Water Pollution Control Commission (KGS Rept. Inv. 2, Krieger and Hendrickson, 1960; and KGS Rept. Inv. 4, Hopkins, 1963).

A study of the occurrence and quality of saline waters and brines and their relation to freshwater sources was begun in 1963 by Hopkins (KGS ser. 10, 1966).

## Louisiana

Condensed from material provided *by* George T. Cardwell *and* Milton F. Cook *and* reviewed *by* Rex R. Meyer

### Introduction

In Louisiana, water-resources programs were planned, negotiated, and carried out by the Branches until February 14, 1966. Rex R. Meyer was named District Chief on that day and was notified that the reorganization to a Division-level District was effective on January 3, 1966. Because programs had been negotiated by Branch District representatives for FY 1966 and were in operation, Branch activities continued as planned. The administrative responsibilities were changed immediately. The reorganization of technical functions was made gradually as projects were completed and personnel made available for new projects. Thus, for nearly the entire period of this epoch of WRD history, District activities were mainly Branch oriented.

Prior to the reorganization of the Branch Districts into a WRD District, the Louisiana WRD Council coordinated planning and programming for interbranch projects. The Council was made up of representatives of SWB, GWB, and QWB, and its chair rotated annually. The chairman was the WRD spokesman and coordinated program financing between the Districts and the Washington Headquarters.

## Organization and Personnel

### *Surface Water Branch*

The SWB District office was on the third floor of the Leach Building at 315 Main Street in Baton Rouge. Fay N. Hansen was the District Engineer until his death in November 1963. He was succeeded in January 1964 by Mack R. Stewart, who transferred from Indianapolis. Stewart continued in this position until the reorganization in February 1966. Milton F. Cook served as Assistant District Engineer during the entire period.

On New Year's Day 1962, the SWB and the QWB moved to the second floor of the Carrollton Building, 6554 Florida Boulevard, Baton Rouge. This location later housed the entire Division-level District. Cars and field equipment that had been stored in a warehouse about a mile north of the Main Street location were moved to the new office site for more efficient operations. Construction materials, boats, and other equipment were stored at Sharp Station military depot.

Rose M. Pittman, District Clerk in 1957, was succeeded by Cecile M. Alderman in 1958. Alderman resigned in 1963 and was replaced by Genevieve G. Floyd, who served as District Clerk until reorganization. Ada J. Rich was appointed Administrative Officer of the Division-level District with Floyd as her assistant.

To carry out special studies of the hydrology and hydraulics of areas in the State of interest to the cooperators, a Special Studies Section was formed with Leland V. Page in charge. Engineers assigned to this unit at various times included Anthony J. Calandro, Daniel B.Y. Chen, Max J. Forbes (entered on duty in 1960), Joseph C. Mehrhoff (transferred to Atlanta, Ga., in 1958), W. John Randolph (moved to Tennessee in 1959), Vernon B. Sauer (from Texas, replaced Randolph), and Raymond Sloss. Sloss also served as Office Engineer of the Data Collection and Analysis Section.

Branch Subdistrict offices were located at Baton Rouge, Jonesboro, and Many. Each office was assigned a geographic area and performed all field and office work within its assigned area. Personnel assigned to the Baton Rouge Subdistrict included Joe H. Holm, Engineer-in-Charge, Arthur L. Bonnet, Jr. (transferred to Florida, 1959), Nolan P. Couvillion, Ludovic J. Dantin, Fred N. Lee, and Alfred S. Lowe. Helen F. Stahl was the clerk.

In Jonesboro, Rufus P. Smith was the Engineer-in-Charge assisted by Joseph W. Dark, Jr., James E. Elkins, and Robert O. Walsworth. Ollie M. Weeks, Erma J. Coleman and Billie E. Greer served successively as clerks.

The Many office was established in 1960 and also served as the principal office of the Sabine River Compact Administration. Earley M. Miller (transferred from Virginia) was Engineer-in-Charge and secretary of the Sabine River Compact Administration. His assistants were Joseph D. Camp (arrived Baton Rouge, 1962), Michael H. Lambert (resigned, 1966), Coleman D. Leach, and Ralph D. Lites. Miller transferred to Charlottesville, Va., in September 1964 and was replaced by Albert J. Heinitz from the Illinois District. Vera M. Eason, then Virginia A. Pass, were the office clerks.

### *Ground Water Branch*

The District office was on the campus of Louisiana State University (LSU) in Baton Rouge, initially in the Geology Building, with several project offices in other buildings, and subsequently was in Atkinson Hall and then in the old Student Union Building. Rex R. Meyer was the District Geologist until named District Chief in February 1966. At that time he moved his office to 6554 Florida Boulevard, site of offices occupied by the former SWB and QWB Districts. GWB personnel remained at LSU until the fall of 1967 when space became available at the Florida Boulevard site.

A field headquarters office was maintained in Alexandria during the period, and in 1960 a project office was established in Lake Charles to facilitate special studies of the Chicot aquifer.

The Baton Rouge staff included Paul P. Bieber, geologist (transferred from Headquarters, 1963); Margaret N. Bobo, clerk-typist (1958–61); Barbara Braud, clerk-typist (1957); Joan O.M. Caraccioli, clerk-typist (1957–58); George T. Cardwell, geologist; Wanza J. Clunan, editorial clerk from 1961; Hannelore M. Davies, clerk-typist (1958–59); Don C. Dial, geologist (moved from Wyoming, 1965); Edwin D. Gutentag, geologist (new hire, 1958, transferred to Kansas, 1960); Richard A. Long (new hire, 1960, resigned 1964); William C. Martin, technician (new hire, 1958); Harold G. May, geologist (transferred from Geologic Division, 1958); Charles O. Morgan, geologist (transferred from Michigan, 1957, then to Kansas, 1963); Gladys C. Payne, clerk-typist from 1960; and J. Norman Payne, research geologist (new hire, 1960, who was assigned to a research project under the direction of the Regional Hydrologist, MCA); Joseph L. Poole, geologist (transferred to California, 1959); Ada J. Rich, Administrative Officer; James R. Rollo, engineer; Alcee N. Turcan, Jr., engineer; Charles D. Whiteman, Jr., geologist (new hire, 1964); and Maurice D. Winner, Jr., geologist (transferred from Alexandria field headquarters, 1959).

Personnel in the Alexandria field headquarters during the period included Jack B. Epstein, geologist (1959–60, transferred to Geologic Division); Stuart W. Fader, engineer (transferred to Kansas, 1958); Murray S. Garber, geologist (new hire, 1957); George D. Graeff, geologist (resigned, 1958); Alfred H. Harder, geologist (transferred to Lake Charles field headquarters, 1960); James R. Marie, geologist (new hire, 1963); Roy Newcome, Jr., geologist (transferred to Mississippi, 1963); James E. Rogers, geologist (from Minnesota, 1959); Charles W. Smoot, technician; John L. Snider, geologist (transferred from Geologic Division, 1959); William H. Walker, engineer, (1957–58, from Kentucky); and M.D. Winner, Jr., geologist (1957–58, new hire). Fader was in charge of the Alexandria office until his transfer to Garden City, Kans., in August 1958. He was succeeded by Newcome, who managed the office until his transfer to Jackson, Miss., in 1963. Rogers assumed charge at that time.

The Lake Charles field headquarters was established as a project office in 1960 for the Chicot aquifer study. George W. Swindel, Jr., who transferred from Alabama, was the project chief. He was succeeded by Harder, who transferred from Alexandria. Other personnel in the Lake Charles office included Anthony H. Devillier, technician (new hire, 1965); Edward J. Doran, technician (new hire, 1963); Helen E. Harris, clerk (from 1960); Arthur L. Hodges, geologist (new hire, 1961); Allen B. Jones, technician (prior to 1960, he operated out of a field headquarters in Oakdale, La.); Chabot Kilburn, geologist (transferred from Idaho, 1960); Stanley M. Rogers, chemist, (transferred from QWB, Baton Rouge, 1963); George R. Tarver, geologist (from Florida, 1962, to Texas, 1963); and Harry M. Whitman, geologist (new hire, 1961).

#### *Quality of Water Branch*

The Baton Rouge water-quality laboratory was established in March 1957, in the Leach Building at 315 Main Street that also housed the SWB offices. Stanley F. Kapustka transferred from Virginia to be the Chemist-in-Charge. Initially a subdistrict of the Texas QWB District, it became the Louisiana QWB District in 1961, which included Mississippi and Alabama, with Kapustka as District Chemist. He was succeeded by Russell L. McAvoy in 1964, who served until the District was reorganized in February 1966. The laboratory and QWB and SWB offices were moved to 6554 Florida Boulevard in January 1962.

Staff at various times during the period included Woodie L. Broussard, chemist (new hire, 1962); Marie C. Chaisson, secretary (transferred from another Federal agency, 1959); Albert C. Duncan, technician (transferred from GWB, 1960); Duane E. Everett, chemist (new hire, 1958; transferred to Nevada 1963, returned to Louisiana, 1966); Larry D. Fayard, chemical engineer (new hire, 1965); Michael W. Gaydos, chemist (new hire, 1960); Stanley M. Rogers, chemist (transferred from Virginia, 1961); Saundra A. Serio, chemist (new hire, 1965); Raymond L. Wayland, technician (new hire, 1962); and Thomas E. White, chemist (1958–59, transferred from Virginia).

### Funding and Cooperation

Funds for all Branch programs were from the Federal-State cooperative (Coop) program, from other Federal agencies (OFA), and from the Federal (Fed) program funds.

Budget totals for all Branch operations in the State are available only for fiscal years 1958, 1965, and 1966. These are shown in the table below to illustrate the general scale and growth of WRD operations in the State during this period of history.

Louisiana WRD funds, indicated fiscal years
[In thousands of dollars]

| Fund source | 1958 | 1965 | 1966 |
|---|---|---|---|
| Coop | 392 | 898 | 954 |
| OFA | 24 | 27 | 28 |
| Fed | 14 | 9 | 25 |
| Total | 430 | 934 | 1,007 |

Source: District program documents.

For the SWB, District funds for FY 1958 totaled $219,425, almost all of which was used for the collection of basic records. The basic-data budget for FY 1965 was $247,273. During the intervening years, there was an increased emphasis, and budget increase, for the interpretation of data for areal and statewide studies.

Total GWB District funds ranged from a low of about $162,000 in FY 1959 to a high of about $623,000 in FY 1965. Cooperative funds for the significant Lake Pontchartrain Basin study, a 3-year project with a total budget of about $400,000, were furnished by the New Orleans Sewerage and Water Board, but were funneled through the Department of Public Works.

Detailed QWB District funding information for the entire period is not available. However, its budget for FY 1958 was $43,250 and more than doubled by FY 1966.

The principal cooperator for all Branches during the period was the Louisiana Department of Public Works (DPW). Ernest J. Taylor, formerly Engineer-in-Charge of the SWB office in Jonesboro, La., was Chief of the Water-Resources Section and the principal WRD contact. Calvin T. Watts, Assistant Director or Director during the period, was a strong supporter of the cooperative program.

The DPW provided matching funds for more than 70 percent of the SWB program. Other SWB cooperators were the Louisiana Department of Highways, the Sabine River Compact Administration, three districts of the U.S. Army Corps of Engineers, the U.S. Soil Conservation Service, and the U.S. Public Health Service.

The Louisiana DPW was also the principal GWB cooperator. The Louisiana Geological Survey, Department of Conservation, which initiated the program in 1938, continued as a cooperator through 1966. Leo Hough was State Geologist during the period.

QWB cooperation was mainly with the DPW and the Corps of Engineers but included limited programs with other State and Federal agencies. Prior to reorganization in 1966, GWB transferred funds to the QWB to support water-quality aspects of ground-water investigations.

## Summary of Program

### *Water Records*

Data ativities are summarized from information reported in "Water Resources Investigations in Louisiana, 1968," effectively at the end of this period of history.

Streamflow Records.—At the end of the period, there were 123 streamflow stations in operation, of which 45 were long-term hydrologic (primary), 10 were short-term hydrologic (secondary), and 68 were operated to meet water-management needs (specific purpose). Additionally, there was a partial-record supplementary network of 146 low-flow stations, 120 flood-profile gages, and 75 crest-discharge stations. The New Orleans and Vicksburg Districts of the Corps of Engineers also maintained and operated gaging stations in Louisiana.

"Statistical Summary of Stream-Gaging Station Records, 1938–64," by M.F. Cook, was published by the Louisiana DPW as Basic Records Report 1, 1968.

Ground-Water Records.—During 1956–59, water levels were measured in 133 wells in 39 parishes. Included were 33 wells equipped with recording gages. During FY 1957, the District obtained a gamma-ray logging tool and began an active program to obtain gamma-ray logs of observation wells and key deep-water wells in the State. By 1967, the number of observation wells had grown to 623, to include all parishes, with the exception of four parishes in the Mississippi River delta with no freshwater aquifers. Other records collected in 1967 included 35 geophysical logs, 185 samples for chemical analysis, temperatures for 191 wells, and 124 well discharges. In addition, thousands of water-well records were collected in areal studies and approximately 265 test wells were drilled as part of the cooperative program during the period. The data program benefited greatly from a close working relationship with Louisiana's water-well drillers, which increased significantly during the period as a result of increased contacts during areal studies, the District logging program, and the Survey's reputation as a reliable source of ground-water information.

Water-Quality Records.—Water-quality observations were made at a total of 41 surface-water sites where records of chemical quality were obtained continuously at 13 sites, daily at 18 sites and monthly at one site. Records of suspended sediment were obtained monthly at nine sites and daily at one site, also a chemical-quality station. Records of temperature were obtained at 26 surface-water sites, of which one was continuously recorded and the others were obtained by periodic visits.

The Baton Rouge laboratory produced an average of about 800 adjusted complete analyses during 1958–61. From 1962–66, production was approximately double that of the early years. In addition to support of the GWB and SWB District programs in Louisiana, the laboratory assisted the Alabama and Mississippi WRD District programs during much of this period of history.

One of the early water-quality monitors in the District was installed on the Pearl River near Slidell to obtain data for the evaluation of a potential auxiliary water supply for New Orleans. The installation crew composed of Duncan, Fayard, and Gaydos, under the supervision of S.M. Rogers, splashed the prefabricated metal shelter into the river on the first try. Rogers, one of the more experienced members of the QWB District staff, was dubbed "the scientist" by his neophyte colleagues. Former staff members still quote his diagnosis of a malfunction of the Model B spectrophotometer as "... the aberration of the monochromatic light source is not conducive to good spectrotrophy."

The flying expertise of District Chemist Kapustka, a licensed pilot, was utilized on a number of projects where an aerial reconnaissance was helpful, such as photographing floods and surveying potential data-collection sites.

Other Data Activities.—The most notable flood of the period occurred in April–May 1958, in southern Arkansas and northern Louisiana, and adjacent areas in Mississippi, Oklahoma, and Texas. More than 18 inches of rain fell in a band 100 miles east-west and 25 miles north-south, centered at El Dorado, Ark. The rain produced major floods during the next 4–5 weeks and was documented in WSP 1660–A (1964) by R.P. Smith. Much of the land area in Louisiana north of U.S. Highway 80 and eastward from the Ouachita River to the Mississippi River levees was under water. Smith, who measured the flood flow, could identify the streams contributing to the flood only by the differences in the color of the water.

Lowe and Camp (HA–126, 1965) prepared reports on the floods of 1962 and 1964 in the Baton Rouge area.

### *Special and Areal Studies*

Interdisciplinary teams made up of members of SWB, GWB, and QWB carried out a number of studies of the water resources of northwestern Louisiana parishes during this period. Reports on the water resources of Sabine (Page, Newcome, and Graeff, DPW Bull. 3, 1963), Natchitoches (Newcome, Page, and Sloss, DPW Bull. 4, 1963), Bossier-Caddo (Page and May, DPW Bull. 5, 1964), Vernon (J.E. Rogers and Calandro, DPW Bull. 6, 1965), Rapides (Newcome and Sloss, DPW Bull. 8, 1966), Red River (Newcome and Page, WSP 1614, 1962), and DeSoto (Page and Pree, 1964) were published before 1966 and that on the water resources of Ouachita Parish (J.E. Rogers, Calandro, and Gaydos, DPW Bull. 14) was in press in 1968. It was also an interdisciplinary team that investigated and reported on the water resources of Pointe Coupee Parish, including a survey of two oxbow lakes, the first lake studies done by the WRD in Louisiana (Winner, Forbes, and Broussard, DPW Bull. 11, 1968).

Sauer prepared many reports analyzing stream characteristics at planned bridge sites for the Louisiana Department of Highways.

Page prepared a comprehensive report on the "Water-supply characteristics of Louisiana streams" (Louisiana DPW Water Resources Bull. 1, 1963), and Sauer made studies and prepared reports on the "Magnitude and frequency of floods in Louisiana" (Louisiana Department of Highways, 1964), unit hydrographs, and the use of spur dikes at highway-stream crossings.

On September 9, 1965, Hurricane Betsy slammed into southern Louisiana with winds of nearly 100 mph that released many barges from their moorings along the Mississippi River. Some barges sank, including one near the main campus of LSU that contained 600 tons of liquid chlorine. An emergency was declared by President Johnson and the resources of the Armed Forces and governmental agencies were mobilized. In addition to the possible release of chlorine gas to the atmosphere from the sunken barge, a critical concern was the impact of chlorine on downriver, domestic water supplies.

A time-of-travel study was required to determine the time the chlorine would reach the intakes of downriver water-supply systems. About 4,100 pounds of 40-percent Rhodamine-B dye were required for the study. Stewart notified Headquarters of the need and arranged for 1,600 pounds to be sent to Baton Rouge immediately. The remaining 2,500 pounds was located in South Carolina. Albert N. Cameron, Georgia District Engineer, SWB, called on friends in the Army and Air Force to deliver the dye to Baton Rouge and they responded immediately. The Air Force had no planes available but furnished trucks to pick up and deliver the dye to the Army; the Army had no trucks available but furnished planes to fly the dye to Baton Rouge. All material, equipment, and personnel were assembled in less than 2 days.

To prevent undue concern by local citizens who might not be informed about the nature or purpose of the red dye in the river, the dye injection was made at night. The study provided the needed information and is documented in HA 260 (1967). (See Part IV, "Tracers in Hydrology" and Part X, "Georgia.")

The "Meyer Years" in Louisiana were marked by a significant expansion in the number and scope of investigations by the GWB. For example, Turcan and Meyer (WSP 1619–V, 1962) made the first detailed study of the Mississippi River alluvial aquifer in northeastern Louisiana. Another pioneering investigation by J.R. Rollo (DPL Water Resources Bull. 1, 1960), was an aquifer-by-aquifer coverage of the entire State that included the first published geologic map and the first base-of-freshwater map for Louisiana.

The effect on water levels of large-scale pumping from the regional Chicot aquifer for irrigation in southwestern Louisiana was monitored annually and estimates of withdrawals were made. During the latter part of the period, a study of saltwater encroachment and the occurrence of methane gas in the aquifer was completed by Harder, Kilburn, Whitman, and S.M. Rogers (DPW Bull. 10, 1967).

An extensive study of the water resources in the developing industrial corridor between Baton Rouge and New Orleans was begun in 1958. Regional interim and data reports (Cardwell and others, LGS and DPW Water Resources Pamph. 9, 1960), and detailed reports on the Geismar-Gonzales area (Long, DPW Bull. 7, 1965) and on the New Orleans area (Rollo, DPW Bull. 9, 1966) were completed by 1966.

A multidiscipline study of the Lake Pontchartrain Basin, in search of an auxiliary water source for the city of New Orleans, began in 1964. In addition to assessing surface-water sources north of the lake, the project included test drilling beneath the brackish-water lake to depths of 3,000 feet or more. Under the direction of Harry D. Wilson, Jr., Regional Hydrologist, MCA, the project was designated as a "demonstration project" to benefit from idealized project planning, including the application of systems-analysis concepts, integration of all disciplines of hydrology, and use of specialists from elsewhere in the Division to ensure application of best available technology. The project successfully identified adequate sources of both ground and surface water and their quality (Cardwell, Forbes, and Gaydos, DPW Water Resources Bull. 12, 1967).

Everett participated with Mississippi District staff in studies of "Available water for industry—Adams, Claiborne, Jefferson, and Warren Counties, Mississippi" (see Part X, "Mississippi"). Similar studies of other Mississippi counties followed in which Baton Rouge staff continued to participate. Gaydos prepared the report "Chemical composition of Mississippi surface water, 1945–62," (Mississippi Bd. of Water Comm., Bull. 65–1, 1965).

In the mid-1960's, J. Norman Payne began a study of the Claiborne Group of aquifers in the lower Mississippi Embayment (PP 569, 1970).

## Maine

*By* Gordon S. Hayes assisted *by* retired District personnel Richard A. Morrill *and* Glenn C. Prescott *and* current District staff members Derrill Cowing, Wayne B. Higgins, *and* Gordon R. Keezer

Programs were developed, administered, and executed by the Branches until April 1, 1966, when Maine became a Division-level District. GWB personnel had been housed with and GWB routine administrative work had been performed by the SWB since 1957. Consequently, the District functioned at the Division level almost immediately with little subsequent change.

### Organization and Personnel

#### *Surface Water Branch (1957–65)*

The District office was located at Augusta in the State House in space adjacent to the Maine Public Utilities Commission (PUC). In 1961 it was moved to the Vickery-Hill Building. Office space had been furnished by the State since 1910. The SWB personnel had always been considered the Water Resources Division of the cooperating State agency and acted for the State in answering questions from the public and advising on water-resource matters. For these services the office space was furnished without charge.

Gordon S. Hayes served as District Engineer throughout the period until the reorganization. Richard A. Morrill was the principal assistant and Lura G. McLain was the District Clerk and mathematical aid for the entire period. Margaret C. Morrill was employed as an engineer, WAE, from 1957 to 1962 and William J. Jewell served in a like capacity during 1963 and 1964. Harrison C. Philbrick was an engineering aid from 1957 to 1960. C. Richard Haskell and Gordon R. Keezer joined the staff as engineering aids in 1960 and worked throughout the period, as did Wayne B. Higgins, who was added to the staff in 1964. Summertime hydrologic field assistants were Robert Dunbar and Samuel P. Hunt, III, in 1961; Joseph O'Donnell in 1963 and 1964; and Michael T. Parker in 1965 and 1966.

#### *Ground Water Branch (1957–65)*

Ground-water investigations in Maine were supervised by the GWB District office in Boston until the reorganization. O. Milton Hackett was District Geologist until 1961, when he was succeeded by Richard G. Petersen. In 1957, a cooperative program was established with the State of Maine. Glenn C. Prescott, Jr., was transferred from Boston to Augusta in September as Geologist-in-Charge of a Subdistrict office located with the SWB. Prescott was assisted by physical-science aids Conrad B. Conant in 1963 and Curtis B. Talbot in 1964 and 1965.

#### *Quality of Water Branch (1957–65)*

Quality-of-water work was supervised by the QWB District office in Albany, N.Y., with Felix H. Pauszek, District Chemist, in charge. No personnel were assigned to Maine.

### *Water Resources Division (1966)*

Maine was activated as a Division-level District on April 1, 1966. Hayes was designated District Chief and Prescott was designated Assistant District Chief. The new District continued to occupy the same space in Augusta previously used by the SWB and GWB. Since planning and cooperative funding work had been done by the WRD Council with Hayes as chairman, little change occurred with the activation of the WRD District.

## Funding and Cooperation

Major funds for work in Maine were from the cooperative program (Coop). Other Federal agencies (OFA) provided support for several international gaging stations and one special flood-investigations project. The Federal program of the Survey (Fed) supported several gaging stations and observation wells and provided funds for a few analyses of water quality. Kennebec Water Power Company and Union Water Power Company, licensees of the FPC, were a source of funds for partial operation of several gaging stations beginning in 1966.

Maine District funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 40.0 | 41.0 | 52.2 | 56.5 | 58.6 | 71.3 | 80.6 | 85.4 | 90.1 |
| OFA | 1.7 | 7.2 | 6.0 | 4.5 | 5.0 | 14.6 | 6.6 | 6.2 | 5.2 |
| FED | 6.2 | 4.4 | 3.1 | 3.3 | 3.5 | 3.9 | 9.7 | 8.8 | 8.4 |
| FPC | -- | -- | -- | -- | -- | -- | -- | -- | 2.3 |
| Total | 47.9 | 52.6 | 61.3 | 64.3 | 67.1 | 89.8 | 96.9 | 100.4 | 106.0 |

Source: Branch of Accounting Services, WRD, and reports of the Maine Public Utilities Commission (PUC).

### *Cooperating Agencies*

The Maine Public Utilities Commission (PUC) was the principal cooperator for statewide water-resource investigations throughout the period. These consisted of streamflow and ground-water data networks, snowpack data collection and dissemination, streamflow analyses, and hydrogeologic studies.

The Maine Department of Transportation (formerly Maine State Highway Commission) cooperated in a study of peak flows from small drainage areas during the period 1963–66. Work consisted of constructing and operating five continuous-record gaging stations and a network of crest-stage stations. Primary financing was by federally allotted highway research funds (100-percent repay by cooperator), and the study was planned to continue for a 10-year period.

### *Other Federal Agencies*

The U.S. Department of State, at the request of the International Joint Commission (IJC), financed the construction of one new gage and the operation of four additional gaging stations on the St. John and St. Croix Rivers. These were designated "international gaging stations" and operated in cooperation with Canada. Records of streamflow and/or water temperature were obtained. Flow data were published by both the USGS and Canada. Funds were also available for work of the District Engineer as chairman of the Hydrologic Subcommittee of the Engineering Section of the IJC St. Croix River Reference. Also financed were joint review and acceptance of both U.S. and Canadian records at the international gaging stations.

The U.S. Army Corps of Engineers provided funds for construction and operation of three gaging stations to accumulate data for 3 years for a floods study on the Ellis River.

## Summary of Program

The collection and publication of water records was the major part of the program throughout the period. Network design made some minor changes in data needs. The use of computer technology improved the methods and speed of data collection, processing, and availability of published data. Many types of statistical analyses became economically feasible, when historical data were placed on computer tapes. Interpretive studies of flood frequencies and other hydrologic characteristics were also pursued.

A major expansion took place in the first year of the period with the start of the cooperative ground-water program. Areal and site studies in the first 2 years made clear the continuing program should be a generalization of hydrologic conditions and ground-water favorability.

### *Water Records*

Data activities are summarized below from information reported in "Water Resources Investigations in Maine, 1968," biennial reports of the PUC, and open-file reports on water data for Maine for the period.

Streamflow Records.—Fifty-two gaging stations (one nonrecording) were operated in Maine during 1957. The number of gages had increased to 57 in 1966. Those operating in 1966 were classified as primary, 26, secondary, 11, and water-management, 20. The Maine District also operated four stations in New Hampshire on the interstate Saco and Androscoggin Rivers with some financial assistance from the Boston District. The Maine District assisted in the field and office work at one international station located in New Brunswick, Canada. In 1966, about 50 percent of the stations had been equipped with the new automatic digital-punch (ADP) recorders. At the end of the period, 23 crest-stage stations were in operation. During the period, measurements of low flow were made at about 15 sites.

Ground-Water Records.—Ground-water records in 1957 were only those from the network of five observation wells where water levels were measured semimonthly. Additional wells were added to the network and by 1966 13 wells were being measured, 2 by continuous recorders.

Statewide collection of geologic and hydrologic information relevant to immediate State and municipal needs was pursued and data furnished to the appropriate water-management agencies. This information was usually placed in the open-file and later used as needed in interpretive maps and reports.

Water-Quality Records.—In 1957, continuous water temperature was measured at one station by the SWB. By 1966, this had been increased to five stations, of which one was an international station, one was a Hydrologic Benchmark station, and one an International Hydrological Decade station. Chemical quality was sampled monthly at three stations in 1966. Water from selected wells located in areas of special studies was also tested for chemical quality.

Other Data Activities.—Surface-water records of the District were reviewed and made ready for publication in WSP 1721, "Compilation of Records of Surface Waters of the United States, 1950–60, Part 1–A." During the late 1960's, a start was made on entering all streamflow data into computer files in order to obtain statistical summaries of low-flow, flood-flow, and flow duration.

Snowpack data were collected monthly during the winter at about 70 sites, and, early in March, a map showing by isograms the water content of the snow cover on March 1 was published and distributed annually. Also computed and furnished with the map was a summary showing, for each of the major drainage basins, the average water equivalent for each of the last 5 years and the long-term average.

A preliminary report of hydrologic conditions in Maine was issued monthly and distributed to all interested users, the press, and television stations. It included runoff data for four index stations, water-level data from about 10 selected observation wells, amounts of water in usable storage in 7 river systems, and the predicted runoff for the next month, if precipitation and temperature were normal.

#### *Special Studies*

The principal topical and areal studies that were conducted all, or in part, within the years 1957–66 included a reconnaissance of ground water in Maine by Prescott (WSP 1669–T, 1963); an areal study of southwestern Maine surficial deposits and their water-bearing characteristics by Prescott (HA-76, 1963); a documentation of historical floods of New England by Hayes and Morrill (in WSP 1779–M, 1964); an areal study of the lower Penobscot River surficial deposits and their water-bearing characteristics by Prescott (HA–225, 1966); and an areal study of ground-water favorability and surficial geology of the lower Androscoggin River Basin by Prescott (HA–285, 1968).

### Other District Activities

The District Chief was a co-founder of the North Atlantic Hydrologic Group. This was an informal group consisting of members from the Boston and Maine SWB Districts, the Water Resources Branch of the Department of Northern Affairs and National Resources (Canada), the Maritime District in Halifax, and others from the State of Maine and the Provinces of Quebec, New Brunswick, and Nova Scotia. The group was an outgrowth of the required joint acceptance of international gaging-station records by the Augusta and Halifax districts and was a means of sharing information of investigations, methods, equipment, and other developments without the long, slow process of following the protocol of the two governments. The group met about every 18 months at sites alternating between the two countries.

The workload to respond to unplanned requests for current water information increased dramatically during the decade, as the State activity in the water quality of streamflow was expanded and the groundwater program of the District became better known to the public.

## Maryland

*By* William E. Forrest with the assistance of Leslie W. Lenfest, Claire A. Richardson, *and* Edmond G. Otton

During the 1957–66 period, programs were developed, administered, and executed by the

Branches until December 1964, when the Maryland-Delaware-District of Columbia WRD District was formed. Prior to that time the SWB office was the District office for the Maryland-Delaware-District of Columbia District; the GWB operated as a single-State District; and the QWB operated as a project office from 1961 on. A research project office of the GHB was established in Baltimore in 1963. It reported directly to the Area Hydrologist from 1965 on.

## Organization and Personnel

### *Surface Water Branch (1957–64)*

The District office was in the Engineering Classroom Building at the University of Maryland, College Park. This association had both professional and cultural advantages for the staff.

Floyd F. LeFever was District Engineer until February 1957 when he transferred to Nebraska to become District Engineer. He was succeeded by John W. Odell who had been Assistant District Engineer in the Utah District. Odell transferred to Colorado late in 1961 and Leslie W. Lenfest, Assistant District Engineer, served in an acting capacity. William E. Forrest, Assistant District Engineer, North Carolina District, was named District Engineer in June of 1962 and served until the reorganization in July 1964. Lenfest was Assistant District Engineer throughout the period except for his stint as Acting District Engineer during 1961 and 1962.

Mary R. Lowry was District Clerk throughout the period. The District headquarters staff at various times included James E. Auvil, Robert M. Beall, David H. Carpenter, John M. Darling, Luther C. Davis, Jr., Carlynn L. Hatcher, Bernard M. Helinsky, Clara V. Lee, Robert O.R. Martin, Ewell H. Mohler, Jr., Kathleen M. Moyer, and Emerick W. Toth.

There were Subdistrict offices at College Park and Cumberland that were responsible for all field and office work in their respective areas.

College Park.—John M. Darling, Engineer-in-Charge (1957–59), was succeeded by Luther C. Davis, Jr. (1960), and by Ewell H. Mohler, Jr., thereafter. Other staff members included William J. Davis, III, Joseph E. Helinsky, Franklin J. Price, Ernest F. Scharff, and Albert G. Tase, Jr.

Cumberland.—Ewell H. Mohler, Jr., Engineer-in-Charge (1957–58), was succeeded by Arthur A. Vickers (1959–62), and by Kenneth R. Taylor thereafter. Brooke C. Atkinson, James E. Auvil, George M. Phillips, and Mary E. Skelly were also on the staff.

### *Ground Water Branch (1957–64)*

The District office was located at Latrobe Hall, Johns Hopkins University, Baltimore, in space adjacent to the cooperator, the Maryland Department of Geology, Mines and Water Resources. Edmond G. Otton was the District Geologist. Other members of the staff included Charles P. Laughlin, Gerald Meyer, and Claire A. Richardson. Some employees of the cooperator were assigned full-time to the program, two of whom were Harry J. Hansen and T.H. Slaughter.

A field headquarters, staffed by Frederick K. Mack, was operated in Annapolis from 1960. In 1964, another field headquarters was established in Salisbury and staffed by Durward H. Boggess and Joseph R. Cherney.

### *Quality of Water Branch (1957–64)*

No QWB office was maintained in Maryland until 1961 when a project office was established in Rockville staffed by John W. Wark, Project Chief, and Frank J. Keller. Later additions to the staff were Sumner G. Heidel and Rose C. Libert.

### *General Hydrology Branch (1963–66)*

A project office, established in Baltimore in January 1963, was initially staffed by John J. Poggie, Jr., botanist, WAE. By 1964, Lucien M. Brush and M. Gordon Wolman, geologists (WAE), were stationed there. After reorganization, the office reported to the Area Hydrologist, ACA. In 1966, the staff included Wolman, John C. Goodlet, botanist, Lawrence A. Hardie, geologist, Charles B. Hunt, geologist, and Robert C. Zimmerman, geographer, all WAE. By the end of the period, the Baltimore office was staffed only by Hunt and Wolman. The office provided thesis support to graduate students at Johns Hopkins University.

### *Water Resources Division (1965–66)*

The Maryland-Delaware-District of Columbia Division-level District was formed in late 1964 and headquarters established in Towson in January 1965. Wark was named District Chief, and in May, Forrest was designated Assistant District Chief. Other personnel from the several Maryland Branch offices were transferred to Towson, including Heidel, Otton, Mohler, Bernard M. Helinsky, and Lowry. Later additions to the Towson staff included Richard A. Gardner, Catherine E. Manly, Larry J. Nutter, Mary E. Schouten-Walters, J. Elizabeth Smith, Jolly D. Thomas, and Wayne E. Webb.

A Subdistrict office was maintained in College Park with William J. Davis, III, as Engineer-in-Charge. Other members of the College Park staff included David H. Carpenter, Earl E. Eiker, Charles P. Laughlin, Michael G. McDonald, Bonnie P. Pfaff, and Wayne B. Solley. The Hydrologic Data Section was also located at College Park with Lenfest as Chief. The Subdistrict office in Cumberland continued in operation with no staff changes.

The former GWB District office was redesignated a field headquarters and staffed by Claire A. Richardson. The existing field headquarters at Annapolis and Salisbury were maintained with the same staff.

### *Other Organizational Arrangements*

Prior to the reorganization in 1964, the Branch Districts collaborated in planning and programming and in cooperating-agency liaison through the Maryland WRD Council.

## Funding and Cooperation

Funds for the District's programs were primarily from the cooperative program (Coop), with lesser, roughly equal amounts, from other Federal agencies (OFA) and from the Federal program (Fed). As shown in the following table, total funds ranged from a low of $169,400 in FY 1958 to a high of $439,400 in FY 1966.

Maryland District funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 130.4 | - | 143.5 | 155.8 | 180.6 | 176.7 | 261.3 | 326.4 | 373.3 |
| OFA | 14.8 | - | 13.8 | 13.3 | 11.3 | 18.2 | 22.2 | 17.5 | 43.0 |
| Fed | 24.2 | - | 14.9 | 12.7 | 15.6 | 21.6 | 25.6 | 22.0 | 23.1 |
| Total | 169.4 | - | 172.2 | 181.8 | 207.5 | 216.5 | 309.1 | 365.9 | 439.4 |

Source: District program documents. Some years contain minor amounts of funds for work in the District of Columbia. Figures for 1959 are not available

### *Cooperating Agencies*

The principal cooperating agency throughout the period was the Maryland Geological Survey (MGS) (until June 1964, it was called the Department of Geology, Mines and Water Resources). In late 1963, Dr. Kenneth N. Weaver became the agency's Director. He vigorously supported the cooperative water-resources program, consisting of streamflow and ground-water data networks, areal hydrologic studies, and hydrologic/geologic mapping. The city of Baltimore also supported part of the streamflow network throughout the period. Beginning in 1964 the Maryland Department of Health made a small contribution to the support of the streamflow network.

The Maryland State Roads Commission supported a portion of the streamflow network in the early years of this period. Then beginning in 1964, after a break of several years, it supported a study of floods from small drainage areas with federally allotted highway research funds (100-percent repay by the cooperator).

The Anne Arundel County Planning and Zoning Commission (1960–61); the Maryland National Capital Park and Planning Commission (1961–62, 100-percent repay by the cooperator); the Commissioners of Charles County (1961–63); the Washington Suburban Sanitary Commission (1962–64); the city of Salisbury (1964–66); the Maryland Planning Department (1965–66); and the University of Maryland (1966) contributed to the support of areal hydrologic studies. Baltimore County (1964–66) supported a county well inventory.

In 1966, a study of sedimentation and hydrology in the Rock Creek and Anacostia River Basins was begun with support from the Washington Suburban Sanitary Commission, the Maryland National Capital Park and Planning Commission, and the District of Columbia Department of Sanitary Engineering.

### *Other Federal Agencies*

The Baltimore District of the U.S. Army Corps of Engineers funded a number of gaging stations in the Susquehanna River and Potomac River Basins. The Pittsburgh District funded stations in the Youghiogheny River Basin. During the years 1960–62 the Baltimore District helped support a Potomac River Basin sediment study.

The National Park Service provided minor support for streamflow records throughout the period, and funded a study of ground water along the C&O Canal during 1963–66.

## Summary of Program

In 1958, the program in Maryland consisted of 68 percent surface-water, 29 percent ground-water, and 3 percent water-quality studies. Collection, compilation, and publication of basic water data comprised 83 percent of the program. The remaining 17 percent consisted primarily of ground-water areal studies. By 1966, the program having more than doubled, the basic-data collection component had dropped to 49 percent. The discipline distribution also changed considerably—52 percent surface-water, 32 percent ground-water, and 16 percent water-quality studies.

### *Water Records*

Streamflow Records.—A total of 89 continuous-record gaging stations were being operated in June 1966, consisting of 23 classified as primary (long-term hydrologic), 32 as secondary (short-term areal hydrologic), and 34 serving water-management needs. In addition there were 38 low-flow partial-record stations and 51 crest-stage stations.

Ground-Water Records.—There were 136 wells in the observation-well network in 1966, 16 of which were daily records. There were also 50 partial records of well discharge.

Water-Quality Records.—In 1966 the District operated six daily and six partial-record sediment discharge stations. Temperature data were collected at 114 surface-water stations, including 11 daily thermograph records, and chemical-quality data were collected at 11 stations.

### *Special Studies*

Among the special studies that were conducted within fiscal years 1958–66 was that of the water resources of Carroll and Frederick Counties by Meyer and Beall (Maryland Dept. Geol., Mines and Water Resources Bull. 22, 1958). Slaughter reported on beach-area water supplies between Ocean City, Md., and Rehoboth Beach, Del. (WSP 1619–T, 1962), and Otton, Martin, and Walton H. Durum (QWB, headquarters) were the interdisciplinary team that investigated and reported on the water resources of the Baltimore area (WSP 1499–F, 1964).

The ground-water and surface-water resources of Allegany and Washington Counties were reported on by Slaughter and Darling (Maryland Dept. Geol., Mines and Water Resources Bull. 24, 1962). Using data from other studies, a report on limestone aquifers of Maryland was prepared by Otton and Richardson (Econ. Geology, v. 53, no. 6, 1958). Ground-water supplies for industrial and urban development in Anne Arundel County were reported on by Mack with a section on the chemical character of the water by Richardson (Maryland Dept. Geol., Mines and Water Resources Bull. 26, 1962).

Records of wells and springs in Charles County were compiled by Slaughter and Laughlin (MGS Water Resources Basic Data Rept. 2, 1966), and Slaughter and Otton reported on the availability of ground water in Charles County (MGS Bull. 30, 1968). The availability of ground water for urban and industrial development in upper Montgomery County was investigated by Johnston and Otton and the results reported to the Maryland National Capital Park and Planning Commission.

Mack reported on ground water in Prince Georges County (MGS Bull. 29, 1966) and Boggess and Heidel appraised the water resources of the Salisbury area (MGS Rept. Inv. 3, 1968). A preliminary, administrative report on ground-water conditions along the C&O Canal was written by Otton and Laughlin for the National Park Service.

On April 17, 1964, a freight train derailment prompted a request from the Corps of Engineers for an estimated time of arrival of the resultant oil spill at Washington's Great Falls water-supply intakes. As a result, a time-of-travel measurement using fluorescent dye was undertaken by James F. Wilson (SWB, headquarters) and Forrest (Lamont Geol. Observatory Symposium on Diffusion in Oceans and Fresh Waters, Palisades, N.Y., 1964, Proc.; see also Part IV, "Tracers in Hydrology").

Laughlin compiled the records of wells and springs in Baltimore County (MGS Water Resources Basic Data Rept. 1, 1966). Mack, Webb, and Gardner reported on the water resources of Dorchester and Talbot Counties, with special emphasis on the ground-water potential of the Cambridge and Easton areas (MGS Rept. Inv. 17, 1971).

Hansen examined the physical geology of the Pleistocene aquifer system in the Salisbury area (Maryland Geol. Survey Rept Inv. 2, 1966). Thomas and Heidel studied the chemical and physical character of municipal water supplies in Maryland (MGS Rept. Inv. 9, 1969)

Crooks, O'Bryan, and others prepared a series of maps depicting the generalized hydrology, streamflow, water budget, chemical quality of surface water, erosion and sedimentation, pollution index of streams, and surface-water movement in the Patuxent River Basin of Maryland (HA–244, 1967).

Hansen documented the subsurface distribution of southern Maryland Cretaceous sediments (MGS Rept. Inv. 7, 1968).

## Massachusetts

*By* O. Milton Hackett, reviewed *by* Richard A. Brackley *and* John E. Cotton

During the period 1957–66, the WRD program in Massachusetts was marked by modest growth and a substantial change in emphasis. This stemmed in particular from the emergence in the mid-1950's of the

Massachusetts Water Resources Commission (WRC), a new State entity, as a persuasive force in shaping State water-resources policies. Beginning in 1956, support by the WRC was the springboard for strengthening and diversifying the State-Federal partnership with the WRD.

### The Branch Districts

At the onset and continuing until 1965, WRD activities in Massachusetts were administered by the Branches. Both SWB and GWB had District offices in Boston, with the former responsible for work in Massachusetts, Rhode Island, New Hampshire, and Vermont, and the latter for work in Massachusetts, Maine, and New Hampshire. The QWB had no formal program in Massachusetts; its work there was administered from the New York-New England QWB District office at Albany, N.Y. Program planning was loosely coordinated by the Massachusetts WRD Council, consisting of the Branch District supervisors at Boston and the QWB District Chemist at Albany. Offices of the Boston District, which had been moved in 1956 from the old Post Office Building to the Oliver Building at 141 Milk Street, were moved in 1962 to 211 Congress Street. The GHB had project offices in Boston from 1957 to 1961 and at Woods Hole beginning in 1963.

According to the Consolidated Work Plan for FY 1958, funding for the Massachusetts program was $161,000, of which about 57 percent supported collecting, processing, and analyzing water records, mostly of streamflow, and about 43 percent supported project-type work, mostly ground-water studies. The largest source of funds was the cooperative Federal-State program, at about 82 percent of the total. Other Federal agencies, mainly the U.S. Army Corps of Engineers, provided about 11 percent and the Federal program, about 7 percent. As in past years, the Massachusetts Department of Public Works was the principal cooperator, although by now the recently established WRC was making a substantial contribution. Other cooperators were the Metropolitan District Commission and the Department of Public Health.

In 1965 the Central New England District was established and made responsible for WRD activities in Massachusetts, New Hampshire, Rhode Island, and Vermont, with support for water-quality activities from Albany, N.Y. The District office was moved in 1966 to the new John F. Kennedy Building.

#### *Surface Water Branch (1957–64)*

Through FY 1960, the surface-water program was relatively static. In the preceding decade it had matured to the point where it met the needs of its old-line supporters, including the Department of Public Works, the Metropolitan District Commission, and the State Department of Health, and the Corps of Engineers. The program was devoted mostly to collecting and processing streamflow records; reflecting the principal interests and needs of those agencies and their satisfaction was expressed by continuing support at a somewhat constant funding level. Some funds, including Federal program funds, were available for special projects—flood frequency, water use, and the hydraulics and hydrology of highway bridge design—plus participation with the GWB in studies of the Reading-Wilmington area and the lower Ipswich River Basin, and with the GHB in a research project on Hop Brook.

In 1961 and continuing through FY 1965, the program grew at an average rate of about 10 percent per year, as cooperation with the WRC increased and the Department of Public Works increased its support. Water records continued to dominate, but beginning in FY 1963 an increasing proportion of the program was devoted to studies of areal hydrology. These included studies of the low-flow and peak-flow characteristics of streams and participation with the GWB in studies of the Housatonic and the Millers River Basins. The District also contributed to a report on historical floods in New England (WSP 1779–M, 1964).

In addition to its routine publication of data, the District continued to issue a monthly summary of precipitation, streamflow, reservoir storage, and ground-water levels for Massachusetts, New Hampshire, Rhode Island, and Vermont.

Charles E. Knox, District Engineer since 1956, and a long-time member of the Boston staff, continued in that position until 1965 when he became District Chief of the newly formed WRD Central New England District. Knox was an intense, hands-on manager, who knew in detail all aspects of the Division's operations in Massachusetts. He served throughout the period as chairman of the WRD Council, and in this capacity, pushed consistently for greater balance in the Massachusetts program, including especially the greater involvement of the SWB in areal hydrologic studies. He was assisted by Gardner K. Wood, Assistant District Chief, and Annette G. Gagnon, District Clerk.

The staff of the SWB District was remarkably stable. The permanent staff remained at about 20, usually with four or five student trainees on the rolls. It is of interest to note that 16 names on the District rolls in 1957 were listed also in 1964. These included John V. Bagley, Richard A. Brackley, Donald F. Farrell, Donald J. Fogarty, Russell A. Gadoury, Gagnon, Charles E. Hale, Marguerite M. Heckman, Carl G. Johnson, Knox, James D. Linney, Norman J. Roy, Gordon H. Searles, Lois A. Swallow, John W. Taylor, and Wood. Kenneth M. Kelley, who died in 1960 while employed, was another long timer. Other full-time personnel who spent considerable time in the District were Paul H. Bedrosian, Frank E. Blackey, Leo F. Cox, Sylvia DeForest, William B. Gannon, Dennis F. Gillen, Myron N. Lys, William J. Macdonough, Paul E. Pronovost, and Benedetto Rizzo. The staff was "home grown," coming mostly from New England. Recruits during the period, Cox, Gadoury, Gillen, and Pronovost, came by way of the student-trainee program. Near the near of the period, Michael R. Collings transferred into the District to head the Millers River Basin project.

#### *Ground Water Branch (1957–64)*

Shortly before the beginning of this report period, the ground-water program had benefited from new funding by the recently established WRC, which increased the support for the program by about 40 percent. As in the past, the Massachusetts Department of Public Works was the principal cooperator. Subsequently the program remained at a plateau until FY 1963, growing at a rate just exceeding that of inflation. In the next 3 years, the program more than doubled, owing mostly to additional funding by the WRC and new funding from the Corps of Engineers for a study of the Connecticut River Valley conducted by Dagfin J. Cederstrom of the Atlantic Region staff, assisted by Arthur L. Hodges, Jr. (HA–249, 1967).

The program was in a formative time. Methodologies were being evolved to fit the particular hydrology of the glaciated terrain. These included geologic mapping specifically for ground-water studies, as needed to supplement the geologic mapping from the Boston office of the Geologic Division under its cooperative program with Massachusetts. Base-flow studies by personnel of the SWB District aided the understanding of the relationship between ground and surface water. Also included were test drilling, and the use of and experimentation with such geophysical methods as resistivity, seismic, and "sparker" seismic (from boats). Infrared imagery was investigated as a study tool.

Projects were focused on towns (the major political units of Massachusetts) and river basins, but included some studies of special problems—for example, the contamination of ground water from the salting of highways, and the hydrology of wetlands. Early release of the results was facilitated by a District-level series of basic-data reports and maps depicting the availability of ground water. By 1965, 16 had been released. These were followed in some instances by reports and atlases published in the formal series of the USGS, including, from projects during this period, three Water-Supply Papers, six Hydrologic Atlases, and one Circular. Open-file reports were utilized also.

Among this series of projects were studies of the geology and ground-water conditions in the Wilmington-Reading area by Baker, Healy, and Hackett (WSP 1694, 1964); of wetland and water supply, by Baker (Circ. 431, 1960); and of the hydrology and water resources of the Housatonic River Basin in Massachusetts by Norvitch, Farrell, Pauszek, and Petersen (HA-281, 1968). Sammel, Brackley, and Palmquist wrote a synopsis of the water resources of the Ipswich River Basin of Massachusetts (HA–196, 1964).

Continuing as District Geologist was O. Milton Hackett, who had assumed this position in 1956 when the Boston District of the GWB was established. His principal assistants were Richard G. Petersen and John A. Baker, with Norma E. Lathrop serving as District Clerk.

In early 1961, Hackett was selected as Chief of the GWB, and in July he moved to Washington. Petersen succeeded him as District Geologist and Baker moved to Connecticut to head the GWB program in that State. Petersen had joined the Boston staff in 1958, transferring from the Geologic Division when its program with the AEC was severely cut. To be selected as District Geologist after so short a time with the Branch was a tribute to his versatility and his technical and management skills. He served in this position for the rest of the period, with Lathrop continuing as District Clerk.

Throughout the period the staff of the District was nearly constant in size, consisting of 9 to 11 people most of the time, but the composition varied greatly. The initial staff of full-time employees included Baker, Edna Beskin, Hackett, Henry N. Halberg, Henry G. Healy, Lathrop, Petersen, Edward A. Sammel, and Charles E. Shaw, Jr. By the end of the period only Petersen and Lathrop remained. In addition, the staff then included John E. Cotton, William B. Fleck (WAE), Janet Drake LaBlanc, Richard W. Macomber, Anthony Maevsky, Ralph F. Norvitch, Wilbur N. Palmquist, Samuel J. Pollock, Donald R. Wiesnet, and John R. Williams. James W. Weigle also spent time at the Boston office before moving to New Hampshire to establish a field headquarters.

#### *Quality of Water Branch (1957–64)*

The QWB had no program in Massachusetts. Occasional work there, mostly laboratory work in support of the Boston Districts but including some work for other Federal agencies, was performed by staff of the laboratory at Albany, N.Y., under the direction of Felix H. Pauszek, District Chemist of the New York-New England District of the QWB. Pauszek also represented the QWB on the Massachusetts WRD Council.

#### *General Hydrology Branch (1958–64)*

From late 1957 to mid-1961, John C. Kammerer of the GHB was housed with the Boston District. The Division was experimenting with reports written especially for the layman, and Kammerer and Helene C. Baldwin of the Washington office were assigned to write such a report for the Springfield-Holyoke area of Massachusetts (WSP 1670, 1962). Kammerer also carried on a research study of the Hop Brook drainage basin in west-central Massachusetts.

Beginning in 1963 the GHB also maintained a project office with full-time employees at Woods Hole to conduct research on marine hydrology. Donald J. Casey was stationed there from 1962 through 1964. He was joined in 1963 by Robert H. Meade, Jr., and Frank T. Manheim, who continued there during the rest of the period.

### The Central New England District

By memorandum dated February 9, 1965, the Division announced the establishment of the Central New England District, consolidating in the new District the Division's programs and personnel in Massachusetts, New Hampshire, Rhode Island, and Vermont, and eliminating the old Branch Districts. Knox was named District Chief and Petersen, Assistant District Chief. Gagnon and Lathrop shared the duties of District Clerk.

The transition was surprisingly easy. Knox and Petersen respected and complemented each other. Knox took over much of the administrative detail required by the enlarged District, freeing Petersen to give more attention to technical supervision of the ground-water activities. Gardner Wood, as before, supervised the technical side of the streamflow activities. The combined staff in the Boston office numbered 34 full-time people and included most of those formerly in the Branch Districts—William W. Caswell, Frederick B. Gay, William S. Wandle; and Richard E. Willey had been added, and Norvitch and Palmquist were to move on later in 1965. Additionally, personnel were stationed at subdistrict offices at Providence, R.I., and Concord, N.H., and at a field headquarters at Montpelier, Vt., as recounted for each of those States elsewhere herein.

Funding for the Massachusetts program in FY 1966, the first full year under the new District, was $348,000. This, allowing for inflation, represented about a doubling of the program as it existed in FY 1958. Striking was the change in program balance, with project-type work increasing from 43 percent of program in FY 1958 to 60 percent in FY 1966, and water-records activities decreasing from 57 percent of program in FY 1958 to 40 percent in FY 1966. As in the past, the largest source of funds was the Federal-State program (both sides) with about 87 percent of the total. The other Federal agencies program (mostly from the Corps of Engineers, but including the National Park Service, the Army, and the Air Force) provided about 12 percent and the Federal program about 1 percent. The New England Power Company, by way of the FPC, contributed a token amount. The Massachusetts Department of Public Works continued as the principal cooperator, with the WRC a close second. The third cooperating State agency was the Metropolitan District Commission.

According to the District Annual Program, as of October 6, 1966, continuous streamflow records were collected at 98 stations and periodic records of low flows at 110. Samples for chemical quality were collected periodically at 86 streamflow stations and contents of 8 reservoirs were monitored. Ground-water levels were measured periodically at 200 sites and samples for chemical quality were collected at 107.

Twelve projects classed as areal hydrology were underway in FY 1966, including studies of ground-water contamination from highway salting, infrared imagery, low-flow characteristics of streams and peak-flow characteristics of small drainage basins, and ground water of the basins of the Assabet River, the Housatonic River, Tenmile-North Taunton River, the lower Merrimack River, the Millers River, the Connecticut River, the central Boston area, and Cape Cod National Seashore.

The closing of this period in the history of the Water Resources Division found the Massachusetts program in its best shape ever—expanding, varied, and relevant to State and Federal needs. The District had a seasoned and competent District staff doing interesting work, and the future was bright.

## Michigan

*By* Sulo W. Wiitala, reviewed *by* Arlington D. Ash, Ray Cummings, *and* Lawrence E. Stoimenoff

Water-resources investigations of the USGS in Michigan, 1957–66, were conducted separately by the

SWB, GWB, and QWB until June 1965 when reorganization as a Division-level District was effected. During the period of Branch-level operation, activities were coordinated by the Michigan WRD Council consisting of the administrative heads of the Branches operating in Michigan. The Council usually met quarterly in Lansing.

District headquarters for the SWB and GWB were located in the Capitol Savings and Loan Building, 112 East Allegan St., about two blocks from the State Capitol in Lansing. Sharing space in the same office building fostered close coordination between the two Branches. Inasmuch as there were no separate QWB programs in Michigan, the regional laboratory of the QWB in Columbus, Ohio, provided water-quality assistance, as needed, to the SWB and GWB.

### Organization and Personnel

In the early 1950's, an Administrative Services Section under the aegis of the Michigan WRD Council was established in Lansing to process financial accounts, payroll, travel vouchers, supply orders, and personnel actions of the two Branches. Doris H. Dahl was Chief Clerk of the Section until October 1957 when she was succeeded by Leota E. Huffman, who had joined the District staff in February 1957. Upon reorganization of the District in 1965, Huffman became the District Administrative Clerk.

#### *Surface Water Branch (1957–65)*

Arlington D. Ash was District Engineer until June 1965 when he was designated District Chief of the reorganized District. Sulo W. Wiitala was Assistant District Engineer until his transfer to Iowa as District Engineer in April 1965. Paul C. Bent, Stanley B. Koks, John B. Miller, Lawrence E. Stoimenoff, and James L. Zirbel served in various capacities in the Lansing office throughout this period. Others on full-time appointments who served in the Lansing office for a year or more during the period were David E. Bower, Virginia C. English, Robert D. Grover, Gordon C. Hulbert, Margaret P. Mayhey, and Martha A. Rochester.

Chester O. Wisler, professor of hydraulic engineering at the University of Michigan, served the District as an advisor and consultant on a WAE basis until 1961. Harold Henry, professor of civil engineering at Michigan State University, served in a similar capacity during 1956–58.

Robert A. Baltzer was assigned to the Lansing field unit of the SWB Research Section full time, 1956–59, and WAE, 1959–63, after which he was transferred to the Branch Research Section in Washington, D.C.

Branch operations in the northern part of the Lower Peninsula were conducted from a Subdistrict office housed in the State Fish Hatchery in Grayling. Dale Pettengill headed the office throughout this period of history. Staffing of the Grayling office was remarkably stable with Robert W. Larson, engineer, and technicians Horace L. and James C. Failing, and Thomas E. Robertson serving throughout the period.

Branch operations in the Upper Peninsula were conducted from a Subdistrict office housed in the State Office Building in Escanaba. Robert L. Knutilla served as Engineer-in-Charge until his transfer to the District office in Lansing in 1965. Gordon C. Hulbert succeeded Knutilla. Technicians Lauritz B. Hough and John L. Oberg served in the Subdistrict throughout the period.

A field unit of the GHB reporting to the Branch Chief functioned briefly in Houghton in 1962–63. Joseph H. Butler, a professor of geography at Michigan Technological University, and Robert E. Roger, a student, both WAE, were assigned to the unit.

#### *Ground Water Branch (1957–65)*

Morris Deutsch was District Geologist until his transfer to Ohio in 1962. Gerth E. Hendrickson succeeded Deutsch and then became Assistant District Chief of the reorganized District in June 1965. Kenneth E. Vanlier served in the Lansing office throughout this period and was Assistant District Geologist during 1957-65.

Paul R. Giroux, technician, served in the Lansing office in 1957–66. Technician Ted E. Thompson was assigned to a field headquarters in Grayling 1956–58, Escanaba 1958–65, and Lansing to end the period. Technician Charles J. Doonan began the period at a field headquarters in Clare, transferred to Lansing in 1957 or 1958, then to a field headquarters in Farwell in 1961, and to Escanaba in 1963 to complete this period. Gary C. Huffman, who had joined the SWB staff in Lansing in 1958, transferred to the GWB in Lansing in 1961 where he remained for the rest of the period. Thomas G. Newport, geologist, transferred into the District in 1961 to head the GWB operations in the Escanaba office where he remained until the end of this period of history. A field headquarters, staffed by James R. Hon (WAE), was maintained in Pontiac during 1960–66. Others, not mentioned above, who served the groundwater program during parts of the period included Gail P. Eitnier, Janet K. Lewis, John R. Rapp, and William C. Sinclair.

Professor Harold R. Henry, Michigan State University, was assigned WAE to a field unit in East Lansing reporting to the Area Chief (GWB), 1959-66.

#### *Water Resources Division (1965–66)*

With designation as a Division-level District in June 1965, the Branch staffs in Lansing merged into a combined operation without change in office location. New staff members of the District office in 1966 included William B. Allen, Jillann O. Brunell, James D. Crays, Jo Ann M. Layden, Frances D. Purdy, and Floyd R. Twenter.

The Subdistrict office in Escanaba and Grayling and the field headquarters in Pontiac remained in place with staff unchanged except for the addition of Gerald L. Guindon in Escanaba.

### Funding

The cooperative (Coop) program with State and local agencies, the principal funding source for the District, provided between 85 to 90 percent of total program funds annually. Federal (Fed) program funds provided less than 10 percent and funds from other Federal agencies (OFA) accounted for the remainder. The following table shows the distribution of funds by years.

Michigan District funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Fed | 22.5 | - | - | - | - | - | - | 6.5 | 7.7 |
| Coop | 194.8 | 229 | 279 | 271 | 316 | 320 | 334 | 396.1 | 486.4 |
| OFA | 11.6 | 19 | 22 | 22 | 22 | 24 | 49 | 54.2 | 51.8 |
| Total | 228.9 | - | - | - | - | - | - | 456.8 | 545.3 |

Source: FY 1958 and FY 1965, actual expenditures from District program documents; FY 1966, planned expenditures; FY 1959–FY 1964, approximate amounts from Headquarters compilations from unknown sources. Federal allocations not available for FY 1959–FY 1964.

### Cooperating Agencies

The Michigan State Department of Conservation through its Geological Survey, Engineering, General Operations, Fish and Fisheries, Parks, and Game Divisions, and the Michigan Water Resources Commission were the principal cooperators. Conservation Department funds supported many areal ground-water studies, ground-water monitoring stations, surface-water investigations in the Rifle River Basin, the operation of stream-gaging stations, and almost the entire program of lake- and pond-monitoring stations. Water Resources Commission funds were used in the stream-gaging program. The bulk of the State monies came from the Conservation Department, which also acted as a collection agency for funds provided by State agencies and by many counties, municipalities, institutions, and private organizations.

The Michigan Highway Department supported a modest program of collecting flood data at crest-stage stations and the preparation of flood reports at specific bridge sites.

Branch, Kalamazoo, Oakland, and Van Buren Counties supported areal studies involving all three Branches. Macomb County supported an inventory of the surface-water resources of the North Branch Clinton River Basin and Clinton, Eaton, and Ingham Counties cooperated in an areal ground-water study of the three-county area. These, and the counties of Genesee, Washtenaw, and Wayne also participated in the collection of water records under the umbrella agreement with the Conservation Department.

The city of Kalamazoo supported a study of controlled recharge at one of the city's well fields. A cooperative program with the city of Alma investigated phenol contamination in an artesian glacial aquifer. The cities of Alma, Battle Creek, Holland, and Kalamazoo supported studies of the ground-water resources of their respective areas.

Seventeen municipalities in the surface-water program and 23 in the ground-water program, 13 institutions and other local agencies in the ground-water program and 3 in the surface-water program, and 5 nonmunicipal organizations in the ground-water program and 12 in the surface-water program cooperated in collecting water records under the Conservation Department agreement.

#### *Other Federal Agencies*

The Detroit District of the U.S. Army Corps of Engineers, the major OFA cooperator, supported the construction, maintenance, and operation of stream-gaging stations. They also provided support for the operation of a modest number of ground-water monitoring stations and for low streamflow and ground-water resources analyses in connection with the comprehensive water-resources study of the Grand River Basin.

The U.S. Fish and Wildlife Service provided partial support for the operation of several gaging stations in the Manistique River Basin where the Seney National Wildlife Refuge is located. The FPC's interest was in streamflow gaging at several stations in the St. Joseph River Basin. The National Weather and

Park Services provided support in the form of services or use of their facilities.

## Summary of Program

The basic component of the District's program continued to be collecting, processing, and publishing water records. From two-thirds to three-fourths of the District's funds were expended on this activity. Compilation and publication of ground-water levels annually on a State basis began in 1956, and of streamflow records in 1961. Toward the end of this period, the conversion from analog to digital recorders and the application of computer technology to the processing of streamflow records began.

As the interest in water resources expanded because of urban and industrial growth and because of increased recreational demands, topical and areal studies became significant segments of the District programs. And there also followed a shift from Branch-oriented to Division-oriented studies. This, of course, culminated in the reorganization to Division-level operations wherein all programs were viewed from the perspective of the complete hydrologic cycle.

### *Water Records*

Surface-Water Records.—Records of daily river stage and discharge were collected at 149 stations in 1958 and at 202 stations in 1966; records of daily water level were collected at 60 lakes and ponds in 1958 and at 89 in 1966; periodic records of chemical quality were collected at 13 river stations in 1958 and at 6 stations in 1966. In 1966 daily records of sediment discharge were obtained at one river station and periodic records of sediment discharge at one station and periodic records of water discharge (peak and/or low flow) were obtained at 119 stations. These numbers represent an expansion of more than 35 percent during this period.

Lakes play an important role in Michigan's recreation industry. Collection of systematic records on lake levels began in the early 1940's in cooperation with the Geological Survey Division of the Michigan Department of Conservation and has remained a staple of the water-records program. In order to achieve broader areal coverage with the available resources, many lake stations were operated for about 5 years and then replaced by stations on lakes heretofore ungaged. Margaret P. Mahey, one of the first female technicians employed by the Survey, headed the lake program until her transfer to Arlington, Va., in December 1958. By 1968, records were available on 257 lakes. At many lakes, periodic measurements of the outflow were also made. John B. Miller and Ted E. Thompson (1970) compiled all of the available data through 1968 on lake levels, outflow, and water quality in a report published by the Michigan Geological Survey.

In 1964, a Hydrologic Benchmark station was established on Washington Creek in Isle Royale National Park. This insular location, where even the picking of a wildflower is prohibited, provided a unique setting for monitoring hydrologic response to purely natural forces. The United Nations has also designated the National Park a Biosphere Reserve that will provide baseline data against which similar ecosystems can be measured. On the reconnaissances for this station in October 1963, Wiitala was treed by a cow moose that simply refused to cede right-of-way to Wiitala and his surveying instrument. Or maybe she was just in a bemused state as it was moose rutting season.

Ground-Water Records.—Daily records of water levels were collected at 27 stations in 1958 and at 92 stations in 1966; periodic records of water levels were collected at 237 sites in 1958 and at 362 sites in 1966.

In addition to annual WSP publication of data on ground-water levels, "Summary of ground-water conditions in Michigan" was published annually by the Michigan Geological Survey, 1956–62, and in open-file reports of the USGS, 1963–66. These reports contained data on water levels, water temperature, and more detailed descriptions of, and data on, selected municipal, institutional, and industrial ground-water supplies.

Water-Quality Records.—Daily records of water temperature were collected at 20 river stations in 1958 and at 28 in 1966. Aside from this program, there was no network approach to water-quality monitoring during this period. Collection and analysis of water-quality data on streams, lakes, and in the subsurface were integral parts of all areal studies.

Other Data Activities.—As a part of areal studies, and occasionally to comply with requests from cooperating officials, low-flow measurements of streams were made to identify reaches of ground-water inflow or outflow. Field determinations of pH, specific conductance, and water temperature were included. The data were published in the annual data reports.

Potent thrust to hydrologic data-collection activities in the Detroit metropolitan area was provided by the Southeastern Michigan Rain and Streamgage Committee. The Committee, established in 1958, was made up of representatives from the city of Detroit; Detroit Metropolitan Planning Commission; counties of Macomb, Oakland, Washtenaw, and Wayne; Michigan Water Resources Commission; U.S. Weather Service; and the USGS. Through its influence, a network of 40 recording rain gages, 35 recording stream gages, and 8 crest-stage gages in the Clinton, Rouge, and Huron River Basins was established and maintained. The Committee published periodic reports on its activities and on hydrologic events.

Record floods occurred in the Upper Peninsula in April and early May 1960. Those in the Montreal and Presque Isle River Basins in the western part of the Peninsula were characterized as the most severe in the memory of long-time residents (WSP 1790–B, 1960).

Stoimenoff documented the floods of May 1959 in the Au Gres and Rifle River Basins and analyzed the magnitude and frequency of floods in southeastern Michigan (open-file repts., 1960 and 1963). As part of a project on flood frequencies in the conterminous United States, Wiitala authored a report on flood frequencies in the St. Lawrence River Basin (WSP 1677, 1965).

### *Areal and Topical Studies*

A major part of the GWB program was geared to areal studies of the ground-water geology and hydrology of specific areas. During this period, studies of the ground-water resources of eight counties in the eastern part of the Upper Peninsula, five municipalities (Alma, Battle Creek, Elsie, Holland, and Kalamazoo), the Jordan River fish hatchery site, and the Tri-County (Clinton, Eaton, and Ingham) Region were completed. Reports resulting from these studies were authored by various members of the GWB staff and were published by the Michigan Geological Survey except for the Alma and Tri-County studies. An example of these reports was that of the ground-water hydrology and glacial geology of the Kalamazoo area by Deutsch, Vanlier, and Giroux (Michigan Geol. Survey, Prog. Rept. 23, 1960). The report on the Tri-County studies was published by the Tri-County Planning Commission and the Alma report, by Vanlier, was published as WSP 1619–E (1961).

Concern about the adequacy of ground-water supplies for expanding population and industry and about declining lake levels prompted investigations of the water resources of Branch and Van Buren Counties. Paul Giroux, Gerth Hendrickson, Lawrence E. Stoimenoff, and George W. Whetstone reported on the Van Buren County study (Michigan Geol. Survey Water Inv. Rept. 3, 1964) and Giroux, Stoimenoff, Jon O. Nowlin, and Earl L. Skinner reported on the Branch County study (Michigan Geol. Survey Water Inv. Rept. 6, 1966).

Wiitala, Vanlier, and Robert A. Krieger reported on the water resources of the Flint area in WSP 1499–E (1963). Wiitala, Newport, and Skinner reported on the study of the water resources of the Marquette Iron Range in WSP 1842 (1967). Knutilla reported on the surface-water characteristics of the North Branch Clinton River Basin, on flow characteristics of Michigan streams, and on regional draft-storage relationships for the Grand River Basin (open-file repts., 1966, 1967, and 1968).

Deutsch became interested in the contamination of ground waters and produced a series of reports on the subject. The first, on radioactive materials in water, was published by Michigan State University as partial fulfillment for a graduate degree in resource development. In quick succession followed a report on hydrogeologic aspects of ground-water pollution (Water Well Jour., 1961); a paper on chromium contamination of ground water in Michigan (USPHS Tech. Rept., 1951); a paper on phenol contamination of an artesian aquifer at Alma, Mich. (British Society of Water Treatment and Examination, 1966); and a report on ground-water contamination and legal controls in Michigan (WSP 1691, 1963).

Hendrickson, Deutsch's successor as District Geologist and an avid fisherman and outdoorsman, became similarly intrigued with the relationships between hydrology and the recreational value of streams. His study of these relationships in the Au Sable River, supported in part by the Survey, was the basis for a thesis to fulfill requirements for a master's degree in resource development from Michigan State University.

In a series of tests between September 1959 and February 1960, Deutsch and Joseph E. Reed (on detail from the Arkansas GWB District) demonstrated the effectiveness of induced recharge to an artesian glacial drift aquifer at Kalamazoo (WSP 1594–D, 1966).

Other projects included investigations of precipitation-runoff relations in the Rifle River Basin and in small agricultural watersheds near Lansing. Stanley B. Koks worked on the determination and coordination of drainage areas throughout the State as modern topographic maps became available.

## Vignettes

Gordon Stearns, prior to his transfer to Texas, was working on the roof of his garage at his home in Lansing. He slid off the roof, falling to a sitting position on the ground. A moment later his hammer followed, hitting Gordie on the head.

Leota Huffman, in a spate of enthusiasm, decided to accompany a stream gager one day to see how streamflow was measured. In her words, "About all that I got out of the field trip was poison ivy. I vowed then and there that I had learned all I wanted to know about stream gaging and would never go on a field trip again."

Wiitala came upon trout-fisherman Gerth Hendrickson wading in the middle of Black Creek in the Upper Peninsula on an ugly, miserable day in early May with a cold rain falling. Gerth, the quintessential fisherman, called out, "Isn't this great!"

There was a time in the 1940's when vendors were asked to include the certification on their bills, "This bill is correct and just and payment therefor has not been received." One billing came into the Lansing office certified, "This bill is correct and just and therefore has not been paid."

During construction of a gage house on Fawn River, Stan Koks decided to salvage the cribbing. He was buried in a cave-in. Dick Ash, a summer assistant, was standing by and quickly dug Stan out. Stan survived with broken ribs and collar bone.

## Minnesota

Based on material prepared *by* David B. Anderson *and* Robert W. Maclay with assistance from Norma Anderson, Henry Anderson, Alex Breitkrietz, Rosa L.V. Chamblee, George Garklavs, Kurt T. Gunard, William J. Herb, James E. Johnson *and* Harold O. Reeder, *and* reviewed *by* Richmond F. Brown

The Minnesota Branch Districts were not reorganized into a Division District until the summer of 1967. Personnel, organization, and operations are discussed by Branches, except where the activities were Divisionwide in scope.

The SWB and GWB District offices were located at 1610 New Post Office Building in St. Paul at the beginning of the period. By January 1960, however, the GWB District office had been moved to 1002 New Post Office Building.

### *Surface Water Branch*

Leon R. Sawyer was District Engineer until December 1962, when he retired after 30 years with the Survey. Charles H. Prior was the Acting District Engineer until April 1963, when David B. Anderson transferred from the California District to become District Engineer for the remainder of the period. Prior served as Assistant (or Acting) District Engineer throughout the period until his retirement in December 1965. William B. Mann, IV, transferred to the Minnesota District from Kentucky in June 1966, as Prior's successor.

Personnel in the St. Paul office who served throughout the period 1957–66 were Lawrence E. Bidwell, Eno G. Giacomini, Lowell C. Guetzkow, Kurt T. Gunard, Joseph H. Hess, and Ralph W. Lamson. James E. Johnson was a member of the St. Paul staff until August 1964 when he moved to Grand Rapids as Technician-in-Charge of the newly established Subdistrict. Others who served in St. Paul during this period were Hildur E. Berry (1958–64), Howard P. Braden (1965–), George H. Carlson (new hire, March 1966), John M. Comer (1961–62), Donald R. Daugs (1960–64), Paul E. Felsheim (1959–), June H. Foss, later Administrative Assistant (1958–), Gerald P. Haas (1958–64, at times WAE), Arthur L. Jackson (1957), Richard P. Novitzki (1965–), Clifford E. Schneider (1958–63), Wendell V. Tangborn (1958-60), Duane A. Wicklund (1963–), and Rosemary Wolf (1957–60). James R. Kari and Thomas F. Thorstenson were students and outstanding WAE (full-time summer) employees for a couple of years. In 1965, a Floods Section was established in the St. Paul office headed by Guetzkow, assisted by Gunard. When Carlson entered on duty, he also was assigned to the Floods Section.

Donald W. Ericson transferred from the Wisconsin District as Engineer-in-Charge of the Grand Rapids Subdistrict (formerly a field headquarters) in November 1965. Johnson remained in Grand Rapids and Donald A. Halverson, Robert J. Hofer, and Terrance D. Sawdey were added to the staff in 1965. Sawdey remained throughout the period. Halverson and Hofer left in early 1966. The Grand Rapids Subdistrict staff operated the gaging stations and computed discharge records for stations in the Great Lakes drainage area, in part of the Red River Basin and in the Upper Mississippi River Basin at and above the gaging station at Aitkin.

A Subdistrict office in Grand Forks, N. Dak., was maintained jointly by the North Dakota and Minnesota Districts until September 30, 1965, when the joint participation was discontinued and the office reverted to the North Dakota District. The Grand Forks office had received more than half its financial support from the Minnesota District, but personnel and administrative matters were handled by North Dakota. Its staff did the field and office work for Minnesota stations in the Red River of the North Basin until September 30, 1965, when the Grand Rapids, Minn., Subdistrict took over the operation of those stations. George M. Pike, in charge of the Grand Forks office, also participated in several areal studies in Minnesota. Other members of the Grand Forks staff were Charles E. Cornelius (throughout the period), Dennis K. Stewart (1957–65), and Clifford F. Schneider from 1957 to 1958 when he transferred to St. Paul.

#### *Ground-Water Branch*

In 1957, Robert Schneider was District Geologist, and he remained in that position until 1960 when he transferred to Arlington, Va., as Assistant Chief, GWB Research Section. Richmond F. Brown transferred from the Reports Section, Washington, D.C., in July 1960 as Schneider's successor.

Ralph D. Cotter and George C. Straka were on the GWB District staff throughout the period. Others who were employed for part of the period included James W. Bingham (1957–59), Alex Breitkrietz (1957–59), Lee C. Burton (1958–60), Mary Jane Cirhan Griffin (1963–), Barbara A. Dibos (1957), Bruce A. Leisch (1957), Roger A. Lyman (1958–60), Beverly J. Marshall (1961–62), Robert W. Maclay (1960–66), William A. Miller (1960–), Ralph F. Norvitch (1957–62), Edward L. Oakes (St. Paul 1960–61, then in Grand Rapids 1962–64), Robert D. Penley (1957–59), George R. Schiner (1957–62), Rose Marie Smith (1959–64), Harry G. Rodis (1957–61), Gerald L. Thompson (1961–62), Thomas C. Winter (1959–, occasionally WAE) and Harley L. Young (1960–63). Karen K. Hitzman, Linda A. Jerabek, Gerald F. Lindholm, Harold O. Reeder, and Leverett H. Ropes were employed only for a year or two at the end of the period in St. Paul, except for Lindholm, who was in St. Paul and later in Grand Rapids. Wayne A. Van Voast was hired in 1963 for watershed studies in the Minnesota River Basin.

The GWB District suffered a severe budget reduction in 1959 (see "Funding and Cooperation", below) and several staff members were transferred out of the District. Except for Cotter, who remained as Acting District Geologist, all personnel working on Iron Range projects were transferred. Straka remained to work on the much-reduced observation-well program. Rodis and Schiner stayed on to complete reports funded by the municipalities of Marshall and Redwood Falls. Rose Marie Smith continued as District Clerk.

When Brown became District Geologist in 1960, Cotter, Straka, Rodis, Schiner, and Rose Marie Smith were his entire staff.

#### *Quality of Water Branch*

Except for the QWB field unit at the University of Minnesota, St. Anthony Falls Hydraulics Laboratory in Minneapolis (see Part IV, "Geomorphic and sediment processes"), the QWB maintained no offices and had no personnel in Minnesota. Don M. Culbertson, who headed the QWB program in Nebraska, regularly visited St. Paul to confer with members of the Minnesota WRD Council concerning water-quality matters within the State.

#### *Water Resources Division District Council*

Starting about 1960, a Minnesota WRD Council was established to coordinate the work of the Branches within the State. Sawyer, initially the Council Chairman, served until he retired in 1962. Brown chaired the Council for the remainder of the period.

### Funding and Cooperation

#### *Federal-State Program*

During FY 1958–66, an average of about 60 percent of the District's funding came from the Federal-State (Coop) program. The Minnesota Department of Conservation, through its Division of Waters, was the designated cooperator for the investigation of water resources on a statewide level. Funds from this source financed much of the streamflow network and a small ground-water data network. A few municipalities within the State provided funds for investigations of streams within their boundaries because these streams were flood prone, or were used by industry, or in the treatment of domestic and industrial wastes.

Beginning in 1958, the Minnesota Highway Department provided matching funds for a gradually expanding, statewide network of crest-stage gages.

The Hennepin County Board of County Commissioners provided a small amount of funding in the early part of the period for surface-water investigations of Lake Minnetonka and Minnehaha Creek and for ground-water observation wells within the county.

The GWB program lost nearly all of its cooperative funding in 1959. The largest GWB cooperative program until then was with the Minnesota Iron Range Resources and Rehabilitation Commission (MIRRRC), which received a tax on ore shipped from the State, and that revenue was the source of funds for the cooperative program. A prolonged strike shut down steel mills in 1959 and shipping of ore ceased immediately, ending the tax revenue and the cooperative program with the Commission. The Iron Range projects were immediately terminated, results of which were to be used to assist in developing new industries in the Minnesota Iron Range communities when ore reserves were depleted and mining was phased out as the principal source of employment in the area.

It was assumed that when the strike was over, the cooperative program with the Commission would be restored. However, in 1960, a new director was appointed to head the Commission who requested a much-reduced program, principally for the completion of pre-strike studies. Cotter was assigned to head these studies. Funds were later obtained to make a small ground-water study in the Grand Rapids area. There were no other cooperative ground-water funds except those from the Division of Waters for measurement of a few observation wells.

During 1961, a proposal was developed for a 10-year study of the hydrology of 39 watersheds throughout the State. The results of the studies were to be presented on 1:125,000-scale maps showing the quantity and quality of ground and surface water. The proposal was presented to the Division of Waters as the basis for a major cooperative program but without success. Later, the legislature passed a special tax on cigarettes to be used for natural-resource studies and the Survey was allocated a major part of the new funds for the watershed studies. Largely as a result of the watershed studies, additional ground-water investigations were funded under cooperative agreements with the municipalities of Stephen, Marshall, St. James, Minneapolis-St. Paul Metropolitan Council, Brooten, Wadena, and Pellston and administered through the Division of Waters.

Additional funds were subsequently made available by the legislature for a study of the recreational potential for rivers. The legislature also provided that matching funds generated by municipalities and watersheds for water-resources studies be exclusively for and used by the Survey.

#### *Other Federal Agencies*

The St. Paul District, U.S. Army Corps of Engineers, provided most of the OFA funds. The Corps needed streamflow information for flood control and to maintain a navigation channel in the Mississippi River downstream from Minneapolis.

The U.S. Department of State funded the operation of certain gaging stations along the International boundary with Canada, and in FY 1958, the U.S. Air Force funded a ground-water investigation at its base in Duluth.

Toward the end of the period, the U.S. Bureau of Sport Fisheries and Wildlife provided funds for stream gaging in the St. Francis River Basin to obtain data needed to manage a wildlife refuge. The FWPCA provided funds for an eutrophication-control project on Shagawa Lake on the Iron Range near Ely. FPC funds were provided by its licensees; Blandin Paper Company, Ford Motor Company, Minnkota Power Coop, Inc., Minnesota Power and Light Company, and Northern States Power Company.

The funds tabulated by source in the table below, although incomplete, show the general distribution by source and the range of District funding during FY 1958 to FY 1966. Some additional funds were made available by the Corps of Engineers to document extreme floods in Minnesota during 1965. There was a special infusion of Federal funds in FY 1959 and FY 1960 to keep the District afloat following the loss of the cooperative program with the MIRRRC in FY 1958.

Minnesota District funds, fiscal years 1958–66
[In thousands of dollars]

| Funds source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 260.9 | 322.2 | 206.2 | 266.0 | 260.8 | 213.1 | 278.6 | 341.2 | 423.2 |
| OFA | 29.8 | - | - | - | - | - | - | 55.8 | 56.5 |
| Fed | 40.3 | - | - | - | - | - | - | 43.0 | 48.2 |
| FPC | 2.5 | 2.3 | 2.4 | 2.4 | 8.4 | 2.5 | 3.4 | 3.8 | 4.0 |
| Total | 333.5 | - | - | - | - | - | - | 443.8 | 531.9 |

Source: Figures for 1958, 1965, and 1966 are from District program documents, adjusted to delete funding for the St. Anthony Falls Laboratory, and are considered reliable. Figures for other years are from other, less reliable sources and are not available for OFA and Fed sources.

### Summary of Program

The collection of basic records continued to be an important part of the program in Minnesota, but increasing emphasis was placed on interpretive, multidiscipline studies.

Surface-Water Records.—In 1957, records were published for 116 gaging stations, a few of which were supplied by the Corps of Engineers or by power companies. In 1963, the District operated 56 long-term hydrologic streamflow stations, 29 short-term hydrologic stations, and 47 specific-purpose or water-management stations for a total of 132 stations. There was little change in the number of data-collection sites from 1963 to 1966.

A small-stream flood-investigation program with the State Highway Department, beginning in August 1958, funded the installation of 159 crest-stage gages by 1965. Emphasis was on streams draining 10 square miles or less. Continuous-record stations which were discontinued were added to the crest-stage program by cooperators other than the Highway Department. During the period 1958–65, 21 of the stations financed in cooperation with the Minnesota Department of Natural Resources and 12 Corps of Engineers-funded sites were added to the small-streams program.

In addition to determining the annual peak stage and discharge at each of these stations, precipitation data were collected at many stations by volunteer observers or by tipping-bucket rain gages. Basin characteristics that might affect the magnitude of floods such as drainage area, main-channel length and slope, mean basin altitude, forested area, and area of lakes and swamps were also determined at the stations.

The data collected in the "crest-stage gage" network were compiled, tabulated, and released as open-file reports covering the period October 1958 to September 1965. These reports, authored by Lowell C. Guetzkow and Kurt T. Gunard, were updated biennially as more data were collected and were to be used with information from the continuous-record network to produce a flood-frequency report in the next decade.

During the period 1957–66, more than 100 indirect measurements of peak discharge were made at crest-stage gages and at miscellaneous, small-area sites.

Ground-Water Records.—The District maintained 46 wells in the observation-well network in 1957 and 42 wells in 1966. The publication "Water resources investigations in Minnesota, 1963," lists a total of 67 wells of which two were key observation wells, measured weekly, 51 were measured monthly and 14, semiannually. This total, considerably more than those measured in 1957 and 1966, included wells that were used to define statewide aquifer systems prior to the start of planned watershed studies. Most wells were measured for a year, then at 5-year intervals. Hydrographs of water levels from the network wells were published in "Graphs of ground-water levels in Minnesota" for the periods 1957–61 and 1962–66 by the Minnesota Department of Conservation. Water levels from selected wells were also published in WSP's 1781 (1964) and 1976 (1969).

Water-Quality Records.—In 1963, the District collected temperature data at 10 surface-water stations and analyzed the chemical quality of samples from 9 stations. WSP 1781 (1964) contained results of chemical-quality analyses of samples from 23 wells obtained during the course of ground-water investigations.

## Areal and Special Studies

The first of the 39 water-resource studies of watersheds, in the Red River of the North Basin, was directed by Maclay and Winter, who developed many of the investigative and format concepts that were used in subsequent reports. The reports summarized the ground- and surface-water resources, water quality, and water use for each watershed, and each included a section that analyzed one or more major water problem that existed in the watershed. Among the publications resulting from these studies were HA–201, (Maclay, Winter, and Pike, 1965); HA–213, (Cotter, Bidwell, Oakes, and Hollenstein, 1966); HA–220, (Cotter and Bidwell, 1966); HA–237, (Maclay, Winter, and Pike, 1967); HA–241, (Winter, Maclay, and Pike, 1967); HA–269, (Cotter and Bidwell, 1968); HA–272, (Maclay, Winter, and Bidwell, 1968); HA–278, (Oakes and Bidwell, 1969); HA–286, (Bidwell, Van Voast, and Novitzki, 1968); HA–296, (Winter, Bidwell, and Maclay, 1969); HA–307, (Maclay, Bidwell, and Winter, 1969); HA–320, (Novitzki, Van Voast, and Jerebek, 1969); HA–339, (Winter, Bidwell, and Maclay, 1969); and HA–345 (Van Voast, Jerabek, and Novitzki, 1969).

Among the special areal or topical ground-water studies in Minnesota was that of exploratory drilling for ground water in the Mountain Iron-Virginia area, St. Louis County, by Cotter and Rogers (WSP 1539–A, 1961). Correlation of ground-water levels and air temperatures in the winter and spring were reported by Schneider (WSP 1539–D, 1961). Aquifers in meltwater channels along the southwest flank of the Des Moines lobe, Lyon County, were studied and reported on by Schneider and Rodis (WSP 1539–F, 1961) and the geology and occurrence of ground water in Lyon County were reported on by Rodis (WSP 1619–N, 1963).

Results of ground-water exploration and test pumping in the Halma-Lake Bronson area of Kittson County were reported by Schiner (1619–BB, 1963). Jones, Akin, and Schneider reported the results of their study of the geology and ground-water conditions in the southern part of the Camp Ripley Military Reservation (WSP 1669–A, 1963). The investigation of the geology and ground-water conditions of the Redwood Falls area, Redwood County, by Schiner and Schneider was completed (WSP 1669–R, 1964) as was that of Nobles County and part of Jackson County by Norvitch (WSP 1749, 1964).

An interdisciplinary study of the water resources in the Mesabi and Vermilion Iron Range area was made by Cotter, Young, Petri, and Prior (WSP 1759–A, 1965), and the same team reported on the water resources in the vicinity of various municipalities in the Mesabi Iron Range (WSP 1759–B to E, 1965). They also prepared a similar report on the eastern Mesabi Iron Range and the Vermilion Iron Range (WSP 1759–F, 1965).

The hydrology of meltwater channels in southwestern Minnesota was studied by Thompson (WSP 1809–K, 1965), and Maclay made a reconnaissance of the geology and ground-water resources in the Aurora area of St. Louis County (WSP 1809–U, 1966).

Plan for constructing an electric analog model of the Minneapolis-St. Paul area began in 1965. The objective of this project, conducted by Harold Reeder, was to analyze the ground-water resources in the Twin Cities area with reference to water development and possibility of artificial recharge. The characteristics of the ground-water system were compiled on maps to be used in the design, construction, and proof of the model and were sent to the GWB Analog Model Unit in Phoenix, Ariz., in December 1965 and early 1966. Design and construction of the model began as this period of history ended.

A report on the magnitude and frequency of floods in Minnesota was prepared by Prior and Hess (Minn. Dept. of Conser. Bull. 12, 1961).

In the spring of 1965, the greatest flood of record occurred in much of the Upper Mississippi River Basin. The discharge of the Mississippi River at St. Paul was 171,000 $ft^3/s$ on April 16, greatly exceeding the previous maximum (since 1842) of 125,000 $ft^3/s$, which occurred on April 16, 1952. The maximum stage at St. Paul exceeded that of any flood since at least 1851 and was 4 feet higher than the stage recorded in the great 1952 flood. A report documenting this event was prepared by Anderson and Ivan L. Burmeister of the Iowa District (WSP 1850–A, 1970).

Late in this period of history, the Survey entered into a cooperative agreement with the Minnesota Department of Conservation to report on the flow of Minnesota rivers as related to their recreational utility and potential. The first report in this planned series of studies was published as a hydrologic atlas (Ropes, Brown, and Wheat, HA–299, 1969).

### Vignette

Dave Anderson has always been interested in the people who form an organization—their personalities, interests, attitudes, and experiences. One of the persons who made an outstanding contribution to the Minnesota District was Charles (Chuck) Prior. Chuck worked in the District from 1937 through 1965. He was honored at a retirement party on December 17, 1965. For that occasion, Dave Anderson, District Engineer, wrote a poem and delivered it in Chuck's honor. The poem which recounted Chuck's career in 28 verses opened like this:

### The Ballad of Chuck Prior

It was years ago in '28
That he made the choice that sealed his fate,
For it's there in the record where all can see
That he began his career in Tennessee,
And since that day he's paved the way
For many another in the Survey.

The Father of Waters runs many mile
And increases in volume all the while,
And finally at Vicksburg this mighty torrent
Is gaged by men who measure the current.
They measure the widths, and they measure the depths,
And they end up with something they call cfs.

It was Charlie's job in these days of yore
To make these measurements, shore to shore.
And there on the bridge as he worked so fast
A cyclone hit with a hell of a blast.
Chuck clung to the bridge in the fierce gale
And last saw his notes as they cleared the rail.
His hat was next, it was torn from his hand,
His mouth was all full of pebbles and sand.
"Hang on, Charlie!" through the gale he cried
As he hoped against hope the wind would subside.
Finally it did, and quickly at that,
And the Engineer Corps had recovered his hat.

and ended with--

He stepped into the little trolley.
He laughed aloud, his mood was jolly,
And then he started to take the ride
Across the span to the other side.
He was soon aware of the force of the gale
Which filled up the tarp and made it a sail.
Above his head the sheaves were whirring,
His coat was flapping, his eyes were blurring.
Faster, faster went the cart;
Chuck was rapidly losing heart.
How could he halt his frantic ride
Ere he hit the tower on the other side?

I could go on and tell you all
Of the things that happened while in St. Paul—
Of the jobs he's done and the friends he's made,
How he stopped so often to give us aid.
But most of us here know Chuck as a friend,
And so I come to my story's end.

## Mississippi

Based on material provided *by* Ernest H. Boswell with the assistance of Irving E. Anderson, B.E. Ellison, Jr., *and* James W. Hudson

In early 1957, the SWB and GWB District headquarters shared office space over the Century Theater in downtown Jackson. Later that year, space was found for both branches in a renovated cafeteria building at 402 High Street that offered much-improved office, storage, and workshop space and parking for vehicles and equipment. Both branches were moved again in 1962 to the U.S. Post Office Building where they remained through this period of history.

## Organization and Personnel

### *Surface Water Branch (1957–65)*

In 1957 Irving E. Anderson, District Engineer, was transferred to the Office of the Chief, SWB, and William H. Robinson, formerly of the Montgomery, Ala., SWB District, became District Engineer. The SWB staff at various times during this period included engineers Harold G. Golden, Carney P. Humphreys, Braxtel L. Neely, Jr., James D. Shell, John Skelton, Winchell Smith, and Kenneth V. Wilson. Career technicians who served during much or all of this period in Jackson and at times, elsewhere in the State, included Wiley K. Bell, James W. Hudson, Russell F. Senseman, and I. Lee Trotter, Jr.

B.E. Ellison, Jr., was the mainstay of the SWB clerical staff as this period began; however, he soon moved to GWB as an engineering aid.

In 1957, the SWB operated field headquarters in Holly Springs and in New Albany. In Holly Springs, James E. Bowie was Engineer-in-Charge. He was assisted by James W. Hudson and Carney P. Humphreys. The one-man staff in New Albany was Billy J. McCollum. The Holly Springs office was closed on completion of the Pigeon Roost Creek project in cooperation with Soil Conservation Service and the Agricultural Research Service and in 1959 Hudson was moved to Pascagoula, where he and Fayne D. Edwards staffed a new project in southern Mississippi. Bowie moved to Phoenix, Ariz., as Engineer-in-Charge of that office. McCollum remained in New Albany through the close of this period. The Pascagoula office was closed in 1961 and Hudson was transferred to Jackson, where he remained through the remainder of the period; Edwards had transferred earlier to Tennessee, SWB.

Robinson reorganized SWB operations in 1960 by creating a Basic Records Section (Shell in charge); a Floods Section (Wilson in charge); and a Special Studies Section (Golden in charge). This organization remained in place with few changes until 1965, when Mississippi became a Division-level District.

### *Ground Water Branch (1957–65)*

Joe W. Lang was District Geologist for GWB operations in Mississippi during the entire period of Branch operations. He and Robinson alternated as Chairman, WRD Council. Lang's staff in 1957 included Ernest H. Boswell, who was soon reassigned to the Mississippi Embayment project, and Edward J. Harvey, who moved to Rolla, Mo., as District Geologist in 1963. With Harvey's departure, Roy Newcome, Jr., moved to Jackson and served as Assistant District Geologist until the reorganization of 1965. Other Jackson-based members of the GWB District at various times during this period included Billie E. Wasson, engineer, Thad M. Shows, technician, Ellison, and Paul E. Grantham, both engineering aids. Amer T. Wilkerson was District Clerk.

The GWB District had no field offices in Mississippi until 1960 when two field headquarters were established; one in Kosciusko, manned by Wasson, and the other in Pascagoula, manned by Shows. In 1961, a field headquarters was established in Hattiesburg to support the geohydrologic investigation requested by the AEC of nuclear explosions in the Tatum Salt Dome. The Hattiesburg project operations were headed by Clarence A. Armstrong, assisted by Robert V. Chafin, Hobart B. Harris, and Richard E. Taylor all geologists. The project was under the immediate supervision of Harvey, and water-quality assistance was provided by Horace G. Jeffery of the Arkansas QWB District.

By 1962, the Kosciusko and Pascagoula offices were closed and work out of Hattiesburg reduced to a two-man level—Chafin and Taylor. Taylor departed in 1963 and Shows moved to Hattiesburg from Pascagoula. Prior to the 1965 reorganization, the Hattiesburg office was closed.

### *Quality of Water Branch (1957–65)*

The QWB maintained neither staff nor office in Mississippi during this period. As the period began, water-quality assistance was provided by QWB staff of the Fayetteville, Ark., District. In 1960, following the establishment of a QWB District in Baton Rouge, La., water-quality assistance to the Mississippi WRD investigations was provided from Baton Rouge. Baton Rouge staff assisted the Mississippi District until WRD operations in Mississippi were reorganized in 1965. The Mississippi District then acquired its first in-house chemist with the arrival from Florida of Donald E. Shattles.

### *Water Resources Division (1965–66)*

Mississippi WRD operations were reorganized into a Division-level District in July 1965, with Robinson as the District Chief and Lang as the Associate District Chief. Wilkinson became Chief Administrative Clerk.

Others on the staff as Division-level operations began in 1965 were: Boswell, Newcome, Shattles, Taylor, and Ernest E. Russell (WAE), geologists; Humphreys, Jack R. McCormick, Neely, Charles B. Nuckolls, Shell, Frederick H. Thomson, Wasson, and Wilson, engineers; Tommy E. Anderson (later struck by auto and killed while making a discharge measurement at Laurel), Bell, Dorris W. Butler, James A. Callahan, Ellison, Grantham, Hudson, Carolyn C. Jessup, Billy J. McCollum, Leila Merle Rimes (later married Hudson), Senseman, Shows, and Trotter, engineering technicians; Frances M. Hester, cartographic technician; Sidney H. Bishop and Wade L. Overby (WAE), engineering aids; Frances R. Barnes and Mary E. Williamson, clerks.

Reorganization as a Division-level District had relatively little impact on staff and operations as the GWB and SWB had for years shared office and storage space, several cooperators, administrative services, and projects where the objectives required a multidiscipline team.

## Funding and Cooperation

Most of the funding for the District's programs were from the cooperative (Coop) program and from other Federal (OFA) agencies. The Survey's Federal (Fed) program provided lesser amounts for the support of a few gaging stations and observation wells of national interest.

The primary State cooperator was the Mississippi Board of Water Commissioners (MBWC), directed by the State Water Engineer, Jack W. Pepper, a former WRD employee and staunch supporter of the Survey's national water-resources programs. The Mississippi State Highway Department was a long-time, continuing cooperator. Other cooperators included the Mississippi Industrial and Technological Research Commission (MITRC) and its successor, the Mississippi Research and Development Center (MRDC), the city of Jackson, Jackson and Harrison Counties, and the Pearl River Valley Water Supply District.

Long-term Federal cooperators were the Mobile and Vicksburg Districts of the U.S. Army Corps of Engineers and the Soil Conservation Service (SCS). Large programs in cooperation with the Agricultural Research Service (ARS) and the AEC required field offices and increases in personnel. Other Federal cooperators included the National Aeronautics and Space Agency (NASA), FWPCA, National Park Service, and Public Health Service.

Although the following table is incomplete, it shows that District funds increased from about $250,000 in FY 1958 to about $440,000 in FY 1966.

Mississippi District funds, intermittent years, FY 1958–66
[In thousands of dollars]

| Fund Source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 130.6 | - | 195.4 | - | - | - | - | 285.9 | 319.5 |
| OFA | 98.8 | - | 16.9 | - | - | - | - | 77.0 | 100.7 |
| Fed | 24.0 | - | 32.9 | - | - | - | - | 13.8 | 16.4 |
| Total | 253.4 | - | 245.2 | - | - | - | - | 376.7 | 436.6 |

Source: District program documents

## Summary of Program

In 1957, the Mississippi District program was essentially stable. Continuing surface-water work included the cooperative stream-gaging program with the MBWC and the Mobile and Vicksburg Districts of the Corps of Engineers. The Pigeon Roost Creek project, a sedimentation investigation in cooperation with the ARS and SCS, continued as a joint surface-water and water-quality program.

### *Water Records*

Data activities are summarized from "Water Resources Investigations in Mississippi, 1962."

Streamflow Records.—The stream-gaging network reported in 1962 was made up of 67 stations of which 37 were primary (long-term hydrologic), 15 were secondary (short-term hydrologic), and 15 were operated to meet water-management needs. There was little change in the routine stream-gaging program during the remainder of this period.

After 1958, the Board of Water Commissioners was granted authority to permit "appropriation of stream water only in excess of established average minimum flow." This generated a need for low-flow data which were needed also for waste disposal and pollution control. Consequently, discharge measurements were made at low-flow, partial-record stations at numerous stream locations in the State throughout the period of this history.

The most spine-tingling surface-water operation in the District was the biweekly measurement of the flow of the Mississippi River from the narrow, 2-lane, heavily traveled bridge at Vicksburg. The 1.5-ton 1937

Ford truck-mounted device was replaced in the 1950's by a Crosley Farm-O-Road mounted rig that was not much heavier than the 300-pound sounding weight that it hoisted.

Ground-Water Records.—In 1957, water levels were being monitored in 67 wells that made up the statewide observation-well network. Additionally, a large number of wells were monitored in ongoing study areas. By 1962, the observation-well program had increased to 85 wells and supplementary and project wells totaled about 200.

Water-Quality Records.—In 1962, the District operated one station where a continuous specific-conductance record was obtained, and monthly samples for chemical quality were taken at 5 stations and quarterly at 15 stations. Observations of stream temperatures that had been recorded for many years were reported by Golden (MBWC Bull. 59–1, 1959).

Other Data Activities.—The cooperative program with the State Highway Department, including bridge-site investigations, measurements of flood discharges, and related studies, was a major SWB activity. The program, which evolved from an earlier program of channel cross-section determinations, was under the immediate direction of Wilson since about 1957. The program completed 340 bridge-site studies between 1957 and 1966. Harry H. Barnes began his career in this program and later became Chief, SWB.

The "highway program" also sponsored the preparation of the report entitled "Floods in Mississippi, magnitude and frequency" by Wilson and Trotter that was published by the State Highway Department in 1961.

The only flood that exceeded the 50-year frequency on a major stream during this period occurred in February 1961 on the Pascagoula River in southeastern Mississippi. The 50-year frequency was exceeded nearly every year on tributary streams somewhere in the State but more commonly in southern Mississippi. The most damaging flood was that of February 1961 on Bowie Creek and Leaf River that inundated much of Hattiesburg. This flood was documented in Circular 452 (Barnes and W.P. Somers, 1961). In December 1961, floods occurred in Mississippi and adjacent States that were reported in Circular 465 (Shell, 1962). Other floods of 1961, 1962, 1963, 1964, and 1965 in Mississippi were reported in Bulletins of the MBWC. Neely documented the floods of May 19 and 21, 1966, in Jackson (open-file rept., 1967).

The District was recognized as the basic source for ground-water data during this period that was characterized by the rapid development of ground-water for industrial and public-water supplies. As a result of ongoing investigations it was found that water of better quality was available at greater depths from more prolific aquifers nearly everywhere in the State. By 1966, several wells were drilled to depths below 2,000 feet, the deepest of which was in Calhoun County and was screened at 2,344 to 2,384 feet.

Data collection by the GWB was greatly enhanced by geophysical logging. The MGS bought a portable logger in 1954, and the District began making logs in 1957 using a portable logger loaned by a major oil company or by using equipment loaned by the Louisiana or Tennessee GWB Districts. Later the District acquired its own equipment and Grantham was assigned full time as operator. The MGS and the District informally agreed to log wells anywhere in the State on call, and much data resulted from a State law requiring that driller's logs and other data be submitted to the MBWC. By 1966 several hundred logs were on file. Through a close working relationship with consulting water engineers and drillers, the District obtained thousands of feet of drill-cutting samples and made logs and pumping tests on new wells.

Wells were initially logged for District ground-water investigations by Shell Oil Co. Borrowing Shell's equipment and operator became so common that Shell finally told the District to keep the logger and Shell would borrow it as needed. Grantham and Boswell then became the equipment operators and immediately concluded that (1) hand cranking 1,000 feet of cable was hard work and that (2) even more cable was needed. A "Rube Goldberg" electric-powered reel and a rack for the logger were designed and built, 2,500 feet of cable was bought, the wiring was modified, and the logger was back in business. Shell was impressed, too. It worked fine, better in fact than the new logger that Shell bought later. Shell would never write off the logger but apparently forgot about it. Eventually the logger required more repairs than were justified and it vanished. Later, it was found in the possession of an extremely cooperative driller who had somehow acquired and continued maintaining the equipment. The logger, a 1952 Widco, was still operating well into 1990.

A compilation of surface-water quality data in Mississippi by Michael W. Gaydos of the Louisiana QWB District was published in 1965 (MBWC Bull. 65–1).

Interest in the low flows of streams in Mississippi resulted in several reports, most of which were published by the State (Golden, MBWC Bull. 60–2, 1960; Robinson and Skelton, MBWC Bull. 60–1, 1960; Skelton, MBWC 62–1, 1962; Golden, MBWD Bull. 62–2, 1962; and Thompson and Humphreys, MWBC Bull. 67–1, 1967).

#### *Special Studies*

In August 1957, the grandfather of regional aquifer-system studies, the Mississippi Embayment project, was started. Boswell was assigned full-time to the project and Golden worked part-time on the surface-water studies. The project is described more fully elsewhere in this volume (see Part IV, "Mississippi Embayment Project").

A program was started in 1958 to study the potential for saltwater intrusion in the gulf coastal area. The monitor-well network was sampled at 5-year intervals. Positive evidence of saltwater intrusion had not been found by 1967.

The Lake Washington investigation of the effects of irrigation withdrawals on a recreational lake, under the technical direction of G. Earl Harbeck, Jr., Denver, Colo., was completed in 1958 as a joint surface-water and ground-water investigation (WSP 1460–I, Harbeck, Golden, and Harvey, 1961).

Work continued on the investigation of Cretaceous aquifers in northeastern Mississippi that was started in 1954. Some of the data collected during the early part of the study were published in 1961 (Lang and Boswell, MGS Bull. 90) and the final report, published in 1963 (Boswell, MBWC Bull. 63–10), described the ground-water resources in 22 counties.

In 1958, a major multidiscipline study of the water resources of the Pascagoula area was started in cooperation with the Jackson County Board of Supervisors and Port Authority. The study provided the water-supply data needed for establishing the Bayou Cassote industrial area, later a complex of refineries, chemical plants, and related industries (Harvey, Golden, and Jeffery, WSP 1763, 1965).

Work continued on the study of the ground-water resources of the Jackson metropolitan area of Hinds, Madison, and Rankin Counties. The final report was published in 1964 (Harvey, Callahan, and Wasson, MBWC Bulletin 64–1).

The first of 16 multidiscipline, multicounty studies was started in 1960 in cooperation with the MITRC to provide water-resources information for the development of industrial water supplies; however, they were also valuable as a source of data for municipal, irrigation, and other water uses. The first study, for Adams, Claiborne, Jefferson, and Warren Counties, was made by Callahan, Skelton, and Duane E. Everett (of the Louisiana QWB District) and Harvey (MITRC Bull. 64–1, 1964). By 1966, reports describing the availability of water for industry had been published for 20 counties.

In 1961, the AEC began testing nuclear devices in the Tatum Salt Dome about 25 miles southwest of Hattiesburg. A 5-kiloton device was detonated in October 1964 (Project Salmon). A later event involved detonating a 350-ton nuclear device (Project Sterling) in the enormous cavity formed by the first explosion. District personnel worked with members of the Denver-based Special Projects Group in documenting the hydrologic effects of the nuclear tests. (See Part IV, "Hydrologic Studies Related to Nuclear Explosions.")

Among other investigations underway or completed during the period 1957–66 was an intensive investigation made in cooperation with NASA to provide data for the development of ground-water supplies for the Mississippi Test Facility (Newcome, WSP 1839–H, 1967). A test-drilling program and water-resources study made in cooperation with the Harrison County Board of Supervisors and Harrison County Development Commission revealed fresh ground water to depths of 2,500 feet (Newcome, Shattles, and Humphreys, WSP 1856, 1968). A study of the ground-water resources of the Pascagoula River Basin in Mississippi and Alabama was completed in 1966 (Newcome, WSP 1839–K, 1967).

Lang completed a geohydrologic summary of the Pearl River Basin of Mississippi and Louisiana that was published in 1972 (WSP 1899–M).

## Missouri

*By* Edward J. Harvey *and* Horace G. Jeffery with typing assistance *by* Vickie Pogue, reviewed *by* John Skelton *and* Elmer H. Sandhaus

WRD programs in Missouri were those of the SWB until October 1963 when the GWB established a District office in Rolla to begin a cooperative program of ground-water investigations. A cooperative program of water-quality investigations in Missouri also began in 1963 by the Arkansas QWB District. With the arrival of the designated Water Quality Specialist in August 1965, the Districts were instructed by the Division Hydrologist, MCA, to plan, develop, and execute all programs as a Division under the direction of the WRD Council chairman. The Branch Districts were reorganized as a WRD District in July 1966 with Anthony Homyk, Jr., as District Chief.

### Organization and Personnel

#### *Surface Water Branch*

The District office was located at 900 Pine Street in Rolla until April 1965 when it, and GWB, moved to space at 103 W. 10th Street. Harry C. Bolon was

District Engineer until he retired in 1963. He was succeeded by Anthony Homyk, Jr., who had been the Assistant District Engineer. In 1964, James E. Bowie was reassigned from Phoenix, Ariz., to be the Assistant District Engineer. Mervin S. Petersen, also Floods Specialist for the SWB Floods Section, was transferred to the Denver Regional Office in 1964. Horace G. Jeffrey, Water Quality Specialist, was reassigned from the Arkansas QWB District headquarters in Little Rock to the SWB Office in August 1965. Verna B. Curtis, District Clerk, was later the Administrative Assistant.

Roy H. Monroe was the Engineer-in-Charge of the St. Louis Subdistrict office until he retired in 1966. He was succeeded by Donald W. Spencer from the Tennessee District. Field headquarters were maintained at Boonville by Harry E. Moore until he retired in May 1965; at Trimble and Gashland by Charles J. Cox from 1957 to 1960; at Bethany by Bob L. Shepard from 1958 to 1966; and in Kansas City from 1960 to 1966. Howard W. Ollar was reassigned from the St. Louis Subdistrict office to be Technician-in-Charge of the Kansas City field headquarters.

### Ground Water Branch

The GWB District office, established in October 1963, was housed in the Missouri Geological Survey and Water Resources Building in Rolla until April 1965, when it was moved to space shared with SWB at 103 W. 10th Street. Edward J. Harvey, reassigned from Jackson, Miss., as the District Geologist, was assisted by Leo F. Emmett, previously of the Arkansas GWB District. Sharlene Evans was District Clerk. Gerald L. Feder operated from a field headquarters office in Joplin.

### Quality of Water Branch

The Nebraska QWB District maintained a field headquarters in St. Louis from 1957 to 1964 for sediment investigations in the St. Louis harbor. The cooperative water-quality program in Missouri was operated by the Arkansas District until October 1965.

## Funding and Cooperation

Most of the funds for the Districts' programs were from the cooperative program (Coop) and from other federal agencies (OFA). The Survey's Federal program (Fed) added support for a few gaging stations and observation wells. Union Electric Company, an FPC licensee, required streamflow data throughout the period. As shown in the following table, total funds ranged from $234,200 in FY 1958 to $530,400 in FY 1966.

Missouri District funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| COOP | 90.4 | 94.5 | 95.9 | 113.0 | 135.7 | 160.3 | 231.7 | 283.0 | 320.9 |
| OFA | 116.5 | 130.1 | 128.5 | 126.1 | 118.4 | 144.6 | 121.1 | 145.5 | 171.8 |
| FED | 26.3 | 26.1e | 26.9e | 26.9e | 27.4e | 27.5e | 27.2e | 31.6 | 35.9 |
| FPC | 1.0 | 1.2 | 1.3 | 3.5 | 1.6 | 1.6 | 1.7 | 1.8 | 1.8 |
| Total | 234.2 | 251.9 | 252.6 | 269.5 | 283.1 | 334.0 | 381.7 | 461.9 | 530.4 |

e = estimated; Source: District program documents.

### Cooperating Agencies

The Missouri Division of Geological Survey and Water Resources (MDGS&WR) was the principal State cooperator throughout the period for statewide surface-water investigations and, beginning in 1963, for ground-water investigations.

The Missouri Highway Commission supported a Statewide program of crest-stage gages, precipation gages, continuous streamflow recorders on small streams, and the analysis of data from those sites for flood-frequency studies.

The Little River Drainage District in southeastern Missouri and the Springfield City Utilities provided funds to operate gaging stations in their areas. The Missouri Conservation Commission provided support for small-lake studies and to obtain streamflow and temperature records at selected research sites. The University of Missouri provided support for sediment-discharge studies at a small-area site. The Missouri Water Pollution Control Board provided support for collection of water-quality records on Missouri streams.

### Other Federal Agencies

Five Districts of the U.S. Army Corps of Engineers (Kansas City, Rock Island, St. Louis, Tulsa, and Little Rock) funded the operation of gaging stations to provide data needed by the Corps in Missouri. The SCS funded the operation of selected gaging stations, and the National Park Service provided funds for the determination of flood elevations and for ground-water development at campsites in the Ozarks Scenic Riverways Area.

## Summary of Program

Until September 1963, the program was largely stream gaging, after which the GWB began its work.

With the inception of work by the three Branches, the program was oriented to assign personnel of all Branches to interdisciplinary studies. Aspects of surface-water studies such as low flows and seepage runs were combined with the spring studies, ground-water appraisals, and quality of surface and ground water in the dolomite and limestone terranes of the Salem and Springfield Plateaus (the Ozarks) to show the interaction of the systems on the environment. Studies in carbonate terranes are especially suited to the pooling of data from all facets of surface-, ground-, and quality-of-water investigations.

Surface-Water Records.—Continuous-record stream gaging started in 1922 with 39 stations and had expanded to 136 sites by 1966. The low-flow network was begun in 1960 with 200 partial-record sites increasing to 250 sites by 1966. Of these, 30 were included in the Mississippi Embayment project (see Part IV, "Mississippi Embayment Project").

The crest-stage network, started in 1947 with 12 stations to obtain flood data from small areas, was expanded to 120 sites by 1966. Of this number, 24 stations were operated as continuous-record stations at times. Concurrent rainfall records were obtained in various years at 42 of the stations.

By 1965, about 75 percent of the streamflow stations were equipped with analog-to-digital recorders.

### *Water-Quality Records*

Ground-Water Records.—The MDGS&WR maintained the observation-well network, and no water-level records were published by the USGS. In 1963, when interest in a series of proposed reservoirs in the Meramec River Basin was high, and about the time the GWB opened an office in Missouri, a network of observation wells was established in the Meramee River Basin, and monitoring continued for a number of years. Monitoring ceased when money for the proposed Meramec reservoir was deleted from the Federal budget.

Several of the large springs in the Ozarks had been measured continuously or periodically since 1921. In 1964, 10 springs, large and small, typical of the Springfield and Salem Plateaus, were measured periodically, a few monthly, and others, quarterly.

Beginning in 1964 and in conjunction with the spring-measuring project, field determinations of pH, temperature, conductance, dissolved oxygen, and bicarbonate, and laboratory determinations of calcium and magnesium were made seasonally to determine carbonate saturation of the spring water. In addition, many of the springs were sampled for the common ions.

Conductance, temperature, and pH were measured at miscellaneous streamflow sites as seepage runs were made, usually in autumn. Similar measurements were made at intervals in several wells, mostly deep ones in the dolomite in the Ozarks.

Water sampling at streamflow stations began in 1963. Continuous temperature and conductivity measurements were made at three sites and sediment content at one site. Samples were obtained to monitor the common ions at 46 stations and for organics at 9 stations. In the new lead belt (Viburnum Trend), samples were obtained at 18 stations for heavy-metal (trace elements) concentrations.

Beginning in 1964, water samples were obtained from many wells supporting various ground-water studies, mostly for determining common ions. In the abandoned Tri-state zinc-mining region, samples were obtained from abandoned mines and from a few springs to determine the zinc content.

Other Data Activities.—Water records were used in preparing the water-resources part of "Mineral and water resources of Missouri." (See Part IV, "Water Resources of States.")

### Special Studies

Among the special studies that were conducted all or in part during FY 1958–66 was that of the water resources of the Joplin area by Feder and others (MDGS&WR Rept. 24, 1969). Skelton investigated and reported on the low-flow characteristics of Missouri streams (MDGS&WR, Water Resources Rept. 20, 1966). Data on the springs of Missouri were analyzed and reported by Vineyard and Feder (MDGS&WR, Water Resources Rept. 29, 1974).

The magnitude and frequency of Missouri floods were studied and reported on by Sandhaus and Skelton (MDGS&WR, Water Resources Rept. 23, 1968), and the floods of June 17 and 18, 1964, in Jefferson, Ste. Genevieve, and St. Francois Counties were documented by Petersen (MDGS&WR, Water Resources Rept. 19, 1965). The floods of July 18–23, 1965 in northwestern Missouri were reported on by Bowie and Gann (MDGS&WR, Water Resources Rept. 21, 1967).

A reconnaissance of the ground-water resources of the Missouri River alluvium from the Iowa State line to St. Louis was made by Emmett (HA–315, 1968; HA–336, 1968; HA–340, 1969; and HA–344, 1970).

## Montana

*By* R. Gale McMurtrey with assistance from retirees Frank Stermitz *and* Charles W. Lane, from Fred C. Boner *and* other District staff members, *and* reviewed *by* Joe A. Moreland *and* Robert S. Roberts

Until mid-1966, the water-resources programs of USGS in Montana were under the jurisdiction of Branches. The organizational structure was changed to a Division-level District on July 1, 1966. Charles W. Lane, GWB District Geologist, was transferred from Billings to Helena, Mont., in June 1966 and was appointed District Chief effective July 1, 1966. George M. Pike, Acting District Engineer, SWB, headquartered in Helena, became the Assistant District Chief.

### Organization and Personnel

#### *Surface Water Branch*

The District headquarters office was in Room 409 of the Federal Building at 6th Avenue and Park Avenue in Helena. Frank Stermitz was District Engineer from before the beginning of the period until he retired on December 31, 1965. George M. Pike, who had transferred to Helena from Grand Forks, N. Dak., in August 1965, was then appointed Acting District Engineer. He continued in that position until July 1, 1966.

John D. Goshorn, Assistant District Engineer until his death in December 1958, was succeeded by Charles H. Carstens from August 1959 until he transferred to the Billings Subdistrict office in 1965. Pike was Assistant District Engineer for a few months before his appointment as Acting District Engineer.

Until 1957, Sumner G. Heidel represented the Chief, WRD, on matters pertaining to division of the waters of the St. Mary and Milk Rivers between Canada and the United States, and on other related issues. Walter A. Blenkarn replaced Heidel and continued in that position through the end of the period.

William M. Michels was the District Clerk; then beginning in 1959, he was the Administrative Assistant through the end of the period. Margaret G. Lee, the District Secretary for the entire period, was assisted by Naomi F. DeLong the first year and by Betty L. Dean, WAE, from 1963 through the end of the period.

Other engineers assigned to the District office for all or part of the period were John H. Bartells, Vernon K. Berwick, Fred C. Boner, Grant W. Buswell, Melvin V. Johnson, Elmer R. Likes, Robert J. Omang, and Joseph M. Virag. Engineering aids who worked in the Helena office during part or all of the period were Fern C. Aagaard, George A. Birdwell, Edward J. Blank, Jay H. Diamond, Warren H. Erskine, Jerry L. Finn, Orrin J. Folsom, Marion L. Kasman, Eugene D. Lovely, Francis M. O'Neill, John D. Roda, and R. Dale Schuller. Their titles were changed to engineering technicians during the period.

Subdistrict offices were in Billings and Kalispell, and a field headquarters was at Fort Peck. Elmer H. Bekkedahl was Engineer-in-Charge of the Billings office until mid-1961. Allen J. Sollid succeeded him and remained there through this period. Others who worked in the Billings office for part of the period were engineers James D. Bohn, Kenneth B. Rennick, and Milton N. Swecker; engineering aids George A. Birdwell, Douglas E. Gibbs, Gerald W. LaRue, Bertha M. Sanderson, K. Leroy Tangen, and Ellen R. Tangvick; and engineering technician Willard J. Page.

Sollid was Engineer-in-Charge of the Kalispell office from the beginning of the period until he transferred to Billings in 1961. Bekkedahl succeeded him and held the position until 1962. Blank, who was placed in charge of the office in 1962, continued until August 1964 when Lynn J. Hull transferred from Bridgeport, Nebr., to Kalispell as Engineer-in-Charge. Others in the Kalispell office for part of the period were engineering aids Gerald W. LaRue, Shirley K. Nicholson, and Raymond J. Weinberg.

In 1957, David E. Barge, an engineering aid, was the only person assigned to the Fort Peck field headquarters. Page moved to Fort Peck as Technician-in-Charge in 1959, then to Billings in August 1964. Tangen then became Technician-in-Charge at Fort Peck. Engineering technician Clifford A. Ramsbacher was assigned to the office in 1963 and engineering aid Kenneth G. Nieskens was assigned there in August 1965.

#### *Ground Water Branch*

Throughout the period, the District headquarters was in Billings. At the beginning of the period it was moved from the Federal Building to the BOR Building at 7th and Central Avenue. The office was moved to 1 North 7th Street West in 1960, then to the Bell Building at 2 South 7th Street West in 1962. Frank A. Swenson was District Geologist from the beginning of the period until he transferred to Denver in June 1962. Lane transferred from Kansas to become District Geologist and continued in that position for the remainder of the period.

In 1957, Swenson supervised five geologists: Douglas C. Alverson, Louis J. Hamilton, Quentin F. Paulson, Everett A. Zimmerman, and Tom V. Zimmerman. In 1958, Tom Zimmerman resigned, Betty A. Tucker was hired as clerk-stenographer and Paulson transferred to Alabama. O. James Taylor, engineer, started in 1959. In 1960, Alverson resigned, William B. Hopkins (geologist) transferred in, and Betty G. Cowger started as a clerk-typist. Besides the change in District Geologists in 1962, Hamilton transferred out and James D. Tkach began work as an engineering aid, WAE. In August 1963, R. Gale McMurtrey moved from Missoula to Billings. In 1964, Tucker transferred to another Federal agency.

A field headquarters was in Missoula throughout the period as headquarters for personnel who conducted the ground-water investigations in western Montana. McMurtrey was Engineer-in-Charge from the beginning of the period until August 1963, when he moved to Billings as Assistant District Geologist. Richard A. Konizeski, geologist, who worked in the Missoula office for the entire period, was then in charge of the office until it closed in September 1966. At that time, he resigned to teach at the University of Montana. Joel K. Montgomery, geologist, was a member of the Missoula staff from 1957 until 1959. Alex Brietkrietz worked out of the Missoula office from 1959 until it closed, then transferred to the Helena office.

### *Quality of Water Branch*

No offices were maintained by the QWB nor were any staff permanently headquartered in Montana during the period. Quality-of-water investigations and analyses for Montana east of the Continental Divide were done by the Lincoln, Nebr., or the Worland, Wyo., District offices of QWB. Quality-of-water work in western Montana was by the Portland, Oreg., District.

## Funding and Cooperation

Most of the funding for the District program came from other Federal agencies (OFA) and the Federal-State cooperative program (Coop) during the period. The Federal program (Fed) supported a few streamflow-gaging stations, some flood investigations, and a few observation wells. Federal Power Commission licensees Montana Power Company and Washington Water Power supported streamflow data collection for the entire period. Federal Power Commission licensee Northern Lights, Inc., funded streamflow-data collection for only the first part of the period. Total District funding ranged from $335,600 in FY 1959 to $657,800 in FY 1965, when a one-time infusion of Federal funds was received for floods studies along with a substantial increase in OFA funds (see following table).

Montana District funds, fiscal years 1958–67
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1952 | 1963 | 1964 | 1965 | 1966 | 1967 |
|---|---|---|---|---|---|---|---|---|---|---|
| OFA | 190.1 | 185.0* | 183.0* | 181.8 | 232.7 | 272.4 | 276.9 | 322.3 | 333.4 | 326.7 |
| Coop | 130.0 | 126.0 | 134.0 | 158.3 | 144.8 | 172.1 | 195.2 | 211.7 | 254.7 | 249.4 |
| Fed | 27.9 | 12.6 | 13.4 | 8.4 | 18.2 | 16.9 | 40.3 | 99.5 | 19.6 | 28.6 |
| FPC | 11.3 | 12.0 | 13.6 | 12.0 | 12.8 | 12.6 | 13.6 | 14.3 | 17.5 | 16.2 |
| Total | 359.3 | 335.6 | 344.0 | 360.5 | 408.5 | 474.0 | 526.0 | 657.8 | 625.2 | 620.9 |

* Estimated. Data source: District program documents, except for 1959 and 1960, which are from WRD Headquarters tabulation.

### *Cooperating Agencies*

The Montana State Engineer was the principal cooperator for the streamflow program through FY 1965. That office was incorporated within the Montana Water Conservation Board, which then became the principal cooperator for stream gaging. The Montana Water Conservation Board had funded streamflow stations at some dams prior to the consolidation of offices.

The Montana Highway Commission supported a crest-stage gage program to collect flood data from small streams during the entire period. The Wyoming State Engineer funded one streamflow-gaging station operated by the Montana District. Beginning in 1964, the Endowment and Research Foundation at Montana State College supported the collection of streamflow data.

The Montana Bureau of Mines and Geology (MBM&G) was the principal cooperator for the ground-water program throughout the period. The program included major areal ground-water studies at selected sites throughout the State and the measurement of water levels in observation wells in a statewide program.

Sediment discharges were measured at selected sites in Montana through a cooperative program with the State Game and Fish Department, but the work was handled by the QWB District office in Worland, Wyo.

### *Other Federal Agencies*

The BOR, through the Missouri River Basin program, funded many streamflow-gaging stations, several ground-water studies, and the collection of quality-of-water and sediment data in eastern Montana throughout the period. The Department of State, under the Waterways Treaty Program, supported streamflow-gaging stations and the collection of other data used for division of boundary waters between Canada and the United States for the entire period.

The U.S. Army Corps of Engineers, Omaha District, funded several streamflow-gaging stations and some snow-survey stations that were needed for operation of reservoirs in the Missouri River Basin for the entire period. The Bonneville Power Administration (BPA) supported a streamflow-gaging station and measurement of observation wells through FY 1966.

Beginning in April 1958 and continuing until March 1966, the BPA funded a study exploring the relation of ground water to surface water in four river basins. During FY 1964–67, the BPA funded a study of ground-water inflow to Hungry Horse Reservoir in western Montana. Data collected by the Montana District staff for both studies were analyzed by M. Irving Rorabaugh and Wilbur D. Simons from other offices of WRD. The results of the reservoir study showed significant bank storage which became available for power generation at lower reservoir levels and thus became an important factor in BPA's reservoir operations.

At various times during the period, the Forest Service, Bureau of Indian Affairs, National Park Service, General Services Administration, Public Health Service, and Air Force funded requests for information on the availability of ground water and for streamflow and quality-of-water information at specific locations.

### Summary of Program

Collecting, processing, and publishing surface-water data were the largest parts of the District program during the period. The greatest increase in District programs was in surface-water data collection. The number of continuous-record streamflow-gaging stations increased, but the increase was largest in special investigations such as the crest-stage gage program, floods, and indirect measurements of peak discharges.

After a 30-percent increase during the first 3 years, the ground-water program remained fairly constant. As one study of the geology and ground-water resources of a specific area was completed, another was started. A few of the projects included evaluation of surface-water resources in the area of study. These interpretive studies varied widely in complexity and length of study.

The program for determining chemical quality of water, fairly small and relatively constant throughout the period, focused primarily on collecting water samples for analysis in the Lincoln, Worland, or Portland laboratories. The program for determining the sediment load in streams increased steadily from about $19,000 in FY 1958 to about $54,000 in FY 1965 and FY 1966. Most of the program was to determine the sediment load in streams in three areas of the State. Several streams in other widely separated areas were sampled 1 to 13 times during the period.

### *Water Records*

Information for the following data activities was obtained from annual District reports to cooperators, summary of program analysis, a report summarizing water-resources investigations in Montana (1962), and other open-filed or published reports.

Streamflow Records.—The number of continuous-record stations operated during the period varied from 194 in FY 1958 to 229 in FY 1963 and 1966. The number of the primary (long-term hydrologic) and secondary (short-term hydrologic) stations remained fairly constant at about 90 and 23, respectively. The water-management (specific-purpose) stations increased from about 80 in FY 1958 to about 115 in FY 1963.

The original network of 45 crest-stage gages was expanded to 155 gages in 1959 and to 215 gages in 1962. A report on the 1961 flood on the Kootenai River near Libby, Mont., was included by Rostvedt in WSP 1810 (1965). The floods of 1964 in northwestern Montana were documented by Boner and Stermitz in WSP 1840–B (1967).

Ground-Water Records.—The systematic collection of data on ground-water levels in Montana began under a Federal program to develop a nationwide observation-well network in 1947. Data collection continued under that program until 1964, when the State of Montana, through the State Engineer's Office, provided funds to expand the network. In 1965, the observation-well network was incorporated into the cooperative program with the Montana Bureau of Mines and Geology. Since 1956, the records of water levels in Montana collected for the Federal program have been published in Water-Supply Papers. Bulletin 57 (MBM&G, 1967) contained measurements of water levels from 1961 through 1966.

In addition to the statewide network of observation wells, project observation wells were established in connection with each of the areal studies of geology and water resources. Water levels periodically measured in those wells were published in project reports or in data reports for the project. The data reports were published as MBM&G Bulletins. The project reports were published by the Survey or by the State.

Water-Quality Records.—At various times during the period, one or more samples were collected for chemical analysis at 102 streamflow stations and at 37 wells other than those wells sampled in connection with ground-water projects. Special emphasis was given to determining suspended-sediment load in three areas: (1) Little Prickly Pear Creek upstream from Sieben Ranch to Wolf Creek, (2) Butcher Creek from near Luther to near Fishtail, and (3) Blue Water Creek from near Bridger to Fromberg. Observations of stream temperatures were made at approximately monthly intervals at most streamflow stations. "Temperature of surface water in Montana," by Fern C. Aagaard was published by the Montana Fish and Game Department (1969).

#### *Special Studies*

Among the special studies in progress or completed during this period was that of the geology and of the surface- and ground-water resources of a 300-square-mile area of the Bitterroot Valley in southwestern Montana by McMurtrey and others (MBM&G Info. Circ. 116, 1956, and Bull. 9, 1959, and WSP 1889, 1972).

Also, the geology and ground-water resources of the Lower Bighorn Valley were investigated by Hamilton and Paulson (WSP 1876, 1968); of the Deer Lodge Valley by Konizeski, McMurtrey, and Brietkrietz (MBM&G Bull. 21, 1961 and Bull. 31, 1962, and WSP 1862, 1968); of northern Blaine County by E.A. Zimmerman (MBM&G Bull. 19, 1960); of the southern Judith basin by E.A. Zimmerman (MBM&G Bull. 32, 1962); of the western and southern parts of the Judith basin by E.A. Zimmerman (MBM&G Bull. 50–A, 1966 and Bull. 50–B, 1966); and of the Missoula basin by McMurtrey, Konizeski, and Brietkrietz (MBM&G Bull. 37, 1964 and Bull. 47, 1965).

The geology and hydrology of the Fort Belknap Indian Reservation were reported on by Alverson (WSP 1576–F, 1965); the geology and water resources of the Bluewater Springs area in Carbon County were investigated by E.A. Zimmerman (WSP 1779–J, 1964); and Taylor reported on the ground-water resources along the Cedar Creek anticline in eastern Montana (MBM&G Memoir 40, 1965) and of the northern Powder River Valley in southeastern Montana (MBM&G Bull. 66, 1968).

The availability of ground water from alluvium along the Missouri River in northeastern Montana was investigated by Hopkins and Tilstra (HA–224, 1966) and a report on the water resources of the Cut Bank area in Glacier and Toole Counties was written by E.A. Zimmerman (MBM&G Bull. 60, 1967).

Many special site studies for other Federal agencies were made during the period. Several water-availability studies were made for U.S. Customs Service stations along the Montana-Canada border. Administrative or open-file reports were made for these site investigations.

Open-file and administrative reports written for studies made under the Missouri River Basin program included a report on the geology and ground-water resources of the Two Medicine Irrigation unit and adjacent areas of the Blackfeet Indian Reservation (Paulson and T.V. Zimmerman, Open-File Report 65–117); a report on the drainage and domestic water-supply investigations in the Milk River unit in Blaine County (Hopkins and Taylor, Open-File Report 63–50); and a report on a reconnaissance of the geology and ground-water hydrology of lands above Two Leggin Canal, Hardin unit (Swenson and T.V. Zimmerman, Open-File Report 58–101).

In August 1959, an earthquake with its epicenter near Yellowstone National Park caused a landslide that dammed the Madison River and impounded about 85,000 acre-feet of water before the flow reached an improvised spillway. District personnel participated in a study of the hydrologic effects of the quake in and around the park, measured flow in, and made degradation studies of the spillway. (See Part VIII, "Floods, Droughts, and Other Hydrologic Events.")

## Nebraska

*By* Lester R. Petri with assistance from *and* reviews *by* Emil W. Beckman, Ray Bentall, *and* Charles F. Keech

### Prologue

Opening of the 1957 to 1966 period followed closely a substantial reorganization of the WRD in Nebraska. By 1957, the Regional GWB Office had been abolished and the Regional Engineer, George H. Taylor, was named "Operations Research Engineer." He and one secretary remained in Lincoln and became a field unit attached to the Office of the Chief, GWB. Ray Bentall, Taylor's principal assistant, and Guila C. Darling staffed a field unit attached to the headquarters GWB Reports Section.

Also, by May 1957, the Regional QWB Office had been redesignated a District office and the Regional Engineer, Paul C. Benedict, had been transferred to Headquarters to head the Research Section, QWB. Don M. Culbertson had been named District Engineer of the redesignated office. Nearly concurrent with Benedict's departure was the resignation of his assistant, Robert F. Kreiss, followed a year later by the transfer to Denver of Irene Paulsen, the office secretary.

In February 1957, Douglas D. Lewis, SWB District Engineer since 1942, became District Engineer in

Arizona. Nearly concurrently, three senior members of his staff also transferred: Lawton W. Furness to the Kansas District, Ivan L. Burmeister to the Iowa District, and a year later, Gilbert W. Caughran to an overseas assignment.

Thus, at the opening of the 1957–66 period, three District offices were in place, one for each operating Branch, with a common Administrative Services Section. The several field units, not incorporated into the District structure, remained in Lincoln but were attached to other offices of WRD.

## Organization and Personnel

Until 1965, each of the three Branches functioned independently but coordinated programs through the Nebraska WRD Council. Added coordination was attained by sharing a common Administrative Service Sections and generally contiguous office space. Administrative responsibility for all activities of the District was consolidated in May 1965 with the arrival of the first District Chief.

All WRD offices in Lincoln, were housed in the Rudge-Guenzel building in downtown Lincoln until February 1961, when those of the GWB and SWB and of the Administrative Services Section moved into remodeled space allotted to the Conservation and Survey Division (C&SD), University of Nebraska, in the "new" Nebraska Hall. Because satisfactory space was not available in Nebraska Hall to house the QWB laboratories, those laboratories and the QWB staff, except the District Engineer and one secretary, remained in the Rudge-Guenzel Building until February 1965, when a new building designed to house both the offices and laboratories of the QWB was completed on North Cotner Boulevard.

Throughout the 1957–66 period, the Administrative Services Section provided support services, first to the Branches and later to the consolidated District. James R. McLaughlin was Chief of this Section until he transferred to the Texas District in 1965. Following dissolution of the Regional Offices in 1957, the staff of this Section was reduced from six to three. Lucile M. Stephens, who succeeded McLaughlin, and Agnes M. Watson remained throughout the period, providing both stability and competence to the Section.

### *Surface Water Branch*

Floyd F. LeFever followed Lewis as District Engineer and remained in that position until 1965. Herman D. Brice replaced Caughran as Assistant District Engineer and David B. Anderson replaced Burmeister as principal records reviewer. Emil W. Beckman, already involved in special studies, assumed most of the duties left by the departure of Furness.

A Hydrologic Studies Section was established in 1961 with Beckman as Engineer-in-Charge, remaining so throughout the period. Norman E. Hutchinson assisted Beckman until he transferred to National Headquarters in 1962. He was replaced by F. Butler Shaffer.

The District maintained five Subdistrict offices during the period, but no more than four at any time.

The Lincoln Subdistrict.—(operating area: Blue, Nemaha, Elkhorn, and Lower Platte River Basins) was established as an entity separate from the District office in 1961, when Ernest S. Dennison was placed in charge. Dennison was reassigned to the District Office in 1962 and Jack A. Anderson was placed in charge of the Subdistrict.

The Bridgeport Subdistrict.—(operating area: White and the North, South, and Middle Platte River Basins) was assigned only one man to provide technical direction and assistance to cooperator personnel to ensure conformance with USGS standards in records collection and preparation for publication. Gordon G. Jamison served from 1957 to 1959, followed by Lynn L. Hull from 1960 to 1964, and by Keith G. Polinoski in 1966.

The Cambridge Subdistrict.—(operating area: Republican River Basin) was supervised by Verrie F. Pearce from 1957 to 1963. He was succeeded by Clarence R. Liggett, who along with Mary Marjorie Gilbert and Loyd K. Thompson, served in the Subdistrict the entire 1957–66 period. Eugene K. Steele, who transferred from Ainsworth, served 4 years in the Subdistrict before transferring to Lincoln in about 1962.

The Grand Island Subdistrict.—(operating area: Loup and part of Middle Platte River Basins) was under the supervision of Alvin F. Pendleton, Jr., until the office was closed in 1959. Pendleton, Donald T. Hartley, and Donald J. Pangborn then transferred out of the District. Polinoski transferred to Ord and Maynard Kubicek to Lincoln.

The Ord Subdistrict.—(operating area: Loup, Niobrara, and part of Middle Platte River Basins), created in 1959, was under the supervision of Gordon G. Jamison from its inception through 1966. This office assumed responsibility for nearly all gaging stations formerly within the Grand Island Subdistrict. With reassignment of Kenneth H. Calver and John R. Wanger to Ord, the Subdistrict also assumed responsibility for most of the Niobrara River Basin.

### *Ground Water Branch*

The GWB District was directed by Charles F. Keech, District Engineer, from 1957 to 1965. His staff consisted of geologists James A. Hyland (1959–62) and Philip A. Emery (1963–66), engineering aid James W. Nelson (1957–66), and secretaries Fern A. Adams (1958–62) and Mildred M. Malhoit (1963–66), supplemented by summertime field assistants. Though small, the staff produced, with cooperator assistance, an average of one comprehensive report per year in addition to regular basic-data reports.

### *Quality of Water Branch*

Don M. Culbertson directed the District from 1957 to 1965, when he transferred to the Office of the Area Hydrologist, PCA. Russell H. Langford was his assistant until he transferred to the Director's Office in 1959. Thereafter, Lester R. Petri was Culbertson's principal advisor on matters relating to chemistry, and James C. Mundorff on matters relating to sediment transport.

Prior to 1957, the Regional QWB Office maintained area offices in Lincoln, Nebr., Norton, Kans., St. Louis, Mo., Rapid City, S. Dak., and in Riverton and Worland, Wyo., and had a chemistry laboratory in Lincoln and sediment laboratories in Lincoln, Norton, and Worland. Also, general oversight was provided for area offices in Fort Collins, Colo., and Minneapolis, Minn., where sediment-transport research was done. Upon reorganization, the Fort Collins and Minneapolis offices were placed under the direction of their Branch Area Chiefs, and the Area offices outside Nebraska were renamed field headquarters of the Nebraska District.

By 1958, responsibility for water-quality work in Wyoming and Montana was assumed by the Worland office, under the direction of Thomas F. Hanly, and the work in northeastern Colorado, by the Utah District. By 1959, the field headquarters in Norton, Kans., under the direction of Melvin L. Thompson, was discontinued and another established in Salina, Kans., under the direction of Calvin D. Albert. By 1960, the only field headquarters remaining were in St. Louis and Salina. However, with development of a new major cooperative program in Kansas in 1962, a new field headquarters was established in Topeka under the direction of Arthur M. Diaz. By 1964, the Nebraska QWB district had divested itself entirely of responsibility for activities in other States, retaining only the responsibility of providing laboratory services to other States as requested.

The newly designated QWB District office was organized into four sections, much as the former Regional office had been organized. The Sediment Section, including the Sediment Laboratory in Lincoln, was supervised by Mundorff from 1957 to 1964, when he transferred to the Utah District. He was succeeded by Howard D. Stevens, who in 1966 became supervisor of the Ord Subdistrict. The Chemical Quality Section was supervised by Langford until 1959 and thereafter by Petri. The Chemistry Laboratory was directed by Bruno V. Salotto from 1957 to mid-1960 and by Sanford C. Downs through 1966. The Data Processing Section, under the direction of Esther M. Gushard throughout the 1957–66 period, prepared data for publication and typed and edited water-quality reports. Leona G. Loerch and Audrey T. Flick served in the Section throughout this period. The Reports and Special Studies Section was under the direction of Sumner G. Heidel until he transferred to Washington in 1957. Supervision passed to Langford and, in 1959, to Mundorff, with whom it remained until 1964. Among the few District staff assigned to this Section were Kenneth J. Braun (draftsman for the entire period), Annie L. Collins, Charles H. Hembree, Blair F. Jones, Paul R. Jordan, Marion L. Maderak, Hugh T. Mitten, John D. Prien, and Cloyd H. Scott. Members of other Sections were assigned as needed.

In 1959, David W. Hubbell, who had been attached to the Branch Area Chief, RMA, moved to the Fort Collins field unit to continue research on the movement of dunes along sandbed streams. In about 1960, Bruce R. Colby, also attached to the Branch Area Chief, RMA, returned to Nebraska to resume research until he retired in 1963.

### *Consolidated District*

Consolidation of the Branches into a Division District began in May 1965 with the arrival from Florida of Kenneth A. McKichan as District Chief. Keech, LeFever, and Petri continued to direct activities involving their specialties until plans for integrating personnel and activities were formed. The District then was reorganized into a Special Investigations Section, under Keech, to conduct and report on special studies; a Basic-Records Section, under Petri, to obtain and compute records of a continuing or repetitive nature, enter them into computer storage, and prepare them for publication; a Data Processing Section, under Esther Gushard, to enter data into computer storage and assist with their preparation for publication; and a Laboratory Section, under Downs, to analyze chemical and sediment samples for the District and for other Districts as requested.

Functions of the Subdistrict offices remained unchanged except that most personnel learned other-discipline field techniques. LeFever was assigned to research, reporting directly to the Area Hydrologist, RMA; Brice became an assistant to the District Chief; and Bentall became District Reports Specialist.

Those not adequately credited elsewhere and who served in the District 5 years or more and contributed significantly to District programs during the 1957–66 period include Lloyd C. Blackburn, Marylu Olson Cords, Russel E. Curtis, Josephine M. Eyen, Neal R. Harmon, Carol Green Hoy, Lynn L. Hull, Jean E. McKinney, Bruce H. Ringen, Phillip G. Rosene, Arlene P. Summers, John R. Wagner, and Alice E. Woitalewicz.

## Funding

Sources and amounts of funds for water-resources investigations in Nebraska are given in the tables that follow. On average, 49 percent of the total funds per year was for Federal-State cooperative programs (Coop), 44 percent for programs financed by other Federal agencies (OFA), and 7 percent for Federal programs (Fed). Funding figures do not include amounts for work for other Districts performed by Nebraska QWB District personnel or reimbursements for laboratory services for other Districts, nor do they include funds for work done by personnel attached to the Area Hydrologist, RMA, or to National Headquarters.

Nebraska District funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 185.0 | 195.0 | 197.0 | 223.5 | 244.5 | 248.8 | 283.7 | 300.0 | 300.2 |
| OFA | 170.3 | 154.6 | 213.4 | 230.0 | 195.5 | 214.8 | 251.3 | 239.5 | 270.2 |
| Fed | 32.0 | 26.5 | 30.5 | 30.7 | 30.2 | 42.0 | 36.1 | 33.4 | 37.0 |
| Total | 387.3 | 376.1 | 440.9 | 484.2 | 470.2 | 505.6 | 571.1 | 572.9 | 607.4 |

Note: Figures for Fed programs are net; all others are gross. Source: District program documents; 1959–61 partially estimated.

Of the sources of funds, Coop funds were the most stable, mostly because major projects in these programs were continuing ones of long standing with firm, local support. OFA funds fluctuated from year to year because much of the work requested by other Federal agencies was for planning purposes or special studies and was curtailed, or redirected, as the construction projects or special studies were completed by those agencies.

As is evident in the next table, SWB funding far exceeded that for the other Branches. If funding for work of the other Branches on behalf of other States were included, the percentages in the table would be substantially different. Both the SWB and GWB depended heavily on Coöp funding; the QWB depended heavily on OFA funding, having only small Coop programs in Nebraska.

| Fund source | Average yearly percentage | | |
|---|---|---|---|
| | SWB | GWB | QWB |
| Coop | 70 | 30 | <1 |
| OFA | 61 | 8 | 31 |
| Fed | 77 | 4 | 19 |

## Cooperating Agencies

The principal cooperating agencies during the 1957–66 period were the Conservation and Survey Division (C&SD), University of Nebraska, with the GWB, and the Nebraska Department of Water Resources (DWR), and the Nebraska Department of Roads, with the SWB. Other cooperating agencies were the Nebraska Midstate Reclamation District and the Lancaster County Sanitary District No. 1.

The program with the C&SD supported the statewide test-hole drilling project, the water-level monitoring project, and county ground-water studies. The program with the DWR was mainly for stream gaging, statewide. The program with the Department of Roads was largely to obtain flood information applicable to drainage-structure design. The program with the Midstate Reclamation District, the local sponsor of a proposed irrigation project, supported collection of streamflow and water-quality records on the Platte River. Work was discontinued in 1965 as local support for the proposed project eroded.

## Other Federal Agencies

Other Federal agencies for which significant amounts of work were done during the 1957–66 period were the BOR, the Fish and Wildlife Service, the Omaha and Kansas City Districts of the U.S. Army Corps of Engineers, and the SCS.

Work for the BOR and the Fish and Wildlife Service was under the Missouri River Basin program. Work for the Corps of Engineers involved operating gaging stations for the timely reporting of flood stages and discharges to Corps offices. The District assisted the SCS in their study of the trap efficiency of small reservoirs by measuring water and sediment inflow to and outflow from two small reservoirs in Brownell Creek subwatershed. Additional work involved stream gaging in Upper Salt Creek Basin, but for 1 year only.

## Summary of Activities

### Statewide Stream Gaging

The number of recording stream-gaging stations in operation during the 1957–66 period ranged from 153 to 166 of which, in 1963, 74 were "primary," 22 were "secondary," and 65 were "water-management" stations. The cooperative program supported 74 stations, 66 were OFA stations, and 21 were funded by Federal program funds.

Beginning in 1959, data for the period of record for selected stations were punched on tape and processed in Washington to provide statistics on low flows, durations of flow, and flood flows. By 1963, records for about 50 stations, aggregating about 750 station years, had been processed. This effort, continuing through 1966, made such statistics available for the first time for a significant part of the large accumulation of streamflow data in Nebraska.

### Special Surface-Water Studies

Crest-stage stations were operated throughout the 1957–66 period at about 110 sites on drainage areas ranging from less than 1 to about 100 square miles. The first stage and rainfall (SR) recorders were installed in 1965. Data from the crest-stage stations, augmented by data from several recording gaging stations operated on small streams in the regular stream-gaging program, provided the basis for a report by Beckman and Hutchinson on floods on small streams (Circ. 458, 1962).

Preparation of both "bridge-site" and "verification" reports continued in cooperation with the Department of Roads. Bridge-site reports, through hydrologic and channel-hydraulic analysis, indicated the probable effects of a proposed bridge structure and highway fill on flow conditions during design floods of specified recurrence intervals. Verification reports, prepared after significant flood events following construction, indicated the agreement, or lack thereof, between conditions anticipated from the bridge-site report and those that actually occurred in order to improve methodology.

### Test-Hole Drilling

In the early decades of this program, test holes were drilled mainly to obtain data needed to locate water supplies for cities. Areas for which such data became available were small. By 1957, a planned network of test-hole sites had been designed so that eventually data would be obtained systematically for the entire State. Data obtained through this project proved invaluable in later decades in providing a data base for analog and digital modeling of ground-water systems.

### Water-Level Monitoring

Depth to water was measured periodically from 900 to 1,200 wells each year during the 1957–66 period. Records of water levels were also obtained from recording gages on 25 to 30 wells in areas where heavy withdrawal of ground water was considered most significant. Records were analyzed each year to identify areas of significant change; results were published in the State's Water-Survey Papers.

### Areal Ground-Water Studies

Reports on five county ground-water studies were published during the 1957–66 period, mostly in cooperation with the C&SD. In addition, eight reports were published on studies of other areas, mostly river basins or parts of river basins.

Philip Emery, with the help of the Division's research scientists in Phoenix, Ariz., pioneered in constructing one of the first electric analog models of a stream-aquifer system. The model demonstrated that there was little connection between the aquifer and the Big Blue River at the Kansas-Nebraska State line, and that any diminishment of flow in the river at the State line caused by large-scale ground-water pumping from the basin in Nebraska was too small to be detected.

### Water Quality

Activities of the QWB in Nebraska during the 1957–66 period involved an average of about 35 full-time persons, of which 25–30 were stationed in Lincoln. The major portion of their work pertained to the water resources of other States and is not described here. The amount of work on water resources of Nebraska was relatively small.

Daily records of the chemical quality of streamflow were obtained for five or six stations, mostly in the National Irrigation Network, and monthly records for 17–26 stations, mostly as part of Missouri River Basin program studies. In addition, about 20 samples per year of ground water, taken by GWB personnel, were analyzed. The Lincoln Chemical Laboratory continued to provide analytical services to other States until the Division's laboratory was established in Salt Lake City, Utah.

In August 1964, the District purchased the first atomic absorption spectrophotometer (Perkin-Elmer, Model 303) to be used in the Division for routine analysis of water samples and developed methods for its use. Use of this type of equipment made possible for the first time at relatively low cost the measurement in water of more than a dozen metals, such as copper, lead, zinc, and molybdenum.

Records of sediment transport by streamflow continued to be obtained at about 20 stream sites during the 1957-66 period, but by 1960, daily sampling had been replaced by periodic sampling at all but one site. Work in the Sediment Laboratory diminished to a one-person work load.

### Reports

Published reports may be the best indicator of the specific activities of the District during the 1957–66 period. (Reports prepared by Nebraska QWB District personnel on water resources of other States are not included here.) Among the special studies by Nebraska District staff that were documented in Survey-published reports was that by Keech on the geology and hydrology of the site of the Hallam Nuclear Power Facility (Bull. 1133–B, 1962). Representative of special studies reported in WSP's was that of the geology and water resources of Clay County, by Keech, V.H. Dreeszen (of the C&SD), and Rainwater (WSP 1468, 1959); of the flow characteristics of the Elkhorn River near Waterloo, by Beckman and Furness (WSP 1498–B, 1962); on methods of determining permeability, transmissibility, and drawdown, compiled by Bentall (WSP 1536–I, 1963); of the ground-water resources of Hamilton County by Keech, with a section on the chemical quality of the water, by Rosene (WSP 1539–N, 1962); and on methods of collecting and interpreting ground-water data, compiled by Bentall (WSP 1544–H, 1963).

Also reported in WSP's were the study by Kister and Mundorff of the sedimentation and chemical quality of water in the Salt Creek Basin (WSP 1669–H, 1963); an investigation of ground-water conditions in the proposed waterfowl refuge area near Chapman by Keech, with a section on the chemical quality of the water by Rosene (WSP 1779–E, 1964); a study of ground water in the Cedar Rapids division of the lower Platte River Basin by Hyland and Keech, with a section on the chemical quality of the water by Rosene (WSP 1779–H, 1964); and Emery's investigation of the geology and ground-water resources of Richardson County (WSP 1779–W, 1964).

Results of the study of the ground-water resources of Mirage Flats by Keech (WSP 1779–BB, 1964); documentation of the floods of March and April, 1960 in eastern Nebraska and adjacent States, by Brice and R.E. West (of the Pierre, S. Dak., SWB office) (WSP 1790–A, 1965); the report on sedimentation in Brownell Creek subwatershed no. 1, Mundorff (WSP 1798-C, 1966); results of the study of the fluvial sediment and chemical quality of water in the Little Blue River Basin in Nebraska and Kansas, by Mundorff and Waddell (WSP 1819–H, 1966); a report on the availability of ground water in York County by Keech, Dreeszen, and Emery (WSP 1839-F, 1967); a study of the geology and ground-water resources of Fillmore County by Keech and Dreeszen, with a section on the chemical quality of the water by Petri (WSP 1839–L, 1968); and the report on water-mineral relations of Quaternary deposits in the lower Platte River drainage area in eastern Nebraska by Barnes and Bentall (1968, WSP 1859–D, 1968) were also published in the WSP series.

A USGS Circular by Mundorff contained the report on sediment discharge during floods in eastern Nebraska (Circ. 470, 1962). Published HA's reported on the availability of ground water in Hall County (Keech and Dreeszen, HA–131, 1964); the flood of August 1966 in the lower Loup River Basin (Shaffer and Braun, HA–188, 1967); the geohydrology of Saline County (Emery, HA–216, 1966); and the floods in the Seward quadrangle, southeastern Nebraska (Shaffer and Braun, HA–258, 1967).

Generally, but not exclusively, ground-water basic data such as those from the statewide test drilling program and from monitoring observation wells were published by the Conservation and Survey Division of the University of Nebraska. Engberg reported on the nitrate hazard in well water, with special reference to Holt County (C&SD Water Survey Paper 21, 1967).

## Nevada

*By* Edwin E. Harris *and* George F. Worts with the help of the Carson City WRD staff *and* with typing assistance from Betty Worts

### Organization and Personnel

The years 1957–66 saw extensive changes in the organization and program of the WRD in Nevada. In 1961, the SWB Subdistrict office of the Utah District became the SWB District office for Nevada. In early 1962, Nevada became the first WRD District in the Nation.

#### *Ground Water Branch (1957–62)*

In 1957 the District office was in the State Office Building on South Fall Street. Omar J. Loeltz, the

District Engineer, was assisted by Philip Cohen, a new employee, Glenn T. Malmberg, who had recently transferred from Las Vegas, and Christe P. Zones. In 1959 the office was moved to a commercial building at 809 North Plaza where the GWB and the SWB were the sole occupants. In 1960, Thomas E. Eakin was transferred from the Foreign Hydrology Section at WRD Headquarters to head the new program of ground-water reconnaissance studies in Nevada. During the 1957–62 period, all Nevada District GWB personnel were headquartered at Carson City. Others assigned to the District office for all or part of the period included Louise E. Davis, Helen C. Johnson, Roger A. Lyman, William C. Sinclair, and Judith Wilson.

In 1959, a project office that reported to national Headquarters was established in Las Vegas to evaluate, with AEC funding, the ground-water system at the Nevada Test Site. Isaac J. Winograd was project chief until 1964 when Richard K. Blankennagel became Geologist-in-Charge. The Las Vegas staff, at various times, also included Alan C. Doyle, Murray S. Garber, Richard H. Johnston, George L. Meyer, Ralph F. Norvitch, Charles E. Price, Jr., Ralph E. Smith, William Thordarson, George E. Walker, James E. Weir, Jr., Lewis R. West, and Richard A. Young. Worts reviewed the project studies to ensure that the work was coordinated with activities of the Nevada District and being done in accordance with the USGS–AEC program requirements.

#### *Surface Water Branch (1959–62)*

Prior to 1961, the Carson City Subdistrict, assisted by staff of the Elko and Boulder City field headquarters, operated gaging stations on streams draining the east slope of the Sierra Nevada and most of the rest of Nevada and prepared the streamflow records for publication. Staff of the Elko field headquarters operated the stations in the northern part of the State, principally in the Humboldt River Basin, and worked closely with the Nevada State Water Master, who also had a field office in Elko. Staff of the field headquarters in Boulder City, Nev., operated the stations in the Lower Colorado River Basin, in southern Utah, in southern Nevada, and in northern Arizona.

Charles H. Carstens was Engineer-in-Charge of the Carson City Subdistrict until August 1959 when he was transferred to Helena, Mont. Leonard J. Snell, who had been in the Philippines, replaced Carstens. Two years later, Snell transferred to the Florida District. In 1961, the Nevada operations were separated from those in Utah and became the Nevada District. In July 1961, Edwin E. Harris was transferred to Carson City from Menlo Park, Calif., to serve as the District Engineer of the new Nevada SWB District.

The reorganization required additional staff for programs in Nevada that had been handled by the Utah and Arizona Districts. Robert D. Lamke was transferred from Santa Fe, N. Mex., as the floods specialist. Ronald L. Hansen from Tacoma, Wash., Lane K. Nalder from Salt Lake City, Utah, and John E. Parks, a new employee, were added to the Carson City staff. Others assigned to Carson City during this period included Ross S. and Donald C. Clendenon, Wilhelmina S. Jensen (the District Clerk for the SWB and GWB Districts), Orvil C. Kamm, and James F. Wilson.

The Elko field headquarters was a one-man operation prior to 1962, staffed by Rulon C. Christensen, who was replaced in 1959 by Lawrence E. Lopp from Page, Ariz.

#### *Quality of Water Branch (1957–62)*

The QWB had neither office nor staff in Nevada during this period. Its District office in Salt Lake City, Utah, assisted the Nevada District programs until 1958, and its District office in Sacramento, Calif., thereafter.

#### *Water Resources Division (1962–66)*

With the designation of Nevada as the first Division-level District in the Nation in the summer of 1962, George F. Worts transferred from the PCA Regional Office in Menlo Park, Calif., to become the new District Hydrologist (later, "District Chief"). Just prior to the reorganization, a commercial office building was built on Washington Street to accommodate several Federal agencies including the SWB and GWB. This assisted in consolidating the clerical staff and aided the transition to a Division District.

During the period 1963–66, there were several personnel changes. Loeltz, who had been in charge of the GWB District, transferred to Yuma, Ariz., to join the staff of the Lower Colorado River project (see Part IV, "Lower Colorado River project"). Harris became Assistant District Chief and supervised the surface-water operations. Donald O. Moore was transferred from the SWB in Arlington, Va., to assist with special surface-water studies. Others who transferred in to join the District staff were Carrol V. Schroer, F. Eugene Rush, Charles J. Huxel, and Duane E. Everett, a water-quality specialist from Baton Rouge, La. Several new employees were hired including James R. Harrill, Hjalmar W. Hjalmarson, Jerry L. Hughes, Virginia R. Jesser, and Pat L. Soule.

During this period, Sinclair was reassigned to Brazil and Malmberg to Pakistan. Cohen was transferred to Mineola, N.Y., and Lopp moved to Salinas, Calif. Lopp was replaced in Elko by Forrest N. Pitts from La Grande, Oreg. Lamke and Hansen completed a year of graduate training at Stanford University under the Government Employees Training Act.

## Funding and Cooperation

The primary sources of funding for the District were the cooperative program (Coop) and other Federal agencies (OFA). Some funding was supplied for soil and moisture conservation (S&MC) studies on Bureau of Land Management lands in Nevada; however, the S&MC program was funded independently of the District.

Exact dollar amounts by source are not available, and only approximate totals are presented in the table below. The total Nevada District funding increased from about $112,000 in FY 1958 to $360,000 in FY 1966. Increases resulted from the formation of the new SWB District in 1962 and the reorganization to a Division District in 1963.

**Nevada District funds, fiscal years 1958–66**
[Funds in thousands of dollars]

| FY | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| | 112 | 130 | 140 | 180 | 253 | 290 | 333 | 347 | 360 |

### *Cooperating Agencies*

The principal cooperator was the Nevada Department of Conservation and Natural Resources (DCNR), which was formed in 1957. Hugh A. Shamberger, who was State Engineer, was elevated to the position of Director of DCNR. (Authors' note: Hugh had been, and continued to be, an old and trusted friend of the Survey, and his cooperation and support of the Coop program is gratefully acknowledged.) After he retired in 1964, he became a part-time member of the WRD staff in Carson City and wrote 10 reports on the water supply of mining districts in Nevada. Elmo De Ricco, Nevada State Engineer, was selected as the new Director and served as the principal cooperating official throughout the remainder of the period. Most of the statewide water-resources activities, the streamflow and ground-water data networks, and areal hydrologic studies were supported by the cooperative program with DCNR.

The Truckee-Carson Irrigation District and Walker River Irrigation District supported some of the gaging stations in the Carson, Truckee, and Walker River Basins as required by their water-management operations and by the California-Nevada Compact for these interstate streams.

The Nevada State Highway Department supported a statewide network of crest-stage gages, flood-frequency studies, and the preparation of reports on flood characteristics at specific stream sites beginning in 1962.

The Clark County Flood Control District supported a network of streamflow stations, crest-stage stations, and precipitation gages to evaluate flood characteristics on streams in the rapidly developing Las Vegas Valley.

The Carson-Truckee Water Conservancy District provided funding in the Coop program for measuring surface-water inflow and outflow to Truckee Meadows, which includes the cities of Reno and Sparks.

### *Other Federal Agencies*

The Sacramento and Los Angeles Districts of the U.S. Army Corps of Engineers funded several gaging stations and precipitation gages in the Carson and Truckee River Basins and in southeastern Nevada. The BOR supported several streamflow and reservoir stations for its irrigation projects. The Carson River project of BOR, including Lahontan Reservoir and the Truckee-Carson diversion canal, was one of the oldest reclamation projects in the West. The SCS funded a streamflow station and a reservoir gage for its sediment trap-efficiency study on Peavine Creek at Reno.

## Summary of Program, 1957–66

### *General Outline*

Prior to 1960, the Nevada District program included three general categories of work: (1) The continuing water-resources inventory, or basic-records program; (2) general quantitative areal ground-water studies of the developing basins of the State, and (3) the Humboldt River research project. In 1960, Hugh Shamberger, Director, DCNR, requested that a program be established to obtain more rapidly the quantitative information needed for the 232 hydrographic areas of Nevada. Thomas Eakin was then assigned to the Nevada District to resume the preliminary-type studies that had been done in the early 1940's (see Nevada Water Resources Bulletin 12) and to outline a more detailed program for the future. The concept developed was a proposed 10-year cooperative program which was partly initiated in 1960 and more fully implemented in 1962. (See Nevada Water Resources Information Series, Report 4.) The program included seven categories: (1) The continuing water-resources inventory, or basic-records program; (2) reconnaissance studies; (3) quantitative areal studies; (4) comprehensive studies; (5) specific-problem studies; (6) topical reports—generally statewide or regional in scope, dealing with selected aspects of hydrology; and (7) research.

### Water Records

Streamflow Records.—A total of 108 continuous-record stations were being operated in the FY 1966 compared to about 80 stations in 1958. The 108 continuous-record stations were classified as: 28, primary; 24, secondary; 45, water-management; and 11, reservoir and lake. There were 12 low-flow partial-record stations and 88 crest-stage stations in 1966. Seven stations were equipped with precipitation gages. As of June 1966 about 45 percent of the stations had been equipped with the new digital recorders.

Major flooding that occurred in the Humboldt River Basin in February 1962 was reported by Thomas and Lamke (Circ. 467, 1962). The winter flood of 1963 that damaged large areas in central California and western Nevada was reported by Loren E. Young, of the California District, and Harris (WSP 1830–B, 1968).

Ground-Water Records.—As of June 1966 the District reported 242 observation wells, 210 of which were measured annually; five were equipped with recording gages. The remainder of the wells were measured monthly or quarterly. In addition, many wells were measured periodically in connection with studies in progress, a few of which were selected as additions to the continuing observation-well program.

Water-Quality Records.—During the years 1957-66, periodic water-quality data were collected at eight stations along six major streams. Four gaging stations were equipped with water-temperature recorders. There was no periodic sampling of network wells or lakes. Samples taken for chemical analysis were those related to the ground-water studies or to the Humboldt River research project, and the results were published in the respective reports.

### Reconnaissance Studies

Because of the near-complete lack of hydrologic data in more than half of the valleys in the State, legislation was enacted in 1960 to provide for reconnaissances studies of ground-water basins in Nevada. The studies, under the cooperative program with the DCNR, were to provide ground-water information to the public and to assist the State Engineer in the administration of ground-water law by making preliminary estimates of the average annual recharge to, discharge from, ground water in storage, and perennial yield of the valleys and basins. As the work progressed, the average annual streamflow, estimated mostly by Moore using the "channel geometry" method, were included in the reports. About 4 months were required to complete each reconnaissance study and report.

By 1966, about 40 reports, prepared by Cohen, Eakin, Everett, Glancy, Malmberg, Rush, Sinclair, and Worts, and covering 58 valleys were published by the DCNR in the "Water Resources—Reconnaissance Series." (See Bibliography of Selected Water-Resources Publications on Nevada by the U.S. Geological Survey, 1885 through 1994, open-file rept. 94–53.)

The preliminary reconnaissance studies were first-stage hydrologic investigations that summarized the general conditions prior to major ground-water development. Though crude, the studies provided the basic framework for the more detailed second and third-stage hydrologic studies undertaken after substantial water-resources development in the basins.

### General Areal Studies

After development in a basin became substantial, overdraft problems commonly arose that required more detailed, or second-stage, studies. By 1962, overdraft had occurred in the Las Vegas, Pahrump, Quinn River, Kings River, and Diamond Valleys and quantitative areal studies, each taking 2–3 years to complete, were made in these valleys. Quantitative areal studies were later made for the Amargosa-Ash Meadows area, Winnemucca Lake Valley, Crescent Valley, and the Fernley-Wadsworth area. Reports on these studies, prepared by Cohen, Eakin, Harrill, Huxel, Loeltz, Malmberg, F.N. Visher, and Zones were published as WSP's or Nevada Water-Resources Bulletins. (See Bibliography, referenced above.)

### Comprehensive Studies

After water-resources development in a basin had been substantial for a number of years, a third-stage comprehensive evaluation of the flow system was anticipated to answer specific problems beyond the scope of the first- and second-stage studies, although it was not anticipated that such studies would be needed until about 1969.

### Specific-Problem Studies

Because water problems arose in developed areas during the course of other studies, provision was allowed in the 10-year plan to accommodate these studies. During the period 1960–66, the water chemistry in the Truckee Meadows was studied by Cohen and Loeltz (DCNR Water Resources Bull. 28, 1964); the surface-water resources of Nevada were inventoried by Lamke and Moore (DCNR Water Resources Bull. 30, 1965); and the regional interbasin ground-water flow in the White River Valley area of southeastern Nevada was investigated by Eakin and Lamke (DCNR Water Resources Bull. 32, 1966).

#### *Topical Reports*

Topical reports were prepared on the ground-water situation in Nevada by Loeltz and Malmberg (DCNR Water Resources Info. Ser. 1, 1961); on land subsidence in Las Vegas by Malmberg (DCNR Water Resources Info. Ser. 5, 1964); and on estimated water use in Nevada in 1965 by Harrill and Worts (DCNR Water Resources Info. Ser. 7, 1968).

#### *Research*

To plan for optimum development of the water resources in the Humboldt River Basin, one of the chief agricultural areas in Nevada, the Nevada DCNR initiated the Humboldt River Research Project. The project, under the direction of Philip Cohen, project chief, included studies of (1) seasonal and long-term changes of ground water in storage, (2) the relation between the Humboldt River and the ground-water reservoir, (3) ground-water underflow into and out of the project area, and (4) the chemical quality of the waters of the area. Thomas W. Robinson from the Menlo Park office operated several phreatophyte tanks (locally known as "Tommy's flower pots") near Winnemucca in connection with the project (see Part IV, "Phreatophytes"). Several students from the University of Nevada-Reno Geology Department worked on the geology of the Humboldt River Basin under the direction of George B. Maxey of the University.

Results of this study, reported mostly by Cohen, were published in four PP's, four WSP's, three Nevada Water Resources Bulletins, two Nevada Water Resources Information Series, and two journal articles. (See Bibliography, referenced above.)

A method for estimating the flow of ungaged streams, developed by Walter B. Langbein using channel geometry as the key parameter, was refined for application in Nevada by Moore (DCNR Water Resources Bull. 36, 1968). The method was later utilized by Moore to estimate runoff in intermittent streams in Saudi Arabia.

The relation of fluoride content to recharge and movement of ground water in Oasis Valley was studied by Malmberg and Eakin (PP 475–D, 1964).

#### *Other District Activities*

The reconnaissance studies, described previously, generated much interest in nearby States, particularly in Utah where ground water occurs similarly in the Basin and Range region. To assist the Utah District in starting such studies, Rush collaborated with James W. Hood, Utah District, on a reconnaissance study of the Snake Valley area along the common border (DCNR Recon. Series Rept. 34, 1965). Previously, Rush had coauthored a report (DCNR Recon. Series Rept. 33, 1965) with S.A.T. Kazmi, Pakistani Geological Survey, who planned to undertake similar studies on his return to Pakistan. Shortly thereafter, Malmberg was detailed to Pakistan to assist in those studies.

In 1964, Worts was a member of a panel of international senior consultants that reviewed Israel's comprehensive "Underground Water Storage Study."

Since 1946, the DCNR had sponsored the Nevada Water Conference, which was attended and participated in by agencies in the fields of water and related land resources. During the period 1957–66, the annual conferences, attended principally by State agencies and WRD personnel from Nevada, were generally held for the purpose of presenting progress reports of each agency and a few technical reports on water and related activities.

## New Hampshire

*By* Charles E. Hale with assistance from Edward Bradley, John E. Cotton, O. Milton Hackett, members of the State of New Hampshire's Water Resources Division who provided the word processing for this report, *and* reviewers James M. *and* Beanie Weigle

The WRD programs in New Hampshire were administered and operated by the SWB and the GWB from their Boston District headquarters until February 1965, when the Boston District and its New Hampshire operations were reorganized as a Division-level District with Charles E. Knox as District Chief. Reorganization, coming late in this period of history, made little impact on the substantive work of the New Hampshire staff. Therefore, this account of the New Hampshire program and staff is by Branches for the entire period.

When the Boston District was reorganized in 1965, the SWB and GWB operations and staff in New Hampshire were integrated with Charles E. Hale of the Concord office as Engineer-in-Charge of New Hampshire WRD operations.

### *Surface Water Branch*

In 1957, 48 stream-gaging stations were in operation in New Hampshire. The New Hampshire Water Resources Board (WRB) cooperated in financing 32 stations, most of which were water-management stations. The U.S. Army Corps of Engineers supported 10 stations as part of its flood-control program. Six stations were financed by Federal funds as benchmark and long-term hydrologic stations. Reservoir-stage records were collected at 14 locations, mostly partial record, for water management with cooperative funds from the WRB. Snow depth and water content were measured biweekly on six snow courses during the winter to help forecast spring runoff.

Until 1962, when a field headquarters was opened in Concord, N.H., the New Hampshire gaging stations were operated from the Boston, Mass., SWB District office. Four stream-gaging stations along the New Hampshire-Maine border were maintained by personnel from the Maine District office with funds from the New Hampshire cooperative program. One station on the New Hampshire-Canada border, was operated cooperatively with Canada.

Charles E. Knox was District Engineer, then District Chief, during this period. He divided the New Hampshire operations into three areas, each containing about 20 gaging stations, with more or less flexible boundaries, depending upon the operating difficulties. One person was assigned the responsibility for operating and maintaining the gaging stations in each area. A field man would spend about a week to 10 days in the field every 5 weeks maintaining and servicing his stations. Except for the winter period, when assistance was needed with ice measurements, the field men worked alone. Per diem and pay were low, while expenses were high, and as a result many of the field men camped out most of the year. Flood-control dams and State-owned gate houses provided excellent motels.

When not in the field, the men worked in the Boston office under the supervision of Gardner K. Wood, Office Engineer, preparing the gaging-station data for publication in the annual reports.

The Boston District participated in a "College Co-op Program," a 5-year program in which students attended college for a semester then worked for the District for a semester. These students were excellent office and field workers. Many remained with the District after graduation, some as full-time members of the office staff, while others were assigned to the field.

Among the engineers and technicians during the period 1957–66 were Frank E. Blackey, later Chief, Hydrologic Data Section in the Concord office; Richard A. Brackley, noted for skidding off the roads in New Hampshire on his winter trips; Donald J. Farrell, who, after he retired, hiked the entire Appalachian Trail from Georgia to Maine in one season; Jerry French, who left the Survey and became Chief Meteorologist at the Portland, Maine, Weather Station; Russell A. Gadoury, currently (1989) Chief, Hydrologic Data Section, Boston District; William B. Gannon, who became Assistant District Chief in Albany, N.Y; Frederick B. Gay and S. William Wandle, both currently (1989) in the Hydrologic Studies Section, Boston District; James D. Linney, retired to Laconia, N.H.; Myron N. Lys now (1989) with the Maryland District; George Miller, retired, who kept the neatest field truck in the Boston District; and Benedetto Rizzo, who left the Survey for the U.S. Fish and Wildlife Service. And there were John V. Bagley, noted for rolling over the District's only concrete mixer while moving from one job to another, and John W. Taylor, known for keeping the neatest gaging stations in New Hampshire, both of whom have passed away.

In 1962, a Subdistrict office was opened in Concord. Hale and Blackey were assigned to New Hampshire on a permanent basis. The office was on the top floor of the city-owned administration building at the Concord airport. The Concord office provided a close working relationship with the New Hampshire Water Resources Board, the principal cooperator. Field and office work was under the supervision of the Boston District office, where streamflow records were prepared for publication.

Between 1962 and 1966, nine gaging stations were added to the New Hampshire program. All were on watersheds of less than 10 square miles, providing information needed for highway-bridge and farm-pond design. The Boston District continued to provide assistance to the Subdistrict in operating and maintaining the gaging stations.

### *Ground Water Branch*

The cooperative ground-water program in New Hampshire began in 1953, initially under the supervision of Joseph E. Upson, II, headquartered in Mineola, N.Y. Its first priority was to investigate the ground-water resources of southeastern New Hampshire. Edward Bradley was reassigned from Wyoming to a field headquarters in Durham, N.H., to conduct the study. In 1956, the New Hampshire program was placed within the newly formed Boston District under the supervision of O. Milton Hackett, District Geologist. Bradley completed his project in late 1957 and transferred to Iraq in 1958.

Bradley's report, part of which was released to the open file in 1955 in order to satisfy the need to make the information available, was published in 1964 (WSP 1695). Bradley's memorandum on the hydrology of the Johnson Creek area was open-filed in 1957 and his preliminary report on part of the study area was open-filed in 1965. The report by Meyers and Bradley on suburban and rural water supplies in southeastern New Hampshire was published by the State Planning Development Commission in 1960. Records and logs of selected wells and test holes, records of selected springs, chemical analyses of water, and water levels in observation wells in southeastern New Hampshire were compiled by Bradley and Petersen and open-filed in 1962 and published by the WRB (New Hampshire Basic-Data Report 1, Ground-Water Series, 1962).

In mid-1958, James M. Weigle transferred to Durham as Bradley's replacement and moved the office from Durham to Manchester to begin a ground-water study of the lower Merrimack River Valley. The study was interrupted in 1959 due to insufficient funding by the WRB, and Weigle was transferred to the Boston office. In 1962, when the Subdistrict office was opened in Concord and funds again became available, Weigle was reassigned to the Concord office to continue the lower Merrimack study (HA–227, 1968).

In 1963, Weigle's "Ground-water favorability map of the Nashua-Merrimack areas" was published and was followed in 1964 by his "Ground-water favorability map of the Salem-Plaistow area." Both were published by the WRB. In 1966, "Records of selected wells, springs and test holes, materials tests, and chemical analyses of water in the lower Merrimack River Valley in New Hampshire," compiled by Weigle and Richard Cranes, was published by the WRB (New Hampshire Basic-Data Rept. 2, Ground-Water Series).

Weigle initiated a cooperative study in 1965 to evaluate the effect of highway salting on ground water. Wells were drilled adjacent to newly constructed highways and water samples collected and analyzed periodically throughout the year. Administrative progress reports were furnished to the New Hampshire Highway Department. The study continued through the end of this period of history.

In 1966, Weigle transferred to Maryland and was replaced by Harold A. Whitcomb from Wyoming. Whitcomb continued the highway salt study, maintained the monthly well-observation program, and began a study of the ground-water resources of the Ashuelot River Basin.

During this period of history, federally financed observation wells were monitored monthly to assist the Boston District's monthly water-resources assessment of central New England.

#### *Quality of Water Branch*

Most water-quality studies in the State during this period were under the direction of the New York QWB District. One surface-water station provided a continuous record of water temperature. Specific conductance, sediment and turbidity samples were taken occasionally as part of the central New England water-quality assessment. Ground-water samples were analyzed as part of the "highway salt" study and well inventories included water quality as part of the aerial reconnaissance assessment.

### Funding

During the period 1957–66, the lion's share of the program in New Hampshire was funded under a cooperative (Coop) matching program with the State. The expanding ground-water studies in the early 1960's nearly doubled the program in 1 year. Other Federal agency (OFA) and Federal (Fed) funds, except for inflation, remained about the same during this period.

New Hampshire District funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 37.7 | 37.7 | 29.5 | 31.3 | 60.5 | 63.5 | 69.4 | 69.4 | 78.4 |
| OFA | 10.5 | 11.0* | 13.8 | 12.5 | 11.5 | 27.4 | 21.3 | 21.9 | 15.5 |
| Fed | 6.2 | 6.2* | 6.1 | 6.4 | 6.4 | 4.6 | 5.0 | 5.2 | 7.2 |
| Total | 54.4 | 54.9 | 49.4 | 50.2 | 78.4 | 95.5 | 95.7 | 96.5 | 101.1 |

*Estimated
Source: District program documents.

## New Jersey

Based on material provided *by* Solomon M. Lang with assistance from Allen Sinnott *and* Justin A. Bettendorf

The New Jersey Branch Districts were reorganized as a Division District in mid-1966 with John E. McCall as District Chief. The New Jersey WRD Council, organized shortly after the start of this period, provided program coordination. The Council was made up of the local heads of the SWB and the GWB, between whom the chair alternated annually. Initially, there was no QWB District in New Jersey. The Pennsylvania QWB Laboratory Chief represented, without vote, the water-quality interests. With the formation of the Council, an Administrative Services Section was established to provide administrative support to both Branches. The offices of both Branches, and later that of the QWB, were in the Federal Building on West State Street in Trenton.

## Organization and Personnel

### *Ground Water Branch*

The GWB program in New Jersey in early 1957 was supervised by Henry C. Barksdale, District Engineer. Barksdale was also a GWB Staff Engineer in which capacity he advised on ground-water investigations in Pennsylvania, Virginia, West Virginia, and North Carolina. In mid-1957, following the establishment of the positions of Branch Area Chiefs, Barksdale transferred from New Jersey to Arlington, Va., as the first GWB Area Chief, ACA.

Allen Sinnott transferred to Trenton from Charlottesville, Va., as Barksdale's successor. On Sinnott's professional staff at mid-1957 in Trenton were geologists James E. Kline, Edward C. Rhodehamel, Jack C. Rosenau, Paul R. Seaber, and John Vecchioli and engineer William F. Hardt. The subprofessional staff included engineering aids Charles R. Austin, James C. Hand, Eugene P. Kaiser, and James G. Rooney, and physical-science aids Harold E. Gill and Leo A. Jablonski. Administrative and secretarial support was initially provided by Veronica B. Kron, Evelyn F. Lehman, Lorraine M. Losowski, and Jo Ann Thorne. With the creation of an Administrative Services Section in early 1957, Lehman, Losowski, and Thorne were reassigned to that Section.

A field headquarters, staffed by geologists James R. Randolph, Irwin Remson, and F. Eugene Rush, was maintained at Seabrook in Cumberland County to conduct research on the impacts of agricultural practices on ground water.

In the latter part of 1957, engineers Charles A. Appel joined the staff and Solomon M. Lang returned from a 2-year assignment in Rhode Island. Gill and Jablonski earned professional ratings as geologists, Kline transferred out of the District, and Rush moved from Seabrook to Trenton. In 1958, physical-science aid Mark M. Poplack and engineering aid James H. Nakao joined the staff and Hardt transferred to another District. In 1959, geologist Ellis Donsky joined the District; Seaber returned to school; Loretta L. Zuczek joined the secretarial staff in Trenton; and Catherine J. Graver was recruited as secretary to the Seabrook staff.

In 1960 the Seabrook office was closed. Remson became a faculty member of the Drexel Institute of Technology; however, he continued to work part-time for the District. Randolph transferred from Seabrook to Washington, D.C.; Seymour Subitzky, geologist, transferred in from the Utah District; and Glenn A. Clark joined the District as an engineering aid. In 1961 Seaber returned after earning a Ph.D. from the University of Illinois; Henry R. Anderson, geologist, returned from military furlough; Rosenau transferred to Hawaii; and Jablonski resigned. In 1962, Lang transferred to the SWB, Research Section, in Arlington, Va.; Appel took leave to return to school; and physical-science technician Frank J. Eckel and draftsman Judith D. Rivera joined the District.

In 1963 Seaber transferred to Florida and Rush moved to Nevada. Oscar J. Coskery, Edward A. Pustay, and Eugene Dorr joined the District as engineering technicians. Eckel and Rivera resigned. In 1964 geologists Louis D. Carswell, William D. Nichols, and Donald Langmuir joined the staff. Appel resigned to work for the State cooperator. In 1965, Anderson transferred to the Connecticut District, and Bruce L. Platon, engineering aid, and Bruce M. Patterson, physical-science technician, joined the staff. Coskery resigned.

### *Surface Water Branch*

In 1957, the SWB District Engineer was Donald F. Dougherty, successor to long-term District Engineer Oliver W. Hartwell, who retired in 1956. Professional members of Dougherty's staff were Justin A. Bettendorf, Stephen Hladio, Alexander C. Lendo, Everett G. Miller, and Richard H. Tice. They were assisted by Richard S. Cole, Jerome M. Ludlow, and Omar L. Wilson. Dorothy W. Kozak provided secretarial support to the District staff.

In 1958, Dougherty was transferred to Albany, N.Y., as SWB District Engineer. His replacement was John E. McCall, who transferred in from Washington, D.C. Janet May Cranmer was recruited as a clerk-typist. In 1959, Alexander C. Lendo was appointed Assistant District Engineer and engineering aid Roman T. Mycyk joined the staff. Janet C. Wood replaced Cranmer as clerk-typist. In 1960, Donald M. Thomas transferred from the Tacoma District, Hladio was transferred to the Albany District, Mycyk was promoted to hydraulic engineer, engineering aid Edward A. Pustay joined the staff, and Dolores C. Gorham replaced Wood as clerk-typist.

In 1961, Karlis I. Ators, engineer, was hired and Florence I. Modica replaced Gorham as clerk-typist. In 1962, Ators resigned, engineering technician Edward W. Moshinsky was hired, Catherine M. Meyer replaced Kozak as clerk-stenographer, and Mary Ann Rush joined the staff as a part-time clerk-stenographer. The job title "engineering aid" was changed to "engineering technician." In 1963, Tice transferred to St. Louis as the Floods Specialist, MCA. Thomas transferred to

SWB headquarters and George M. Farlekas, geologist, and Arthur A. Vickers, engineer, joined the staff. Pustay, engineering technician, resigned. Two student trainees were recruited. Stanley E. Dlugosz, engineer, was hired, part-time.

In 1964, Thomas J. Buchanan transferred from the Washington office as Assistant District Engineer and Owen O. Williams, mathematician, was hired. Lendo was assigned to special studies. In 1965, student trainees Thomas G. Ross and Stanley J. Stankowski became engineers: Ross, full-time, and Stankowski, part-time. The number of student trainees increased from 2 to 5, and 2 additional part-time engineering technicians were hired. Anna S. Homer replaced Catherine M. Meyer as clerk-stenographer.

By April 1966, on the Branch staff in Trenton, there were seven professionals, three engineering technicians and two secretarial employees); two engineers (WAE), two technicians (WAE); and five student trainees. All of the trainees were enrolled at the Drexel Institute of Technology in Philadelphia, with which the District maintained an active cooperative program and in which students alternated periods of academic study with on-the-job training, during much of the period.

### *Quality of Water Branch*

A field headquarters of the QWB, Pennsylvania District, was established in Trenton in 1963, reflecting an increased interest in water quality by the New Jersey Department of Conservation and Economic Development (DCED). Previously, water-quality activities in New Jersey were handled by the District office in Philadelphia. The new QWB office was also in the Federal Building on West State Street.

Peter W. Anderson was Chemist-in-Charge, initially assisted by Robert L. Nelson, physical-science technician, Donna C. Worrell, clerk-typist, part-time employees Samuel D. Faust, chemist, and Richard D. Wright, engineering technician. In 1964, Gilbert M. Horowitz, chemist, joined the staff and Nelson resigned. In 1965, Wright and Worrell resigned and Worrell was replaced by Nancy Muccioli.

By 1966, there were three full-time and one part-time employee on the QWB staff: Anderson, Horowitz, Muccioli, and Faust.

## Funding and Cooperation

The following table lists the funding available for each Branch for alternate fiscal years from 1958 to 1966. The dominant part of the program throughout the period was the study of ground water in the Atlantic Coastal Plain Province.

New Jersey District funds, intermittent years, FY 1958–66
[In thousands of dollars]

| Activity | 1958 | 1960 | 1962 | 1964 | 1966 |
|---|---|---|---|---|---|
| Ground Water | 192 | 253 | 269 | 276 | 467 |
| Surface Water | 109 | 118 | 126 | 168 | 208 |
| Quality of water | 17 | 25 | 33 | 72 | 73 |
| Total | 318 | 395 | 428 | 516 | 748 |

Source: District program documents.

Well-water samples, sent to the Philadelphia laboratory for analysis by the GWB and paid for on a repay basis, accounted for about half of the total expenditure for water-quality activities at the beginning of the period ($17,000). The major increase in the water-quality program, from $33,000 in FY 1962 to $73,000 in FY 1966, represented a broadening of interest in the quality of the ground water in the Atlantic Coastal Plain aquifers as part of the baseline studies for the county reports. It also involved an expansion of the basic water-quality network.

### *Funding*

Financial support for the WRD program in New Jersey was from the Federal program, the Federal-State cooperative (Coop) program, and from other Federal agencies (OFA). In FY 1958, when the total District program in New Jersey was $318,000, $48,000 was from the Federal program, $261,000 from the Coop program, and $9,000 was from OFA sources. By FY 1966, the total program had increased to nearly $748,000, the Federal program had decreased to $10,000, the Coop program had increased to $506,000, and OFA funds were up to $231,000 (figures rounded).

The Federal program funded the operation of two or more gaging stations and at various times contributed to the Seabrook Farms project; to completing the 1950 compilation report; assistance in developing the moving-boat discharge-measuring technique and to the Delaware River Basin project; limited sediment and chemical-quality data collection; and other short-term activities. Minor funds were from New Jersey Central Power and Light Company, a licensee of the FPC.

### *Cooperating Agencies*

The principal State cooperator for all Branch activities in New Jersey throughout the period was the

Department of Conservation and Economic Development (DCED), Division of Water Policy and Supply, and at times, its Division of Fish and Game. Although the major concern of the DCED was the protection of the ground-water resources of southern New Jersey, it was the principal source of cooperative funding for the reconnaissance studies of the geology and hydrology of the various counties in the State. The DCED provided the State share of the cooperation funds for the QWB assessment of the quality of the ground water in the Atlantic Coastal Plains aquifers as part of the county ground-water studies and for collecting and interpreting streamflow, ground-water, and water-quality data statewide, and for such topical studies as that of floods in New Jersey.

The State Department of Health cooperatively funded the expansion of the basic water-quality network to acquire data for pollution control and environmental monitoring and, later in this period of history, supported special studies such those in the Passaic and Raritan River Basins. Cooperative programs were in effect at various times with Rutgers University, the Delaware River Basin Commission, and several cities, counties, districts, and planning boards. Streamflow and sediment data were collected in cooperation with the State Department of Agriculture for its study of the sediment-trap efficiency of Baldwin Creek Reservoir.

#### *Other Federal Agencies*

The New York and Philadelphia Districts of the U.S. Army Corps of Engineers continued major OFA support for District activities by providing funds for the operation of certain gaging stations and for special activities such those needed to define tidal-flow patterns in the Delaware River estuary, water-resources information for the New Jersey part of the Delaware River Basin planning study, and an evaluation of the ground-water supply for Picatinny Arsenal. Later in the period, the Public Health Service, the SCS, the Air Force, and the Office of Emergency Planning provided funds for limited District assistance.

### Summary of Program

The New Jersey ground-water program included collection of basic data at more than 300 observation wells, description of the geology and ground-water hydrology in a number of the counties in the State, quantitative evaluation of the ground-water resources at several sites based on aquifer-test analyses, and research on impacts of agricultural and silvicultural practices on the ground-water resources.

The surface-water activities were largely concerned with the collection and interpretation of streamflow data with emphasis on documenting floods caused by extraordinary tides or rainfall and on low flows, flow durations, and flow probabilities.

Early in the period 1957–66, most water-quality activities of WRD in New Jersey were handled by the GWB and SWB. The exceptions were a cooperative study with the Stony Brook Watershed Association and a Federal and Federal-State cooperative program on the chemical characteristics of Delaware River water, Trenton, N.J., to Marcus Hook, Pa., which were responsibilities of the Pennsylvania QWB District. Interest in water quality grew steadily during the first half of the period and justified the establishment of the QWB field headquarters in Trenton in 1963. At that time, the water-quality staff in Trenton assumed responsibility for maintaining the water-quality networks that were previously the domain of the other Branches. By late in this period, local QWB staff were taking the lead roles in investigations and report preparation where water quality was the dominant issue.

The Branches collaborated in local studies where the objective was an evaluation of the total water resource, such as that of the Wharton Tract in southern New Jersey, and in providing streamflow, ground-water, and water-quality data for use in defining the water resources of the New Jersey part of the regional Delaware River Basin planning project.

#### *Water Records*

Data activities are summarized from information reported in District program documents.

Ground-Water Records.—The District reported 379 observation wells in FY 1962, of which 97 were equipped with continuous recorders, 17 were measured weekly, 101 were measured monthly, and 164, semiannually.

Streamflow Records.—In 1962, 77 continuous-record streamflow stations were operated, of which 17 were classified as long-term hydrologic, 30 were short-term hydrologic, and 30 were operated for water-management purposes. In addition there were 84 partial-record sites where low flows were measured, 2 where stages only were recorded, 5 where peak stages only were recorded, and 1 where both high and low flows were measured. Most of the stations were operated for the principal State cooperator; others, to meet the legal and operating commitments of the Delaware River Basin Compact and the Delaware River Master. The streamflow data, in addition to being published by the Survey in the WSP series, were also published as Special Reports of the DCED. The State also published a report by McCall and Miller on New Jersey streamflow records analyzed with an electronic computer (DCED Water Res. Circ. 6, 1961).

Water-Quality Records.—In 1962, in addition to temperature records at 7 streamflow-measuring sites and nearly 300 wells where samples for chemical quality were taken, there were 44 water-quality stations reported. Of the 44 stations, 8 were sampled daily, 6 monthly, and 30 seasonally. Three daily sediment-discharge stations were maintained and two, where sediment samples were obtained periodically.

Other Data Activities.—Ground-water data were incorporated into county studies, research programs, and quantitative analyses of the resource, Statewide. Austin, Rooney, and other technicians assisted in compiling the data for publication in the WSP series.

Data especially acquired for the study were used by Miller in his report on observations of tidal flow in the Delaware River (WSP 1586–C, 1962), and Lendo used special low-flow data for his documentation of the record low tide of December 31, 1962, on the Delaware River (WSP 1586–E, 1966). Other New Jersey streamflow data, more routinely acquired, were used in special studies by members of SWB at headquarters, such as that by C.H. Hardison and R.O.R. Martin on the water-supply characteristics of streams in the Delaware River Basin and in southern New Jersey (WSP 1669–N, 1963).

### *Special Studies*

Most of the reports on geology and ground-water resources were prepared on a county basis and included reports by Rosenau (Salem County); Donsky (Camden County); Jablonski (Monmouth County); Anderson (Ocean County); and Rush (Burlington County). Reports on the ground-water resources only were prepared by Gill (Morris County); Nichols (Essex County); and Rooney (Cumberland County). Hardt reported on the water resources and geology of Gloucester County and Appel on the ground-water hydrology of Middlesex County.

Other reports on ground water in areas and river basins were those by Anderson, in the Rahway area; Randolph, in the Phillipsburg area; Vecchioli, in the Ramapo River Basin; and Carswell, in the Hackensack River Basin. These county, area, and basin studies were normally published by the DCED in its numbered series of Special Reports; for example, that of the Rahway area was Spec. Rept. 27 (1968).

Seaber reported on the impact of ground-water withdrawals from coastal plain formations on the chemical character of water in those formations (DCED Spec. Rept. 22, 1963, and PP 498–B, 1965).

Rhodehamel was the leader of a special project evaluating the water-supply potential of the Wharton Tract in the Pine Barrens area of southern New Jersey. His report on the geology and water resources of the Wharton Tract and the Millica River Basin was published by the State Department of Environmental Protection (Spec. Rept. 36, 1973). Lang provided engineering support to this study that yielded locally and topically significant results. Lang and Rhodehamel described the movement of ground water beneath the bed of the Millica River (PP 450–B, 1962). The Wharton Tract study renewed Lang's interest in aquifer-test techniques, and he wrote several papers on the subject. One paper described methods for determining the proper spacing of wells in artesian aquifers (WSP 1545–B, 1961), and another, with L.E. Ramsahoye, described a simple method for determining specific yield from pumping tests (WSP 1536–C, 1961).

The synthesis of flood data was given special attention by SWB staff during the period 1957–66, during which period Thomas did pioneering studies of flood-depth and flood magnitude for ungaged areas of the State. The tidal flood map of Atlantic City by Thomas and George W. Edelen used 2-foot contour intervals and was unique in its description of coastal flooding from severe ocean storms (HA–65, 1962). Thomas and Tice reported on floods on the Raritan and Millstone Rivers (HA–104, 1964) and Bettendorf, on floods on Millstone River and Stony Brook (HA–245, 1967). Thomas also reported on the magnitude and frequency of floods (DCED Water Res. Circ. 13, 1964) and on flood-depth frequency in New Jersey (DCED Water Res. Circ. 14, 1964).

Miller's analysis of low flows, flow durations, and flow probabilities of New Jersey streams was published by the State (DCED Water Res. Circ. 15, 1966).

Special water-quality studies applicable to New Jersey were prepared, early in this 1957–66 period, by Pennsylvania QWB District staff, and later by the New Jersey staff. Among the former were reports on the salinity of the Delaware estuary by Bernard Cohen and Leo T. McCarthy (WSP 1586–B, 1962); and the quality of Delaware River water at Trenton by McCarthy and Walter B. Keighton (WSP 1779–X, 1964). Among the latter were the reports on water-quality characteristics of New Jersey streams by Peter W. Anderson and John R. George (WSP 1819–G, 1966) and characteristics of water quality and streamflow of the Passaic River Basin above Little Falls by Anderson and Samuel D. Faust (WSP 2026, 1973).

## New Mexico

Programs were developed, administered, and conducted by the Branches until January 1966 when

New Mexico was designated a Division-level district with William E. Hale, former District Engineer, GWB, as its first District Chief and with Albuquerque as the District headquarters. Reorganization occurred immediately before the end of this period and therefore had little impact on Branch operations during the remainder of this period of history. WRD programs in New Mexico are therefore described in terms of the activities and staff of each Branch during the period 1957–66. Santa Fe was headquarters for the SWB District and Albuquerque for the GWB and QWB Districts.

Heads of each Branch District made up the New Mexico WRD Council, the chair of which rotated annually. An Administrative Services Section that provided administrative assistance to the Branches was based in Albuquerque since before this period (1957–66) began. Johnnie E. Marquez was in charge of the Section until about the close of this period when he was succeeded by Elsie M. Sanchez.

The GHB had a small staff in New Mexico, housed with the GWB and the QWB until 1962, when its work was completed. (See Part III, "General Hydrology Branch.")

## Organization and Personnel

### *Surface Water Branch*

Condensed from material supplied *by* William K. Dein, reviewed *by* Eugene S. Buell

Wallace T. Miller was District Engineer until he transferred to Denver, Colo., in April 1958, as District Engineer for the Colorado District. Wilbur L. Heckler, Assistant District Engineer in Tucson, Ariz., became Miller's successor on July 1, 1958, and continued in that position until the reorganization in January 1966. Heckler then became Assistant District Chief and was on duty in Albuquerque at the close of this period. Leon A. Wiard served as Assistant District Engineer until his transfer to Cheyenne, Wyo., as District Engineer, during the summer of 1961. George L. Haynes was the Assistant from 1962 to 1965.

The District headquarters was in the Federal Courthouse until 1962 when the office was moved to the Krueger Building at 227 E. Palace Avenue and, after a year, to the Greer Building at 113 Washington Avenue. A more enduring move was made in 1964 to the former Post Office on Cathedral Place, which had been renovated and renamed the Federal Building.

Personnel assigned to the District office during this period included R. Elton Cook, "office engineer"; Harold J. McDowell (until October 1959), in charge of records compilation; Louis J. Reiland, responsible for Rio Grande Compact computations and special studies; and Charles R. Seiber (until 1965), who headed construction and maintenance. Others included Edwin E. Cerny (from Tucumcari, 1958), Ralph W. Clement, Eugene L. Hogue (1959–64), Robert D. Lamke (until 1961), Owen J. Larimer (from 1964), Elizardo Lucero (to 1959, from 1961–65), Kyle D. Medina (until 1964), and Arthur G. Scott. Administrative and secretarial personnel included Helen W. Conlin, Massie F. Ortiz, and State-employee Agnes Santistevan.

A "flood unit" was included within the structure of the District office. Lamke, Medina, and Scott headed this unit at various times assisted by Hogue, Larimer, or Lucero. Its primary responsibilities were operating the crest-stage gage network and making indirect measurements of peak discharges.

Subdistrict offices were located in Santa Fe, Albuquerque, and Carlsbad. The Santa Fe office generally was responsible for work in the upper Rio Grande Basin, the Canadian River Basin, and, at times, the San Juan River Basin. The Albuquerque office's area of responsibility included the Rio Grande Basin through central New Mexico and the Gila River Basin. At times, staff from the Albuquerque office would also operate the gaging stations in the San Juan River Basin. Carlsbad's area of operation was the Pecos River Basin in central and southeast New Mexico.

The Santa Fe Subdistrict office was established in 1958 under the supervision of L. Gordon Stearns. Stearns left in early 1965 and William K. Dein, formerly in charge of the Carlsbad Subdistrict, was designated Engineer-in-Charge. Other personnel, at times, included J. Pat Borland, Fred K. Fields (to Albuquerque 1962), Don D. Gonzales (to Albuquerque 1961), Pedro Gonzales, Ronny L. McCracken (from 1963), State-employee Perry Rathbunn, Douglas M. Sayre, Jim C. Schafer, Virgil L. Spiers (to Carlsbad 1958), Richard P. Thomas, and Bobby R. Tribble. The Subdistrict office was located with the District office until early 1966, when WRD operations in New Mexico were reorganized and Albuquerque became District headquarters.

The Albuquerque Subdistrict office was located in the Geology Building on the University of New Mexico (UNM) campus. Godfrey L. Oakland was Engineer-in-Charge until his reassignment to Salt Lake City, Utah, in 1958. David D. Harris succeeded Oakland until his transfer to Portland, Oreg., in 1961. Oakland returned from Salt Lake City at about that time, was again in charge until he retired in 1965, and was succeeded by Fred K. Fields. Other Albuquerque staff at various times included Allan Asquith, Borland, Eugene S. Buell (until 1963), C. Clare Cranston (from 1958, then to Carlsbad 1959), Fields (from Santa Fe

1962), Don D. Gonzales (from Santa Fe 1961), Bernard F. Heiler, and Felix E. Trujillo (until 1962). Secretarial personnel included Lois D. Lennox and Alice N. Wilson.

Sherman O. Decker was Engineer-in-Charge of the Carlsbad Subdistrict office until he transferred to Boise, Idaho in late 1959. Dein arrived from Ellenville, N.Y., in January 1960 to succeed Decker, then transferred to Santa Fe in 1965. The Carlsbad office was located at 201.5 South Canal Street until 1958, when the building was condemned because of large cracks in the exterior walls. (It was still standing in 1989 with apparently minimal repairs). The office was moved to the Downey Building (formerly the Memorial Hospital) and into the former operating room, complete with a floor of small white octagonal ceramic tiles, where it remained until 1964 when it was moved to the newly renovated Federal Building (another former Post Office) on Halagueno Street. The staff in Carlsbad included Cranston (from Albuquerque 1959), R. Kirk DeWees (to Tucumcari 1959), Louis C. Ostrander (until 1963), Terry J. Perkins (until 1961), Ronald L. Rogers (from 1965), and Spiers (from Santa Fe, 1958 until 1960). Secretarial support was provided by Bobbie J. Cloud (to GWB, Albuquerque 1960) and Wilma I. Garner.

Five field headquarters supported the Subdistrict offices. The Tucumcari field headquarters, staffed by Cerny until he moved to Santa Fe in 1958 and thereafter by DeWees from Carlsbad, also assisted the Carlsbad Subdistrict. The Springer-Las Vegas field headquarters, staffed by Dale A. Reynolds, also reported to the Santa Fe Subdistrict. The Albuquerque Subdistrict had Thurman E. Yates in Gila, later in Silver City; also, the Farmington field headquarters was staffed by Walter E. Sperry until 1958, then replaced by the Durango, Colo., field headquarters with Orville McCoy in charge. The Socorro field headquarters was staffed by James N. Fitch until his death in 1958, then by Lorenzo B. Baca.

#### *Ground Water Branch*

Condensed from material written *by* Samuel W. West *and* James E. Weir, Jr., assisted *by* Walter A. Mourant

District headquarters of the GWB were in the Geology Building on the UNM campus during the entire period 1957–66. Clyde S. Conover, the District Engineer in 1957, was transferred to Washington, D.C., in 1958, and was succeeded by William E. Hale. In 1962, Hale was transferred to Denver, Colo., and Samuel W. West became District Geologist. Hale returned to New Mexico as WRD District Chief in January 1966, and West moved to Denver.

The GWB staff who served at various locations in New Mexico during part or all of this period included: John H. Abrahams (until 1962), Sydney R. Ash (until 1961), Wilbur C. Ballance (1958–65), Elmer H. Baltz (1959–65), James A. Basler (from 1965), Utley N. Benge (until 1963), Charles F. Berkstresser (until 1958), Louis J. Bjorkland (until 1961), Fred E. Busch, W.D.E. Cardwell (1958–1960), Alfred Clebsch, Jr. (until 1962), James B. Cooper, Ronald E. Cotten (until 1959), Edward S. Cox, Robert L. Cushman (1959–65), Leon V. Davis (from 1958), George A. Dinwiddie (from local QWB in 1959), Gene C. Doty, Ellis D. Gordon (until 1958), Merton J. Grogin (until 1959), John S. Havens (from 1958), Eugene H. Herrick (until 1959), William L. Hiss (from 1965), James W. Hood (until 1958), James R. Huber (until 1958), Jim D. Hudson, Edward C. John (from 1963), Francis C. Koopman (from 1963), J.L. Kunkler (from local QWB about 1965), Howard E. Lobley (from about 1965), George E. Maddox (from 1962), Bruce W. Maxwell (until 1960), Ward S. Motts (to WAE in 1961), Walter A. Mourant, Reed W. Mower (until 1959), William D. Purtymun, John R. Rapp (until 1960), Harold O. Reeder (until 1965), John W. Shomaker (from 1964), Frank B. Titus (until 1965), Frederick D. Trauger, John F. Waldron (until 1958), James E. Weir, Jr. (until 1961), and Isaac J. Winograd (until 1960).

Draftspersons were Winifred E. Bryant, Adeline P. Elmore, and Edwynne G. Hereford. Secretarial and clerical staff at various times included Rosemary S. Ames, Ruth V. Bass, Lois N. Bird, Bobbie J. Cloud, Ruth V. Jones, Melba W. Magee, Laura J. McMillin, Natalie N. Pace, and Linette W. Ward.

A field office was maintained during the entire period in Roswell, where Hood, Mourant, Motts, Mower, Maddox, Hudson, and Lobley were stationed for varying lengths of time; most were ultimately transferred to Albuquerque. A field office was also maintained in Carlsbad, where Cox, Havens, Motts, and Doyle served during all or part of the period. Havens was assigned to a field office in Lovington from 1960 to 1962, then he returned to Carlsbad. A field office was maintained briefly at Three Rivers during 1957.

#### *Quality of Water Branch*

Based on material supplied *by* James K. Culbertson *and* reviewed *by* William F. Curtis

Headquarters and laboratories of the QWB District were also in the Geology Building on the UNM campus during the entire period of this history. Jay M.

Stow, District Chemist, was initially in charge of the QWB programs in New Mexico and Arizona; however, responsibilities for the Arizona operations were shifted to the Arizona WRD District in 1963. In January 1965 Stow transferred to another Federal agency and in June was succeeded by Robert G. Shupp. After the January 1966 reorganization, Shupp became an assistant to the District Chief, then resigned later in the year. Helen E. Hagen, secretary to the District Chemist until the reorganization, was then reassigned to the staff of the District Chief.

The Branch District organization contained the Chemical Quality Section and the Physical Quality (or Sediment) Section. James R. Averett headed the Chemical Quality Section and was Assistant District Chemist until February 1962 when he transferred to Tuscaloosa, Ala. William F. Curtis then became Acting Assistant District Chemist.

In June 1957, Lester R. Kister transferred from Albuquerque to Tucson to head water-quality operations in Arizona and reported to Stow until November 1963, when the Arizona WRD District was organized. In January 1958, Herman R. Feltz transferred from Austin, Texas, to head the Chemical Quality Laboratory and remained until January 1961 when he transferred to Washington, D.C. Harry E. Koester served as laboratory chief until he transferred out in May 1965.

Also in 1958 Kim Ong, engineering aid, WAE, graduated from UNM with a B.S. in chemical engineering. He enrolled in graduate school and remained a part-time member of the laboratory staff until October 1960 when he became a full-time employee. Ong succeeded Koester as laboratory chief in May 1965.

Others who served in the Chemical Quality Section for various lengths of time during this period included Arthur M. Diaz (until January 1958), Ida M. Gutierrez (until about 1958), J.L. Kunkler, and Earl F. Williams. In 1960, Richard L. Lepp, engineering aid, WAE, graduated from UNM with a degree in biology and was later promoted to biologist.

The Sediment Section was headed by William G. Bratschi until his death in December 1957. Curtis filled in until the arrival of James K. Culbertson the following April. Culbertson resigned in September 1961 to work for a private firm, then rejoined the District in October 1963 as assistant to the District Chemist. Culbertson was Acting District Chemist from January 1965, when Stow left the Survey, until June 1965, when Shupp arrived. In July 1965, Culbertson was designated project chief of the newly created Albuquerque Field Research Unit that was established to study sediment transport and bed forms in alluvial channels. (See Part IV, "Geomorphic and Sediment Processes.")

Others who were assigned to the Sediment Section for varying lengths of service during this period include Joseph P. Beverage (until early 1964); Jack D. Dewey (from November 1958); George A. Dinwiddie (from 1959 when he transferred from the local GWB); George Porterfield (until July 1958); Vernon M. Norman (from June 1965, when he received an M.S. degree from UNM); Cloyd C. Scott (from August 1964, following his receipt of an M.S. degree from Colorado State University), and Carl F. Nordin, engineering aid, WAE. In June 1958, after Nordin received the M.S. degree from UNM, he accepted a full-time position and remained with the Sediment Section until March 1959, when he resigned to work for a private firm. He returned in April 1960 and remained in Albuquerque until March 1963 when he transferred to Fort Collins, Colo.

William F. Curtis, an engineering aid with the Sediment Section at the beginning of this period, was briefly assigned to GWB in April 1959 to assist with the Lake McMillan tritium-tracer study. (See Part IV, "Tracers in Hydrology.") Curtis worked in Nepal from June to November 1964, was promoted to engineer in March 1965, and took another foreign assignment in 1966.

A field headquarters was maintained in Fairview early in this period, staffed by Marvin H. Biederman and Trancito Diaz. Biederman died in the late 1950's, and the field headquarters was moved to San Antonio in June 1959 with Diaz as its staff.

#### Funding and Cooperation

The District's programs were funded from the cooperative program (Coop), other Federal agencies (OFA), and from the Survey's Federal program. The Federal funds provided major support for such diverse activities as library maintenance, hydrologic data collection, sediment research, and report preparation.

Total SWB funding during FY 1958 was $265,000; that for GWB, $282,000; and for QWB, $116,000. In FY 1965, the last year for which funding figures for each Branch were available, funding for each Branch, in the same order, was $429,000, $338,000 and $95,000.

Total funds for all WRD operation in New Mexico for those fiscal years for which records are available are shown in the following table.

New Mexico District funds, fiscal years 1961–66
[In thousands of dollars]

| Fund source | 1958 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|
| Coop | 447 | 489 | 500 | 507 | 619 | 622 | 494 |

New Mexico District funds, fiscal years 1961–66 --Continued
[In thousands of dollars]

| Fund source | 1958 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|
| OFA | 116 | 175 | 199 | 236 | 189 | 171 | 221 |
| Fed | 134 | 115 | 84 | 93 | 118 | 89 | 75 |
| Total | 697 | 779 | 783 | 836 | 926 | 882 | 790 |

Source: District program documents.

#### *Cooperating Agencies*

The State Engineer of New Mexico was the principal cooperator for all Branches, not only providing the major support for the streamflow, water-quality, and ground-water data-collection programs on a continuing basis but also providing financial support for special water-resources studies, particularly of areal ground-water investigations. In certain large ground-water study areas, cooperation was shared with the State Bureau of Mines and Geology (BM&G). Much of the cooperative funding for the chemical quality-of-water investigations was from the BM&G and the State Department of Health.

The Pecos River Commission was also a major cooperator of all three Branches. The Interstate Stream Commission, which came into being during this period, became a principal cooperator in streamflow, sediment, and chemical-quality data collection.

Other cooperators were the several river-compact commissions, the Jicarilla Apache Indian Tribe, the State Highway and Game and Fish Departments, the Pecos Valley Artesian Conservation District, and several municipalities where there were ground-water problems. Cooperation with municipalities was often shared with the State Engineer.

#### *Other Federal Agencies*

Other Federal agencies that funded WRD activities in New Mexico were the U.S. Army Corps of Engineers, for streamflow and sediment data and for ground-water studies at the White Sands Missile Range; the BOR, for streamflow and water-quality information; the AEC, for water-supply and waste-disposal assistance at Los Alamos and at the Project Gnome site near Carlsbad; the U.S. Forest Service, for streamflow information; and units of the Armed Forces.

A program of drilling and testing for the AEC at the Nevada Test Site in southern Nevada was done by members of the New Mexico GWB staff, temporarily detailed to Nevada. Detailees involved in this work included Clebsch, Hood, Cooper, and Weir. (See Part IV, "Hydrologic Studies Related to Nuclear Explosions.")

Work for the Bureau of Indian Affairs included studies on the Acoma, Laguna, Mescalero Apache, Pojoaque, San Ildefonso, Zia, and Zuni Indian Reservations. Most of these studies involved selection of sites for wells to supply water for Indian villages and livestock.

Work for the National Park Service included studies of the water supply at Rattlesnake Springs near Carlsbad Caverns National Park by Hale and Cox; at Capulin National Monument by Cardwell; at Chaco Canyon National Monument by West; at El Moro National Monument by West; at Gila Cliff Dwellings National Monument by Trauger; and at Gran Quivira National Monument by Clebsch and Titus.

Six stream-gaging stations were installed during the early 1960's for the U.S. Forest Service on small drainage areas in the Santa Fe Ski Basin of Santa Fe National Forest.

Throughout this period, the SCS supported a sediment-trap-efficiency study at the Piedra Lisa sediment-detention reservoir near Bernalillo.

Gaging stations constructed and operated for the BOR included several required for the San Juan-Chama Diversion Project. Other stations needed by the BOR for the operation of Navajo Reservoir on the San Juan River were completed in 1963.

Gaging stations were installed above and below Abiquiu Reservoir on the Rio Chama, a flood-control reservoir, for the Corps of Engineers.

#### *Summary of Program*

The stream-gaging program continued to be the major thrust of the work of the SWB.

The period 1957–66 was one of pronounced changes in the operations of the GWB District. The high-density statewide water-level program was reduced by 65 percent, freeing personnel for other studies, and preparation of water-level change maps was continued without compromising the quality of the maps.

The main emphasis of the ground-water studies shifted from collection of general geologic and hydrologic data and preparation of descriptive reports to more quantitative analyses of ground-water systems under stress of pumping. Examples were a quantitative analysis of ground water in the Albuquerque area and preparation and analysis of an analog model of the Roswell Basin. Tritium was added to Lake McMillan in order to compute the storage capacity of the ground-water reservoir downstream from the Lake. (See Part IV, "Tracers in Hydrology.")

Beginning in the mid-1960's, as an employee completed his project, he was assigned to another that had become inactive due to the transfer or resignation of the person previously assigned to that project. Additionally, two employees were assigned to all new, large-scale projects to speed completion of the work and to avoid some of the problems caused by transfers and resignations.

The sediment-investigation programs of the District suffered two major reversals during this period, and it was largely through the intervention of Luna Leopold that the programs were not only salvaged but produced noteworthy results. The first setback occurred in 1958 when the BOR and the Corps of Engineers withdrew their funding for the operation of several sediment-data collection stations in the middle Rio Grande Basin, necessitating the transfer of some key members of the Sediment Section. Leopold discussed the problem with the State Engineer and obtained his commitment to include sufficient funding in the cooperative program to resume operation of those stations considered important to both parties.

The second reversal was rooted in a program that began in 1952 when the BOR requested and funded WRD assistance in an intensive study of sediment transport under a wide range of flow conditions through a reach of the middle Rio Grande. The agreement called for the Survey to provide the results of all field observations, data collection, and laboratory analyses needed by the BOR to calculate the geometry of river cross sections required to convey flood flows and sediment through the reach without excessive scour or fill of the channel. The agreement, however, did not address the preparation of reports by WRD authors. When the Survey revealed to the BOR its plans for a series of reports based on the observations and data obtained during the study, the BOR objected, evidently apprehensive that there would be conflicting interpretations of the data. Leopold, when informed of the objections, met with BOR officials and negotiated an agreement that freed the Survey to proceed with its reports. It was emphasized to the BOR that the Survey reports would address topics other than that of estimating channel dimensions for given flows.

Federal funds to begin the preparation of the Rio Grande reports were made available in 1959 with an initial allocation of $8,000. With this modest beginning, reports were prepared on a study of fluvial characteristics and hydraulic variables in the middle Rio Grande by Culbertson and David R. Dawdy (WSP 1498–F, 1964) and on sediment transport in the Rio Grande by Nordin and Beverage (PP 462–F, 1965). Other significant reports included those on the formation and deposition of mud balls in the natural streambed of the Rio Puerco by Nordin and Curtis (PP 450–B, 1962), on the vertical distribution of velocity and suspended sediment, middle Rio Grande, by Nordin and Dempster (PP 462–B, 1964), and on some aspects of flow resistance and sediment transport in the Rio Grande near Bernalillo by Nordin (WSP 1498–H, 1964).

### *Water Records*

Most of the data activities summarized below are from "Water Resources Information in New Mexico, 1962."

Streamflow Records.—In 1962, at about the mid-point of this period of history, 188 gaging stations were in operation, including 43 primary stations (long-term hydrologic), 28 secondary stations (short-term hydrologic), and 117 water-management stations (specific purpose). Many of the records from water-management stations were used to administer the Rio Grande, Costilla Creek, Canadian River, and Pecos River Compacts.

About 146 crest-stage stations were operated in order to provide additional flood data, particularly from small drainage areas. It was to make these data more usable by the Highway Department and by others that Circular 464, "Floods in New Mexico, magnitude and frequency," was prepared (Wiard, 1962).

During the winter of 1965–66, the District supervised the construction of concrete controls at the gaging stations on the Rio Chama, where there was a need to improve the accuracy of flow records that documented diversions by the BOR from the Colorado River Basin into the Rio Grande Basin.

Ground-Water Records.—By 1962, the observation-well program had grown to the extent of requiring six man-years of effort per year. A decision was made to reduce the effort by 65 percent, while assuring that the data were adequate for defining ground-water depletion. The reduction was made successfully. It was reported in 1962 that 1,747 wells were measured, of which 1,165 were measured annually; 518, quarterly; 33, bimonthly; and 31 were equipped with recorders. Measurement data were compiled, alternately, by Reeder, Busch, Benge, and Ballance. Results of the observation-well program were published in WSP's until 1962, when the State Engineer began publishing these data.

Water-Quality Records.—In 1962, water-quality data were regularly obtained at 38 sites. The data included water temperature, chemical quality, suspended-sediment load, and particle-size distribution.

Other Data Activities.—With passage of the Water Quality Act of 1965 (P.L. 89–234), the State was required to establish water-quality standards for interstate streams. Ong and Hale prepared, for each major basin of the State, an administrative report to the State Department of Health summarizing available water-quality information.

A significant flood occurred on May 30 and 31, 1965, on several tributaries to the Pecos River near Carlsbad. Details of the flood were reported by L.P. Denis (WSP 1850–E, 1965).

A major flood that occurred in June 1965, the greatest known in most of the Canadian River Basin upstream from Conchas Reservoir, was documented by R.J. Snipes and others (WSP 1850–D, 1974).

Measurements of very low flows, commonly referred to as "seepage runs," were generally made at least annually on various segments of the Pecos River with additional runs on tributaries of both the Pecos and the Rio Grande.

#### *Special Studies*

Among the more significant studies was an investigation of the chemical and radiochemical quality of water at Los Alamos. An administrative report by W.D. Purtymun of the GWB and J.L. Kunkler of the QWB was furnished to the AEC in 1967.

The feasibility of injecting brine from Malaga Bend into the Delaware Mountain Group in Eddy County was investigated by Cox and Kunkler in 1958 (open-file rept., 1962)

A special study during the early 1960's involved measuring the total outflow from Rattlesnake Springs, the water supply for Carlsbad Caverns National Park. This study involved the GWB and the SWB.

#### *Summary of Ground-Water Reports*

The large number of reports on ground water released during the period precludes a bibliographic listing of all; however, all reports resulting from studies made during this period are on file and available for examination in the Water Resources Division District Office, 4501 Indian School Road, Suite 200, Albuquerque, NM 87110.

The following table summarizes the number of reports by publisher, by type of report, and by year.

Summary of reports prepared by the Ground Water Branch in New Mexico and published from 1957 to 1966

[Source: Borton, Robert L., 1979, Bibliography of ground-water studies in New Mexico, 1873–1977, Special Publication, New Mexico State Engineer.]

| Publisher | Number of reports by publisher and by year | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | Total |
| USGS short research papers[1] | | | | | 1 | 2 | 1 | | | | 4 |
| Open-file reports | 8 | 4 | 4 | 14 | 4 | 8 | 8 | 3 | 2 | 3 | 58 |
| Circulars | | | | | 2 | | | | | | 2 |
| Hydrologic Atlases | | | | | 2 | | | | 3 | | 5 |
| WSP's | | | | | | 1 | 2 | 4 | 3 | 1 | 11 |
| Professional Papers | | | | | 1 | | | | | | 1 |
| New Mexico State Engineer Office | 1 | 1 | 1 | 6 | 3 | 6 | 2 | 3 | 1 | 4 | 28 |
| New Mexico Bureau of Mines and Mineral Resources | | | | | | | 1 | | | 1 | 2 |
| Others[2] | 2 | 4 | 3 | | 2 | 4 | 2 | 3 | 4 | 3 | 27 |
| Total | 11 | 9 | 8 | 20 | 15 | 21 | 16 | 13 | 13 | 12 | 138 |

[1]Short papers on active research projects that were published in a series of USGS Professional Papers.

[2]Includes papers written for scientific conferences, field trips, and special compilations.

Some of the projects for other Federal agencies were not funded for publication of complete reports because the agencies preferred simple administrative reports. The New Mexico State Engineer was interested in all the ground-water studies in the State, so an agreement was reached to set aside funds each year to upgrade administrative reports for formal publication.

### Other District Activities

Many foreign trainees were assigned to the New Mexico GWB District during the period. Most came from the Middle East and North Africa, where climatic conditions are similar to those in much of New Mexico.

A District conference was convened in Albuquerque, May 17 and 18, 1962, in which all Branches participated.

### Vignette

On unilaterally moving the headquarters...

Wilbur Heckler was shocked one day in 1962 when Dale Reynolds, visiting the District office, nonchalantly mentioned that he had a new address—he had moved to Las Vegas, some 70 miles from his headquarters in Springer. Reynolds' daughter was attending Highlands University in Las Vegas so Dale just moved his headquarters there to reduce expenses. He was correct that he could operate as efficiently from Las Vegas, but did not realize the political and administrative problems involved in unilaterally relocating his headquarters. After a year or so things were straightened out and Reynolds was again living at his Las Vegas headquarters, much to the relief of the District Engineer. At least there were no moving expenses.

### The flying stream gager

Thurman Yates, an accomplished pilot, was a stream gager who preferred to make his rounds in his personal plane rather than drive long distances in a Government vehicle. He had many friends in aviation throughout the State so he could usually borrow a vehicle at an airport or landing strip to complete the trip to the gaging stations. Flying often permitted him to complete a normal 3-day trip in 1 day, which offered obvious benefits to District operations but did lead, at times, to difficulties with those at Headquarters who reviewed expense accounts and were not always in tune with such unorthodox modes of transportation.

## New York

Condensed from material written *by* Robert M. Beall assisted *by* Kenneth I. Darmer, Ronald E. DeMatteo, Donald F. Dougherty, George E. Ferguson, Ralph C. Heath *and* Garald G. Parker, Sr.

### Introduction

The New York District operated as three Branches until it was reorganized and consolidated in February 1965. Administrative consolidation and technical coordination was strengthened in July 1961, when the New York WRD Council was re-energized. The Long Island program was operated essentially along integrated Division lines beginning in 1964. While SWB programs were limited to New York State, the GWB and QWB operations headquartered in New York had multi-State responsibilities that continued throughout the 1957–66 period.

### Organization and Personnel

#### *Surface Water Branch (1957–65)*

The District office was in the Federal Building on Broadway in Albany for all of the period. Arthur W. Harrington continued his long tenure as District Engineer until his retirement in 1958. He was succeeded in September 1958 by Donald F. Dougherty, who transferred from Trenton, N.J. Until he retired in July 1960, Holbert W. Fear was Harrington's principal assistant and continued in that capacity under Dougherty. Herman D. Brice served as a technical assistant to the District Engineer until he transferred to Lincoln, Nebr., in July 1957. Fear was succeeded by Kenneth I. Darmer, previously Engineer-in-Charge of the Pierre, S. Dak., office. Dougherty and Darmer remained in their positions until the reorganization of February 1965. Margaret E. Woods (Ithaca Subdistrict office), although not on the Albany staff, was Harrington's personal, technical assistant and contributed significantly to the District program in the western part of the State until she retired in November 1959.

In a rather bleak evaluation of District operations by a reviewer from the ACA headquarters in February 1960, the reviewer wrote: "It has great resources in both money and men; however, the District presents one of the greatest problems on the Atlantic Coast because of massive inertia. The personnel are conscientious and I am sure they are fundamentally sound and capable but most of them are in a rut."

This assessment was presumably based mostly on the progress in preparation of gaging-station records for publication. This, in turn, was confounded and compounded by the revisions generated by the Compilation Report review process; by adaptation to ADP systems; and also by the District's long-standing propensity for "meticulitis" in records collection and analysis, which reflected Harrington's firm, personal control of the process. The reviewer also noted the unreplaced loss of six men by transfer or resignation during 1959. The record improved under Dougherty's leadership, abetted by reassignments and the delegation of more responsibility to the Subdistrict offices.

Laura E. Teres served as District Clerk until July 1961 when, under the aegis of the New York WRD Council, an Administrative Services Section was created under Ronald E. DeMatteo, a new hire from Shell Oil Co. Teres was reclassified as administrative assistant in September 1960, and continued in that position until she retired in November 1965. Ida J. Gates was the clerk-typist-steno in the District office (DO) until her reassignment to the Hydrologic Unit (HU) in February 1960. Carol L. Woodward was reassigned from the HU to the DO in 1961 and was the District secretary for the remainder of the period. DeMatteo continued to head the Administration Services Section until his transfer to the Washington office in 1967.

The District office staff at the outset of the period included Bernard J. Frederick, essentially a field operative for the SWB Research Section, who transferred to

Chattanooga, Tenn., in November 1958 to continue dispersion and diffusion studies for the Research Section. The staff also included six engineering aids, three of whom were soon reassigned to the District's operating units. William J. Schneider, a transferee from Columbus, Ohio, assisted in a study of the hydrologic effects of reforestation from September 1957 to September 1958.

The Hydrologic Unit (HU), with Districtwide responsibility for special and interpretive projects related to floods, droughts, and other surface-water studies, was headed by Dean B. Bogart until he transferred to Puerto Rico in October 1957. Lamar E. Carroon was in charge of the HU from September 1957 to September 1959 when he transferred to Montgomery, Ala., to be succeeded by Gordon R. Ayer for the remainder of the SWB District operational period. The HU staff included, for varying terms, engineers John R. Crippen, Bernard Dunn, Stephen Hladio, Oliver P. Hunt, John P. Monis, Charles L. O'Donnell, F. Luman Robison, Frederick H. Ruggles, Richard C. Shipley; geophysicist Donald E. Vaupel; and engineering aids, Joseph W. Lalley and Joseph A. Robideau. Ida J. Gates, Virginia M. Whitlock, and Carol L. Woodward provided clerical and typing assistance to the unit.

Conducting field operations, preparing streamflow records for publication, and contacting cooperating agencies were carried out under the direction of Engineers-in-Charge (EIC) of four Subdistrict (formerly Area) offices (SDO's) located in Albany, Ellenville (to September 1964, and Middletown, thereafter), Ithaca, and Mineola. The Albany and Ithaca SDO's established field headquarters to facilitate operations in their areas.

The Albany Subdistrict Office (ASD) operating area included the St. Lawrence and Lake Champlain Basins, and the basins of the Black, Mohawk, and upper Hudson Rivers. The office, located with the DO, was headed by William E. Forrest until he transferred to Raleigh, N.C., in November 1958. He was succeeded by Thomas J. Buchanan until January 1962 when Buchanan was reassigned to the SWB Hydrologic Studies Section. Robert M. Beall followed Buchanan and remained as EIC until the 1965 rorganization. Other technical staff of the ASD were Frank N. Dalton, Gerald L. Feder, Bruce K. Gilbert, Cavis B. Ham, Paul H. Hamecher, William E. Harding, Jr., William J. Kenney, Eleanor L. Kirchner, Joseph W. Lalley, Irving R. Leonard, Charles L. O'Donnell, F. Luman Robison, Salvatore D. Schiavo, Richard C. Shipley, and Ellsworth S. VanDerVeer. A field headquarters (FHQ) reporting to the ASD was established in Potsdam in February 1959 to operate gaging stations north of the Adirondacks and to construct stations on tributaries of the St. Lawrence River in New York. Gilbert initiated this operation with construction assistance from the ASD. He was succeeded by Harding, Shipley, O'Donnell, and Hamecher for varying periods. William J. Kenney assisted Hamecher in Potsdam from June 1963 to May 1964 and was succeeded by Howard J. Lent, Jr. Virginia M. Whitlock was reassigned from the HU in July 1959 to provide clerical and typing assistance and remained with the ASD for the rest of the period.

The Ithaca SDO was in the First National Bank for the entire 1957–66 period, relatively undisturbed by the reorganization, and under the direction of Clair L. Whitaker as EIC throughout. Its area included the western Susquehanna and the Allegheny River Basins, Lake Erie and Niagara River drainage, and tributaries to Lake Ontario. The stability of the field and office operations is reflected in the fact that, in addition to Whitaker, the following served in the SDO throughout the period: Mabel B. Blomgren, Donald K. Roth, C. Russell Wagner, Robert B. Wall, and Imogene D. Wheater. Lloyd A. Wagner was also assigned to Ithaca for the period but operated from a Cheektowaga FHQ after 1960. William H. Johnson was on the ISD staff throughout, but was WAE from 1960. Roy E. Campbell (transferred from Ellenville) and Glen E. Saam joined the staff in 1958 and served for the rest of the period. Among those on the staff initially, but later transferred to other offices, were Michael A. Cervione, Philip Pfannebecker, Salvatore D. Schiavo, John Shen, and John E. Wagar. Donald H. Ahrens was a member of the Ithaca staff until his death in a hunting accident in 1960. Serving from about 1962 on were James B. Hood, Jr., and Paul Foster. William E. Harding transferred from the Albany SDO and manned the Hamburg FHQ after 1963. Margaret E. Woods, the offices' institutional memory, retired in November 1959. Her presence, competence, and familiarity with the District's operations served to make Ithaca Harrington's alternative (and perhaps preferred) "District Office." Of four others who were on the staff for a short period and then went on military furlough, only Peter J. Bruck, Jr., returned to the District.

The Ellenville SDO, headquartered in offices first on Canal Street and then on Main Street before it was relocated to Middletown in September 1964, was responsible for streamflow programs in the lower Hudson, Delaware, and eastern Susquehanna River Basins. Gordon R. Ayer was EIC in early 1957 and was succeeded by Wagar in September 1957. Wagar transferred to South Dakota in October 1960 and Wilson G. Bonham, from Dover, Del., assumed charge in February 1961, remaining until August 1965.

Henriette D. Evans, Antoinette M. Nigro-Bruck, and Forrest E. Owen served in the Ellensville office throughout the period. Fredren E. Warner and William A. Washington (formerly of the Topographic Division) and were hired early in 1958 and remained with the SDO. Others serving for shorter periods included Bruck, Roy E. Campbell (to Ithaca), Robert M. Comegys (to Washington), William K. Dein (to New Mexico), Edward S. Graham, Stephen Hladio, Frank J. McLean, Robert A. Perry, Albert G. Ruff, and Bernard F. Strain.

The Mineola SDO was headquartered on Old Country Road until it, and the GWB District office, moved to Kellum Place in 1959, where it remained for the rest of the period. Richard M. Sawyer was Engineer-in-Charge for the entire period, during which time Margaret M. Nolan and Raymond M. Kutil also served. Edward J. Pluhowski was on the staff until he transferred to the Washington office in 1963. Gordon S. Craig, Jr., Robert G. Eagle, Anthony G. Spinello, and Robert W. Wylie were staff members for 2 to 4 years; Spinello and Wylie were there through the close of the period. The Mineola office operated stations in the New York City metropolitan area and was more closely allied with GWB operations than were the other SWB District units.

#### *Ground Water Branch (1957–65)*

The District Office was located on Old Country Road, Mineola, Long Island, until its move to Kellum Place in 1959. The District directly managed groundwater activities on Long Island and in "downstate New York," that is, Westchester County and the New York City area. The office also had jurisdiction over "upstate New York" activities through its Subdistrict office in Albany. During 1960 and 1961 the Mineola office was also responsible for minor GWB activities in Vermont.

Joseph E. Upson, II, District Geologist, became a representative of the ACA, Branch Area Chief in February 1957, but remained in Mineola until October 1963 when he transferred to the GHB in Washington, D.C. His responsibilities included studies of seawater encroachment on coastal aquifers and of the management of freshwater resources in a marine coastal environment. He also assisted with geologic field interpretations for investigations in the Northeastern States.

George C. Taylor, Jr., was District Geologist from March 1957 until September 1960, when he was named Chief of the Division's Foreign Hydrology Section. Shortly thereafter the District headquarters was moved to Albany and Ralph C. Heath, then Geologist-in-Charge of that Subdistrict office, was named Acting District Geologist for New York, Connecticut, and Rhode Island. He was confirmed in April 1961 and continued in that position until the reorganization of February 1965. Nathaniel M. Perlmutter became Geologist-in-Charge of the Long Island Subdistrict after Taylor's departure and until Bruce L. Foxworthy arrived from Oregon in 1964.

During the fall of 1963, operations on Long Island had been the subject of considerable discussion within the New York WRD Council, with heads of the Mineola suboffices, with representatives of ACA, and with other WRD officials. The Council proposed an ad hoc reorganization of the Long Island operations as a test (for New York) of a coordinated Division approach to water-resources studies. The restructuring became effective with the arrival of Bruce L. Foxworthy as Hydrologist-in-Charge. Staffing was enhanced by the transfer in of Philip Cohen, from Nevada, and Charles N. Durfor, from QWB headquarters, in 1964. O. Lehn Franke and William R. Miller were also added to the Long Island staff in 1964, and Gerald E. Seaburn came on board in 1965.

Jennie B. Gottfried, John Isbister, Martha E. Kutil, Nathaniel M. Perlmutter, and Lauren R. Wistoft served in the Mineola GWB District, then Subdistrict, throughout the 1957–66 period. Frank A. DeLuca, Norbert J. Lusczynski, and Julian Soren were on the office staff for much of the period. Other staff members, on the rolls for more than a year, included Richard L. Barnwell, Carol Ann Bross-Backman, Herbert C. Crandall, Jr., Marjorie F. Hughes, Irwin H. Kantrowitz, E. Ronald Lubke, Robert C. Reinhart, Jane T. Samoske, and Wolfgang V. Swarzenski. The staff complement ranged from about 15 members in the earlier years to about 8 in the year preceding reorganization of the Long Island program.

The Albany GWB office was under the direction of Ralph C. Heath as Geologist-in-Charge and District Geologist until the February 1965 reorganization when he became District Chief. Reflecting the 1960 change from SDO to DO status, the staff size increased from about 10 in the earlier years to 17 in the pre-reorganization year. Marion A. Endres (WAE from 1962), Helen A. Miller, and James A. Ziarno served with Heath throughout the period. Others on the staff for significant terms included: Ronald V. Allen; Louise L. Caldwell; Leslie J. Crain, for a time in the Jamestown FHQ and in Seneca Falls; Virginia M. Jerome-Whitlock, until she transferred to the SWB HU in July 1959; Richard H. Johnston; Frederick K. Mack; Edward H. Salvas, also in Massena for a time; Jordan A. Tannenbaum, in Albany from 1958 to 1960 and then until 1964 in a FHO in Syracuse; Frank W. Trainer, at a Massena FHQ part of the period; Richard A. Wilkens, WAE for several years; and John D. Winslow. Also on the Albany GWB staff were John A. Kammerer; Irving Kantrowitz, from the Mineola office in 1962 to a Syracuse FHQ; Albert M. LaSala, Jr., in a Hamburg FHQ; Robert B. Ryder; Herbert J. Stewart, Jr.; and Beatrice A. Tokat. Eugene S. Simpson operated from a FHQ in New York City until his research project on flow in porous media was completed in May 1958, at which time he was reassigned to the GWB Chief's office. Michael H. Frimpter, hired in 1963, moved to the Middletown, N.Y., office in June 1964.

The GWB office in Albany was reorganized in 1963 into District and Subdistrict offices. Stewart became Geologist-in-Charge of the latter, and Kammerer remained on the District staff. In February 1965, Allan D. Randall transferred from Middletown, Conn., to a Binghamton FHQ. Robert G. LaFleur, of Rensselaer Polytechnic Institute, joined the District staff, WAE, in about the summer of 1964.

#### *Quality of Water Branch (1957–65)*

The QWB District Office and laboratory were in the Federal Building through the period and continued to be directed by Felix H. Pauszek, District Chemist. Initially, the principal chemists on the staff were Albert L. Mattingly, who remained with the laboratory throughout; John A. Shaughnessy, who left in March 1962; John A. Creatura; Philip J. Morgan, Jr.; and Daniel Tanski, who left before 1960. Roger J. Archer transferred to Albany from Columbus, Ohio, in April 1962 as Assistant District Chemist and remained for the rest of the period. William J. Shampine transferred from Florida in January 1965 and was assigned to the Seneca Falls project office. Joseph W. Barr joined the staff in June 1964. Chester E. Thomas, Jr., geologist, joined the District in October 1961 and remained until January 1964 when he transferred to Hartford, Conn. Charles N. Durfor transferred from QWB in Washington in January 1964 to be water-quality specialist in the Long Island program. Officially he was with the Mineola field headquarters unit of the District office but worked exclusively under Foxworthy's direction. Frank J. Keller transferred from Rockville, Md., in June 1964 to the interbranch project office in Seneca Falls. He resigned in January 1966.

Technicians George J. Canzeri and Robert A. Doyle served for the entire period. Technician William F. Noble left in November 1961. George J. Medick joined the staff in September 1964. Rita M. Vincent provided clerical and typing services until October 1961, when she moved to the Administrative Services Section. Loree E. Hodina, was a clerk-steno for the first 4 years, a position subsequently occupied by others for short periods. Barbara Ann Pauley and Donna P. LaDue-Cree joined the clerical staff in 1962 and 1963, respectively.

The QWB District was responsible for quality-of-water investigations in New York and in Connecticut, Maine, New Hampshire, Massachusetts, Rhode Island, and Vermont, serving primarily as a support facility for reconnaissance studies of the chemical characteristics of the streams of the region.

#### *The WRD Council (1961–65)*

The New York WRD Council was less than fully effective until about 1960 when Dougherty became established in the District Engineer position and when Albany was designated as the GWB District office. It was re-energized in July 1961 to facilitate closer cooperation among the three Branches in planning and pursuing interbranch studies. The Council also collaborated in effecting liaison with the several cooperating agencies whose programs had begun to expand. Heath was responsible to the Council for WRD operations on Long Island, and the Council effected the formal integration of WRD operations there prior to reorganization of the District. Dougherty was chairman in 1961, Pauszek in 1962, Dougherty in 1963, and Heath in 1964.

The Council established an Administrative Services Section in July 1961. Ronald E. DeMatteo was its first chief and served in that capacity to the end of this period of history. During the Council period, DeMatteo was assisted by Laura Teres, from the SWB District, and Rita Vincent, from the QWB District. The Section consolidated the administrative functions of the three Branches.

By 1963 the New York State Division of Water Resources was planning a series of regional basin planning studies and had asked WRD to initiate complementary water-resources studies. The Council responded by establishing integrated field staffs that, in effect, reported to the Council through the Branch District chiefs. The first such study (1962–65) was that of the Lake Erie-Niagara area headed by LaSala (GWB), assisted by Harding (SWB). A study of the Genesee River Basin was started by Gilbert (SWB) and Kammerer (GWB) in 1963, assisted by William A. Hobba. The third major integrated study was that of the Western Oswego basin by Shampine (QWB), Shipley (SWB), and Crain (GWB).

Others coming on board during this period prior to reorganization were: Joseph W. Barr (to QWB, June 1964); O. Lehn Franke (to GWB, 1964); Robert D. MacNish (to GWB, 1964); William L. Miller (to GWB, 1964); Harold L. Shindel (to SWB, 1963); and Donald E. Vaupel (to GWB, 1959, and to SWB, 1962).

### *Water Resources Division (1965–66)*

The reorganization of the New York District became effective on February 11, 1965, with Ralph C. Heath as the new WRD District Chief. Dougherty retired on May 8, 1965, after 28 years of USGS and military service. The official announcement of the reorganization was in a memorandum of April 20, 1965, to all WRD personnel in New York from the Area Hydrologist, ACA. The sections, units, and those in charge of each were: the Technical Support Section, Pauszek; containing the Laboratory Unit, Archer; Publications and Training Unit, Beall; and Special Studies Unit, (no designated head); the Water Records and Information Section, Darmer; containing the Record Compilation Unit, Bonham; Albany Record-Collection Unit, Ayer; Ithaca Record-Collection Unit, Whitaker; and Middletown Record-Collection Unit, Bruck (acting); the Areal Studies Section, Stewart; Lake Erie-Niagara Area; LaSala; Genesee Basin Area, Gilbert; Western Oswego Basin Area, Shampine; Syracuse Area, Kantrowitz; Orange and Ulster Counties, Frimpter; and Susquehanna Basin Area, Randall; and the Long Island Section, Foxworthy; Water Records Unit, Sawyer; Interpretative Studies Unit, (no designated head); and Applied Research Unit, (no designated head).

The changes were not universally acclaimed, particularly among the former SWB and QWB staff members in Albany. The loss of the Hydrologic Unit left several of the traditional surface-water functions in limbo for several months. Administrative Memorandum #14, May 14, 1965, to All Personnel, WRD, Albany, from the District Chief established a "Coffee Break" Policy instituted to "expedite the integration of the Branch staffs and to facilitate exchange of technical information and ideas." It was not overly popular nor long lived.

During the last half of 1965, Darmer temporarily became Assistant District Chief and the Record Collection Units were redesignated Hydrologic Records and Information Sections. The records-management system in Albany was in a state of flux through the remainder of the period. George E. Williams joined its staff in June 1965 and Bonham came from Middletown in August 1965 to oversee the operations. Campbell moved from Ithaca to Middletown to replace Bonham and Bruck transferred from Middletown to Albany. Gerald L. Giese, Carl W. Noll, and Gerald L. Seaburn were hired in 1965. John R. Teel, Jr., draftsman, transferred from GWB Tallahassee, Fla.

LaSala closed the Hamburg FHQ in August 1965 and returned to the Areal Studies Section of the reorganized District office in Albany. Harding relocated to Ithaca to work with Randall (based in Binghamton). Kantrowitz terminated his Syracuse FHQ in August 1965 and was reassigned to the Areal Studies Section.

The shakedown cruise through the stormy sea of reorganization had almost come to an end.

## Funding and Cooperation

The dominant source of funding throughout the 1957–66 period was the Federal-State cooperative program (Coop) that, in fiscal year (FY) 1958, provided 86 percent of the total operating budget. Federal program (Fed) funds amounted to 5 percent of the total, and funds provided by other Federal agencies (OFA) and FPC licensees were 9 percent. In FY 1966 the Coop funds were 94 percent of the District's total. Using FY 1958 figures to illustrate relative size of Branch operations, 66 percent of the funds were for the SWB, 28 percent for the GWB, and 6 percent for the QWB.

About 75 percent of the District's funds were for the collection of water records; the remainder, for topical and areal water studies and research. By 1966, the water-records component of the budget had declined to 56 percent. The following table shows District funding by source.

New York District funds, FY 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 629.2 | - | 741.3 | 712.1 | 741.1 | 735.7 | 845.9 | 1,150.6 | 1,192.9 |
| OFA | 60.8 | - | 60.0 | 58.6 | 61.5 | 62.5 | 63.6 | 59.3 | 51.8 |
| FPC | 2.9 | - | 3.1 | 3.1 | 3.2 | 3.2 | 3.5 | 3.6 | 3.7 |
| Fed | 42.0 | - | 14.8 | 17.1 | 27.6 | 29.8 | 24.3 | 52.9 | 28.1 |
| Total | 734.9 | - | 819.2 | 790.9 | 833.4 | 831.2 | 937.3 | 1,266.4 | 1,276.5 |

Source: Data in files of the Branch of Planning Support, WRD.

The funding growth after 1963 resulted from the State's expanded interest in basin and regional planning and the District's response with increases in many aspects of the ground-water program and initiation of integrated studies. The major drought of the early 1960s was also a factor.

### *Cooperating Agencies*

The New York State Department of Public Works (DPW) in 1958 supported 160 of the almost 280 stream-gaging stations in the State. It also funded other efforts including drainage-area determinations and gazetteer compilations; flood-inundation studies and mapping; development of a crest-stage gage program; annual statewide flood reports and periodic bridge-site reports; base-flow and flood-flow studies of small streams; flow measurements at ungaged sites; and flow-duration and frequency analyses.

The New York State Conservation Department (CD) Division of Lands and Forests supported a few gaging stations, part of the snow-survey activity, and the closing phase of the reforestation project. The CD's Water Power and Control Commission (WP&CC) was the principal supporter of the upstate ground-water program which, in 1958, consisted of nearly 200 observation wells and ground-water studies of five counties including an intensive study of the water-bearing characteristics of the Lockport dolomite in the Niagara Falls area. It also contributed to the support of the observation-well program on Long Island and to the continuing evaluation of seawater encroachment. The WP&CC was renamed Water Resources Commission (WRC) in 1960 when, also, a Division of Water Resources (DWR) was created as its operating staff. By 1964 the DWR had become the principal cooperating entity in the CD supporting ground-water data programs, county and area ground-water studies, and eventually, multidiscipline areal investigations. By 1961 the WRC was funding studies in 10 areas, including Queens County on Long Island.

In 1965 the DWR was supporting a basic observation-well network upstate, supplementing that on Long Island, and continuing several county or areal ground-water studies. Additionally, it supplemented county support of several programs on Long Island: seawater encroachment; studies of the effects of synthetic detergents; and data storage and retrieval procedures. Surface-water studies were started in two areas as well as a statewide study of low-flow characteristics. Integrated ground-water, quality-of-water, and surface-water studies were continued or initiated in three regions. Finally, a comprehensive evaluation of the water resources of upstate New York was underway as this period ended.

The New York State Power Authority funded a ground-water study of the Massena-Waddington area from 1957–60 in support of the St. Lawrence Seaway Project. The work was continued through 1962 under the New York State WRC agreement.

The New York State Commerce Department provided funds for collecting water-quality data at 8 to 37 sites and funds to begin the Hudson River tidal-flow studies in 1966. Until 1962 it supported evaluations of the chemical and physical quality of waters of the Delaware and St. Lawrence River Basins.

The New York State Department of Health funded discharge determinations at selected problem sites, field studies at several of their project areas, analyses of low-flow data for stream classification, and time-of-travel studies beginning FY 1964.

The New York State Office of Atomic (and Space) Development supported an intensive hydrologic investigation of the Western New York Nuclear Service Center area in Cattaraugus County.

The long-standing agreement with the Board of Hudson River-Black River Regulating District supported 10 streamflow and 2 reservoir stations.

The major county cooperators were those of Nassau and Suffolk on Long Island. Nassau County Department of Public Works initially supported 8 streamflow stations, 18 recording and 225 periodically measured observation wells, of which about 100, where well discharges were measured, were sampled for chemical quality. After 1964, the observation-well program was reduced to 11 recording and 130 nonrecording sites. Seawater-encroachment studies continued throughout the period, and a special study of cadmium-chromate ground-water contamination was in progress from 1962 to 1967. Small-scale artificial-recharge studies began in 1962 and developed into a major program element in 1965 when a full-scale project was started at Bay Park.

The Suffolk County Department of Public Works and the County Board of Supervisors, in twin agreements, were the principal cooperators for the work on the eastern two-thirds of Long Island that required 11 streamflow stations and 60 to 140 periodically measured observation wells. Early in the period, well discharges were measured at 75 sites and chemical quality was sampled at as many as 134 sites. During the second half of the period the ground-water network stabilized at 95 monthly measurement sites, 1 recording station, and water-quality sampling of 40 wells. Sampling was done at about 65 surface-water sites beginning in 1965. Areal ground-water investigations were completed in two areas of the county, and a special investigation of synthetic detergent contamination was begun in 1963. A deep test well on Fire Island was a major program item in 1963 and 1964. Suffolk County also contributed to the funding of work on the preliminary water budget for Long Island in 1966.

Six gaging stations were maintained for Westchester County throughout the period, and the Onondaga County Water Authority and the Onondaga County Department of Public Works funded three gaging stations in the Oneida Lake area. The Dutchess County Board of Supervisors cooperated in funding four gaging stations. The Rockland County Board of Supervisors funded construction and operation of 15 gages between 1960 and 1962, leading to an analysis of surface-water resources with emphasis on low flows and chemical characteristics.

The largest continuing agreements with cities were those with the New York City Board of Water

Supply and the city's Department of Water Supply, Gas and Electricity, consolidated into a single agreement in FY 1963. The program involved operating from 22 to 28 gaging stations and collecting precipitation records at 13 sites. From 1960 to 1963, the city of Schenectady funded work in part of Schenectady County that included a study of the yield of the aquifer supplying its well field in the Mohawk River Valley. The city of Jamestown supported a study (1960-63) of the availability of ground water in Chautauqua County and the yield of the aquifer supplying its well field.

Other cooperators that required streamflow data included the State Department of Law, Oswegatchie River-Cranberry Commission, and the cities of Albany and Auburn, the Brighton Sewer Commission, and the Village of Nyack.

#### *Other Federal Agencies*

The principal Federal collaborator in the New York WRD program was the U.S. Army Corps of Engineers through its Baltimore, Buffalo, New York, Philadelphia, and Pittsburgh Districts. From 27 to 44 gaging stations were operated for the Corps and up to 6 reservoir gages. Work for the Atomic Energy Commission (AEC) was performed at the West Milton atomic-reactor testing site in Saratoga County, where the ground-water evaluation was completed in 1961, but surface-water data collection continued through the period. Surface-water studies were completed in 1963, as was most of the water-quality work. The AEC also funded ground-water studies at the Brookhaven National Laboratory on Long Island until about 1959. Three gaging stations were operated for the Soil Conservation Service through FY 1962. A small ground-water study of the Saratoga Historical Park for the DOI, National Park Service, was ongoing until FY 1960. Water-quality analyses were made for the Departments of Army and Air Force and for the Veteran's Administration.

#### *Licensees of the Federal Power Commission*

Using stage-discharge ratings developed in the District, discharge records for the Hudson River at Green Island were computed and furnished by the Ford Motor Co., an FPC licensee. For two other licensees, discharge records were obtained on the Sacandaga River at Stewarts Bridge near Hadley and the Raquette River at South Colton.

#### *Federal Program*

In FY 1958, Federal program funds supported 6 gaging stations, 1 sediment station, 28 observation wells, completion of industrial-area reports for Utica-Rome and Syracuse, a quality-of-water network evaluation, cleanup work on the 1950 Compilation report, and surface-water and quality-of-water activities for the Delaware River Basin project. By 1961, the funding provided only for the operation of nine gaging stations and two observation wells. In FY 1962, there was quality-of-water support for the national public water-supply evaluations and the beginning of a limited study of diurnal fluctuations in small streams and of seawater encroachment. In FY 1963 funds were available to construct a Hydrologic Benchmark station on Esopus Creek at Shandaken and for the national flood-frequency study. Construction of an analog model of the Long Island ground-water system was supported substantially in FY 1964. At the end of the period, Federal funds were supporting only seven gaging stations and two observation wells.

### Program Elements

Collecting, processing, and publishing water records continued to be a strong, stable element of the District's programs. The development of computer technology in the late 1950's permitted marked advances in data processsing, thus improving the timeliness of data acquisition, processing, and publication.

Applied hydraulic and hydrologic projects as well as site and areal water-resource studies continued but increased in scope and diversity during the period. Additional factors spurring program growth were the severe drought of the mid-1960's and national legislation on regional planning and on water quality.

#### *Water Records*

Summary information on water-data sites for FY 1958, 1961, 1962, and 1964–67 was available from District program documents and from informational folders "Water resources investigations in New York."

Streamflow Records.—In 1966, continuous records of daily discharge were being obtained at 294 sites, of which 98 were classified as primary (long-term hydrologic), 142 as water-management, and the remainder as secondary (short-term hydrologic). Peak discharges were being determined at 114 additional sites and low-flow data at some 527 sites.

Ground-Water Records.—Late in 1965, daily ground-water levels were being measured at 38 sites; and by periodic, less-frequent observation at 363 sites, a sizable number of which were on Long Island to support the islandwide water-budget study. In some years, data were obtained at more than 500 sites statewide. Water-level data for key wells with significant periods of record were published by groups of years with similar data for other Northeastern States as follows: 1956–57, WSP 1537; 1958–62, WSP 1782; 1963–67, WSP 1977.

Water-Quality Records.—Chemical-quality (CQ) sampling of surface waters and sediment-discharge determinations were quite variable in numbers of sites over the years, being geared more to areal study projects than to network concepts. By 1966, daily CQ determinations were being made at 4 sites, with monthly or intermittent CQ sampling at 113 sites. Sediment data were being obtained periodically at 25 sites. Stream temperatures were continuously recorded at 15 to 30 stations during the 1957–60 period. Chemical-quality sampling was performed at more than 300 wells in some years, depending on study needs.

Climatological Records.—Records of daily precipitation were obtained at 15 to 25 sites as an adjunct to rainfall-runoff studies or as an element of the New York City Coop program.

Snow depth and water content were measured at some 50 snow courses in support of the New York Cooperative Snow Survey, part of a cooperative effort of the Eastern Snow Conference, an informal association of Federal, State, local, and private entities. The SWB HU coordinated the New York effort and made available periodic regional analyses of water content to water managers. Gordon Ayer was the Secretary, Eastern Snow Conference, through the 1957–66 period. The National Weather Service published an annual compilation of New York and New England data following the "snow season."

Other Data Activities.—The SWB HU measured drainage-area sizes and maintained a set of topographic maps on which these areas were outlined and planimetered. Drainage-area data were used internally within the District and by cooperators, and gazetteers of these data were compiled periodically.

Flood data were important to the New York State DPW and to others. Records of floods, another function of the Albany HU, were documented in national summaries, for example: Rostvedt, J.O., 1965, WSP 1810. Hydrologic details of the floods on Chenango River and Canasawacta Creek at Norwich were documented by Hladio (HA–297, 1968). Hydraulic evaluations of floods at prospective bridge sites were also made.

F. Luman Robison investigated the magnitude and frequency of floods in New York (Circ. 454, 1961) and compiled the maximum known discharges of New York streams (NYS-WRC Bull. 54, 1965). These and other data compiled by the District were used as input to the WSP series entitled "Magnitude and frequency of floods in the United States." Information pertinent to New York appeared in WSP's 1672, 1675, and 1677.

From the early 1960's, statistical summaries of low-flow and flood-flow data and flow-duration analyses of gaging-station data, prepared on the Washington Headquarters computer, were widely used by the District and by cooperators. The New York State Conservation and Health Departments were the most common requestors of low-flow and frequency information.

Among the data compilations that warranted publication separate from project reports were Isbister's report on ground-water levels and related hydrologic data from selected observation wells in Nassau County (NYS–CD Bull. GW–41, 1959); the report on chloride concentration and temperature of the waters of Nassau County by DeLuca and others (NYS–CD Bull. 55, 1965); and Gilbert's and Kammerer's summary of water-resources records in the Genesee River Basin through 1963 (CD Bull. 56, 1965).

#### *Project Studies and Reports*

Most District activities that required field studies, analysis, or interpretation were reported and published by the USGS or the cooperator. A complete listing of the USGS products can be found in the December 1986 compilation, "List of U.S. Geological Survey Geologic and Water-Supply Reports and Maps for New York." The 1968 folder "Water-Resources Investigations in New York" lists USGS-prepared bulletins published by the New York State Department of Commerce (DC) and the New York State Conservation Department or its constituent agencies, usually cited as "CD Bull."

Areal Ground-Water Investigations.—The ground-water appraisals of counties, and of certain areas, include those of Putnam, by Grossman (CD Bull. GW–37, 1957); Chemung, by Wetterhall (CD Bull. GW–40, 1959); Rockland, by Perlmutter (CD Bull. GW–42, 1959); Dutchess, by Simmons, Grossman, and Heath (CD Bull. GW–43, 1961); Sullivan, by Soren (CD Bull. GW–46, 1961); the Massena-Waddington area in St. Lawrence County, by Trainer and Salvas (CD Bull. GW–47, 1962); Ontario, by Mack and Digman (CD Bull. GW–48, 1962); Plum Island in Suffolk County, by Crandall (WSP 1539–X, 1962); Saratoga, by Heath, Mack, and Tannenbaum (CD Bull. GW–49, 1963); Delaware, by Soren (CD Bull. GW–50, 1963); southern Nassau and southeastern Queens County by Perlmutter and Geraghty (WSP 1613–A, 1963); town of Southold in Suffolk County, by Crandall (WSP 1619–GG, 1963); the Montauk Point area of Suffolk County, by Perlmutter and DeLuca (WSP 1613–B, 1963); northwestern Nassau and northeastern Queens County, by Swarzenski (WSP 1657, 1963); the Niagara Falls area, by Johnston (CD Bull. GW–53, 1964); the Huntington-Smithtown area of Suffolk County, by Lubke (WSP 1669–D, 1964); eastern Schenectady County, by Winslow, Stewart, Johnston, and Crain (CD Bull. GW–57. 1965); the Jamestown area, by Crain (CD Bull. GW–58, 1966); and northeastern Nassau County, by Isbister (WSP 1825, 1966).

Information from the earlier of these reports and from those done in prior years was summarized by Heath and published in an atlas-type format (CD Bull. GW–51, 1964).

Special Ground-Water Studies.—The problems associated with development on Long Island resulted in a several special studies that were reported as: "Sources of ground water in southeastern New York," by Perlmutter (Circ. 417, 1960); "Ground-water levels and their relationship to ground-water problems in Suffolk County," by Hoffman and Lubke (CD Bull. GW–44, 1961); "Sea water in coastal aquifers," by Cooper and others (WSP 1613–C, 1964); "Hydrology of the Babylon-Islip area, Long Island, Suffolk County," by Pluhowski and Kantrowitz (WSP 1768, 1964); "Salt-water encroachment in southern Nassau and southeastern Queens Counties," by Lusczynski and Swarzenski (WSP 1613-F, 1966); and "The changing pattern of ground-water development on Long Island," by Heath, Foxworthy, and Cohen (Circ. 524, 1966).

Among the special surface-water and water-quality studies reported were: The chemical and physical quality of water resources in the St. Lawrence River Basin of New York by Mattingly (DC Bull. 4, 1961); The effect of reforestation on streamflow in central New York by Schneider and Ayer, (WSP 1602, 1961); Water quality in the Delaware River Basin, New York, by Archer and Shaughnessy (DC Bull. 5, 1963); Creeks, brooks, and rivers in Rockland County by Ayer and Pauszek (DC Bull. 6, 1963); and Effects of waste water from the AEC plant on the hydrology of Glowegee Creek at West Milton, 1958–61, by Pauszek and Ruggles (WSP 1809–N, 1965).

Other reports during the period included those on the water resources of the Utica-Rome area, by Halberg, Hunt, and Pauszek (WSP 1499–C, 1962); the water resources of the Albany-Schenectady-Troy area by Halberg, Hunt, and Pauszek (WSP 1499–D, 1964); and the water resources of the Lake Erie-Niagara area by LaSala, Harding, and Archer (CD Bull. GW–52, 1964).

A series of reports documenting results of geologic and hydrologic studies of the Brookhaven National Laboratory area of Suffolk County, Long Island, were issued as chapters of USGS Bulletin 1156.

There were more than two dozen research, topical, and areal studies in progress as this period of history ended.

### Other District Activities

Annual District convocations faded out with the retirement of Harrington except for conferences of all SWB District personnel in 1958 and 1959. District Geologist Heath convened a conference in March 1965, in essence an in-service training school in "the role of ground-water hydrologists in water-resources investigations."

Monthly publication of the "Gage House Gossip" was the principal inter-Branch mechanism for Districtwide communication throughout the period, reporting on personal and personnel matters, project activities, and elaborating District policies. Eleanor Kirchner continued to be a frequent illustrator for the paper.

Beginning in the mid-1960's, monthly streamflow data for a few "index" stations, end-of-month water-level data for a few key observation wells, and other data were used to prepare monthly State water-situation reports, distributed mainly to the media and to cooperators.

### Summary

The New York WRD program had significant resources of both personnel and funding and enjoyed supportive relations with many Federal, State, and local cooperators, statewide. This was reflected in the quality of its publications products, in its assistance to many national programs, and in other ways.

Among many of the technical contributions made by New York personnel during this period of history were Luscznyski's development of concepts related to head and flow of ground water of variable density; Perlmutter's work on pollutant movement through granular material; Winslow's use of water temperature in conjunction with pumping records to determine the yield of the aquifer at Schenectady; Johnston's demonstration of the dominating hydraulic effect of bedding-plane fractures in flat-lying sedimentary rocks at Niagara Falls; and Crain's discovery, in his Jamestown study, of the key to the surface- and ground-water hydrology of the glaciated valleys in the Allegheny Plateau region—that is, the hydraulic connection between valley-side deltas and the unconsolidated aquifers in the valley. Also, Schneider and Ayer demonstrated conclusively, in their analysis of long-term streamflow records in central New York, that reforestation did result in a decrease in runoff, although flood peaks were attenuated.

## North Carolina

*By* Philip M. Brown, M. Douglas Edwards, *and* N. Macon Jackson, Jr., assisted *by* Edwin O. Floyd, Gerald L. Giese, H. Curtis Gunter, Margaret V. Harrington, Harry E. LeGrand, Margaret R.V. Rachal, *and* James F. Turner, Jr.

The Branch staff and activities were integrated as a Division-level District in July 1965 with the designation of Edward B. Rice as District Chief. Prior to the reorganization, WRD programs were negotiated and conducted on Branch bases. Beginning in about 1958, and ending with reorganization in 1965, the Branch District supervisors were organized and functioned as a WRD Council, the chair of which rotated annually.

Integration of the previously autonomous Branches was facilitated by the close proximity of the Branch District headquarters to each other. All were located on the fourth floor of the Federal Building in Raleigh and shared an Administrative Services Section during the entire 1957–66 period of this history. Worth noting is the long-time stability of the Administrative Services Section. Margaret V. Harrington headed the Section, assisted by Maudie L. Ellis during the entire period and by M. Ruth Rachal, followed by Nannie F. Williams, serving in a third position on the staff.

### Organization and Personnel

#### *Surface Water Branch 1957–65*

Edward B. Rice was District Engineer and head of SWB District operations in 1957 and remained in that position until the reorganization of July 1965, when he was selected as the first WRD District Chief for North Carolina.

There were about 40 members of the SWB District staff in 1957, most of whom were headquartered in Raleigh. The Raleigh staff included Robert E. Fish, Assistant District Engineer, who transferred to Milford, Penn., in 1958 to head the Delaware River Master's operations, Grover C. Goddard, and Patrick H. Walker, who also transferred to Milford in 1962. Goddard directed the District's "low-flow" program. Also on the Raleigh SWB staff were Ivan L. Burmeister, until he transferred to Iowa in 1959, Herbert G. Hinson, and James D. Simmons, who transferred to Florida in 1966, and John L. Lamson. Simmons directed the gaging-station operations. Lamson, until he retired in 1961, was in charge of the compilation of streamflow records and assisted Simmons in gaging-station operations. Later additions to the Raleigh staff included William E. Forrest (from Albany, N.Y., in 1958 to replace Fish as Assistant District Engineer, then on to Maryland in 1962 as District Engineer) and Nathan O. Thomas (arrived in 1963 to replace Forrest). Thomas remained as Assistant District Engineer until the reorganization of 1965. Lawrence A. Martens arrived Raleigh in 1962 and remained through the end of this period.

In the early 1960's, as water-management and environmental needs emerged and the District's interpretive studies expanded, several new members were added to the staff, including H. Curtis Gunter, Ernest F. Hubbard, Arthur L. Putnam, Clyde E. Simmons, and James F. Turner, Jr.

Branch Subdistrict offices were in Asheville and Statesville and a field headquarters was in Bryson City. Staff of these offices performed all field and office work within their designated areas.

Thomas G. Johnson was Engineer-in-Charge of the Asheville office during this period. His staff included Mary R. Armstrong, Hugh C. Creasman, Duncan C. Murrow (Creasman and Murrow resigned early in this period), Adolph Summerlin (transferred to Florida in 1963), and Harold D. Meyer (resigned to join the Peace Corps in 1962). N. Macon Jackson, Jr., transferred in from the District office in 1960 and then back to the District office in 1966, to replace James D. Simmons. Junior K. Ogle, a transferee from Bureau of Public Roads in 1962, and Clifton E. Siler, a transferee from the U.S. Weather Records Center in 1963, rounded out the staff at the close of the period.

Thomas E. Dillard ran the Bryson City field headquarters under the direction of the Asheville office.

Ernst G. Wollin was Engineer-in-Charge of the Statesville office. His staff included James F. Baily, who transferred to Fairfax, Va., in 1960, and was replaced by Kenneth R. Taylor (to Maryland in 1963), in turn replaced by Wayne H. Hammond, both of whom were from the Raleigh office. Boyd L. Jarvis and Maxine A. Harbin were also on the staff.

A field headquarters staffed by W. Harold Eddins was established in Charlotte in 1961 to install and operate a data-collection network to evaluate the effects of urban development on floods. Two additional field headquarters were established in 1965–66 for the same purpose. Duncan Murrow operated a network of gaging stations in Lenoir and Morganton from Morganton, and Clarence M. Ray, Jr., operated stations in Winston-Salem.

The Wilmington field headquarters, staffed by James C. Futrell, was established late in this period to collect data on the tide-affected Cape Fear River.

Other permanent, full-time employees with the SWB District for more than about 2 years and not heretofore listed included Edna G. Arledge, Dorothy A. Costa, Catherine E. Harrington, Wayne F. Hensley, Martha I. Hunter, Eloise H. Stephens, and Sherman G. Thompson.

A Field Unit of the SWB, staffed by Albert B. Goodwin, was in Asheville until 1959 when Goodwin transferred to Portland, Oreg., and the office was closed. Goodwin reported to the Branch Area Chief, ACA, in Arlington, Va., and looked after regional activities of SWB such as streamflow-records compilation and flood-frequency studies.

#### *Ground Water Branch (1957–65)*

Philip M. Brown was District Geologist and head of GWB operations in North Carolina as this period of history began. He continued in that position until October 1963, when he transferred to GHB to begin research on waste storage in the Atlantic coastal region with emphasis on the geologic framework. Although he remained in Raleigh, he reported to Robert R. Bennett in Arlington, Va. With his new assignment, Brown and his staff, including James A. Miller, Frederick M. Swain, and Marjorie S. Reid, moved from the Federal Building to the GWB rock-sample laboratory in the Park Shop Building on the Raleigh campus of the University of North Carolina. Among the reports produced by Brown and his team on the geohydrology of selected formations of the Atlantic coastal region were Professional Papers 795 (1972), 796 (1972), 881 (1976), and 1088 (1979).

Brown's predecessor as District Geologist was Harry E. LeGrand, who had resigned from the Survey to enter the consulting business and had returned to the Survey at the Washington, D.C., headquarters early in this period. LeGrand returned to Raleigh in 1965 but not to District operations. He was organizationally attached to the Office of the Regional Hydrologist, ACA, to study the ground-water resources of the Piedmont and Blue Ridge Provinces, extending from Pennsylvania to Alabama. He also continued research on ground-water contamination and began research on karst hydrology in collaboration with Victor T. Stringfield.

Granville C. Wyrick was named Acting District Geologist in 1964. Wyrick served in that position until the reorganization of 1965. He then headed the five-person group that staffed the Ground Water Hydrology Section of the reorganized District until 1966 when he transferred to West Virginia. Joel O. Kimrey and Mary Elizabeth Hansen were members of the Raleigh GWB staff during most of the 1957–66 period, along with Vester J. May (from the SWB) for about 3 years, 1961–63, and Richard D. Pusey early in the period.

Field headquarters of the GWB District were established and abolished in response to the logistical and staffing requirement of ground-water studies. At various times during this period, temporary, one-person field headquarters were maintained near project locations for the duration of the projects. In 1959, for example, Reginald R. Blankenship was at Southport and Granville G. Wyrick at Williamston. In 1962, Henry Trapp was at Asheville; Henry C. Norman and Orville B. Lloyd, Jr., at Edenton; William H. Harris at Elizabeth City; Carlton T. Sumison at Morganton; Chester L. Dodson at Murphy; Owen T. Marsh at Waynesville; and Edwin O. Floyd at New Bern. In 1963, George L. Bain was in Wilmington. Most served 2 to 4 years in a field headquarters, and moves were obviously frequent.

Worth noting are careers of Edwin O. Floyd, Joel O. Kimrey, and James A. Miller, who began working as student/technicians with the GWB District in Raleigh during this period and, before the period ended, were professional-level members of the staff.

#### *Quality of Water Branch (1957–65)*

In 1957, the North Carolina QWB District included North and South Carolina, Tennessee, and Virginia. In 1960, water-quality work in Tennessee was assigned to the Little Rock, Ark., District. Responsibility for water-quality activities in South Carolina and Virginia was relinquished to those States in 1966 as each became Division-level Districts.

Granville A. Billingsley was District Chemist as this period began, then transferred to QWB headquarters in Washington in 1963 as Chief, Automation and Data Management Section. He was succeeded, temporarily, by Joseph C. Chemerys, who had transferred to Raleigh from Columbus, Ohio, in 1958. Robert A. Kreiger was transferred to Raleigh in 1964 as District Chemist and, with reorganization, became Assistant District Chief in 1965.

Other key members of the QWB District staff included Russell L. McAvoy (until 1958 when he transferred to WRD Publications Section at Headquarters) and Kay F. Harris (until 1962, when he moved to the California QWB District). Those who began their careers as technicians in the QWB District office or laboratory in Raleigh and later achieved prominence as hydrologists elsewhere in the Division include Ann C. Beam, Melvin D. Edwards, and Garald G. Parker, Jr. Edwards left the District in 1965 to join Billingsley in the Branch's Automation and Data Management Section.

Although QWB District operations did not require subdistrict or field headquarters, the District did maintain a major Regional laboratory throughout the period 1957–66 that employed up to 16 chemists and technicians. The laboratory was located in the Century Building on Fayetteville Street in Raleigh and engaged in both the chemical analyses of water samples and the analysis of sediment concentrations. The laboratory maintained a cooperative program with the State of North Carolina and employed one or two State chemists during the period, one of whom, Edward J. Phibbs, Jr., became a member of the WRD staff in 1960.

### *Water Resources Division (1966)*

Reorganization into a Division-level District, occurring shortly before the close of this period, made little impact on the substantive work of the District during the closing months of this period. Edward B. Rice, the first District Chief, retired in December 1966, and Robert A. Krieger, the first Assistant District Chief, transferred to the MCA regional headquarters in St. Louis in 1966. Nathan O. Thomas served as Acting District Chief until Ralph C. Heath arrived in the spring of 1967.

Organizationally, the Raleigh headquarters took on a new look with the creation of five functional sections, added to the long-existing Administrative Services Section, still headed by Harrington. The new sections were the Surface Water Hydrology Section, an eight-person group containing engineers, a geologist, a chemist, a mathematician, and a physicist, headed by Goddard, former Chief of the SWB Hydrologic Unit; the Ground Water Hydrology Section headed by Wyrick; the Laboratory Section, with 10 chemists and technicians headed by Edward J. Phibbs, Jr.; the Hydraulics and Operations Section, a six-person engineering group led by Herbert G. Hinson; and the Records Processing Section made up largely of punch-card operators supervised by Thomas H. Woodward, formerly of laboratory operations. The first year of the new organization was a shakedown period with the major organizational changes coming after the end of the period and after the arrival of Heath.

The Subdistrict offices in Raleigh, Asheville, and Statesville continued largely unaffected by the reorganization in staff and function.

## Funding and Cooperation

Funds for WRD operations in North Carolina were from the cooperative (Coop) program, other Federal agencies (OFA), the Federal (Fed) program, and from licensees of the Federal Power Commission (FPC). More than 80 percent of the funds were in the Coop program, less than 10 percent from other Federal agencies, and even less from the Survey's Federal program. Very small amounts were available to obtain streamflow records required by FPC.

Funding for combined Branch operations, for most years of this period, is shown in the table below. At the beginning of this period, funding for SWB operations represented 68 percent of the total, QWB operations (North Carolina, only), 21 percent of the total, and GWB, 11 percent. In 1963, the last year for which figures for each Branch are available, SWB District funds were 47 percent of the total, QWB 16 percent, while GWB District funds had increased to 34 percent of the total. Funding for ground-water studies, from all sources, increased from about $30,000 in FY 1957 to more than $200,000 in FY 1963, then by the end of this period, had virtually disappeared from the cooperative program. State support remained only for the observation-well network.

North Carolina District funds
[In thousands of dollars]

| Fund source | 1958 | 1960 | 1961 | 1962 | 1963 | 1965 |
|---|---|---|---|---|---|---|
| Coop | 307.6 | 357.5 | 395.4 | 650.3 | 644.4 | 549.6 |
| OFA | 34.5 | 41.2 | 48.5 | 37.7 | 63.0 | 51.1 |
| Fed | 27.2 | 30.6 | 38.8 | 57.4 | 42.0 | 106.3 |
| FPC | 2.6 | 7.8 | 7.8 | 8.2 | 8.2 | 9.0 |
| Total | 371.9 | 437.1 | 490.5 | 753.6 | 757.6 | 716.0 |

Source: District program documents; those for 1957, 1959, 1964, and 1966 were not recovered.

### *Cooperating Agencies*

The principal State-level cooperator for all Branch programs during the early years of this period was the North Carolina Department of Conservation and Development (DCD), which later became the North Carolina Department of Water Resources (DWR), and still later the Department of Water and Air Resources. In practice, however, each Branch negotiated its principal State-level cooperative program with different State agencies, which were organizationally within the DWR. The GWB, for example, negotiated its programs at the beginning of the period, with the State Geologist, head of the North Carolina Geological Survey, an agency in the Department of Conservation and Development. The DWR supported, through the Coop program, the State streamflow-data network, the collection and analyses of chemical-quality samples from surface- and ground-water sources, sediment investigations in several stream basins, and ground-water studies in many areas of the State. In FY 1963, a rather typical year, the DWR was the cooperative partner in programs totaling more than $590,000 in a total District program of about $757,000.

The State Highway Commission was also a major cooperator with its need for flood information from the Statewide network of crest-stage gages. The Commission also funded, on a 50-50 cost-sharing basis, several flood-frequency studies and selected site investigations where its bridge-design engineers needed information on the hydraulics and hydrology of floods.

Several cities and towns cooperated financially in areal and topical water-resources investigations, most notably Charlotte, Durham, Winston-Salem, Morganton, Lenoir, Greensboro, and Asheville.

The other Federal agencies that provided funds for hydrologic assistance to their programs, each year of this period, were the U.S. Army Corps of Engineers, Soil Conservation Service, and Tennessee Valley Authority. The National Park Service funded several ground-water studies on the Outer Banks, and several departments of the Armed Services funded limited water-quality analyses from their installations.

## Summary of Program

The largest and most stable component of the District's activities during this period was the collecting, processing, and publishing of hydrologic records. Those activities that represented the largest growth, during these years, however, were areal, site, and topical studies stimulated largely by urban growth and environmental concerns.

### *Water Records*

Hydrologic data activities as of 1965 are summarized from "Water Resources Investigations in North Carolina, 1965."

Streamflow Records.—The District operated 173 streamflow-measuring and stage stations in 1965, 68 of which were classified as primary (long-term hydrologic), 55 as secondary (short-term areal hydrologic), and 50 as water-management stations operated for specific water-management needs.

A network of low-flow, partial-record stations was operated throughout the period. Stations were deleted from the network as low-flow characteristics were defined, and replaced by new stations, so that the network was maintained at about 200 stations. During droughts when streamflows fell below the 10-year recurrence interval, numerous miscellaneous measurements were made in the affected areas.

A crest-stage gage network of 120 stations on small streams established in the early 1950's was continued in operation throughout the period.

Throughout the period, the District documented notable flood events. Most notable were the floods of October 1964, in eastern North Carolina and in the headwaters of the Tennessee River in western North Carolina, that were reported by Rostvedt (WSP 1840–C, 1970).

Ground-Water Records.—The District reported 179 wells in its observation-well network in 1965, of which 105 were measured monthly, 6 weekly, 1 daily, and 67 were equipped with continuous recorders.

Water-Quality Records.—In 1965, the District reported 65 sites in its sampling network with chemical-quality samples being taken at 21 sites on a monthly basis and 33 on a daily basis. Temperatures were recorded continuously at 21 sites, observed daily at 33 sites, and monthly at 21 sites. Suspended-sediment samples were taken daily at three sites and weekly at one site. Additionally, temperature observations were recorded at the active streamflow-measuring stations each month, and samples were taken at those stations semiannually for chemical-quality analyses. Chemical and physical data were also obtained from 91 other previously discontinued sites and from about 150 miscellaneous streamflow stations.

### *Special Studies*

A listing of water-resources publications for North Carolina is contained in Open-File Report 86–226.

Among the principal studies that were conducted, all or in part, within FY 1958–65 were of the water-supply characteristics of North Carolina streams, by Goddard (WSP 1761, 1963); of the magnitude and frequency of floods on small streams in North Carolina, by Hinson (Circ. 517, 1965); and of the magnitude and frequency of floods in North Carolina, by Forrest and Paul R. Speer (open-file rept., 1962). In addition, drainage areas at selected sites on streams in the State were compiled by Walker (open-file rept., 1962, revised in 1965); Martens investigated flood inundation and the effects of urbanization on floods in metropolitan Charlotte (WSP 1591–C, 1968); and Turner studied the evaporation from Lake Michie (PP 272–G, 1966, see Part IV, "Evaporation Studies").

From 1957 to 1963, the ground-water program included a group of multicounty reconnaissance studies as well as detailed studies of individual counties, towns, and National Park Service recreational areas. From 1957 through 1963, more than 20 special ground-water investigations were undertaken, resulting in 19 reports published by the State.

Notable among these were the definitive detailed study and description of the major phosphate deposits in Beaufort County by Joel O. Kimrey published in 1965 (DCD Bull. 79, 1965). The deposits were first described by Brown and published as "The relation of phosphorites to ground water in Beaufort County, North Carolina" in Economic Geology, v. 53 (1958), p. 85–101. The results of Brown's work were later cited in a justification of a Survey budget before Congressional appropriation committees.

Other studies completed or begun within this 1957–66 period were those of the Goldsboro area, by Pusey (DWR Ground-Water Bull. 2, 1960); of the Monroe area, by Floyd (DWR Ground-Water Bull. 5, 1965; of the Southport-Elizabethtown area, by Blankenship (DWR Ground-Water Bull. 6, 1965); of the Durham area, by Bain (DWR Ground-Water Bull. 7, 1966); of the Waynesville area, by Marsh (DWR Ground-Water Bull. 8, 1966); Martin County, by Wyrick (DWR Ground-Water Bull. 9, 1966); of the Hertford-Elizabeth City area, by Harris (DWR Ground-Water Bull. 10, 1966); of the Morgantown area, by Sumison and Laney (DWR Ground-Water Bull. 12, 1967); of Pitt County, by Sumison (HA–291, 1968); of Chowan County, by Lloyd (HA–292, 1968); of the Murphy area, by Dodson and Laney (DWR Ground-Water Bull. 13, 1968); of the Raleigh area, by May and J.D. Thomas (DWR Ground-Water Bull. 15 1968); of the Asheville area, by Trapp (DWR Ground-Water Bull. 16, 1970); and of New Hanover County, by Bain (DWR Ground-Water Bull. 17, 1970).

It was also during this period that the first of a number of quantitative studies of ground water on the barrier islands, known as the "Outer Banks," were undertaken for the National Park Service and for several town and water districts. Joel Kimrey conducted the Cape Hatteras study and supervised others. Among the reports on the ground-water supply of the Cape Hatteras area were those by Brown (DWR Rept. Inv. 1, 1960); Kimrey (Part 2, DWR Rept. Inv. 2, 1960); by Harris and Wilder (Part 3, DWR Rept. Inv. 4, 1964); by Lloyd and Wilder (Part 4, DWR Rept. Inv. 5, 1968); and by Lloyd and Dean (Part 6, DWR Rept. Inv. 7, 1968). Eugene Shuter and other personnel from the Denver Hydrologic Laboratory aided in the data-collection phase of some of these projects. Also during the 1957–63 period, several ground-water studies were undertaken by District personnel at sites along the Blue Ridge Parkway for the National Park Service.

Work was underway at the beginning of the period in the automation of the preparation of quality-of-water data publications including both Water-Supply Papers and the State data publications, which were begun in 1961. Early efforts in this area were directed by Billingsley and focused on the use of automated typewriters that used data stored on punched paper tape. By 1962, the paper tape was beginning to be replaced by punched cards, which provided a more flexible and better managed storage medium. Work began on the development of computer programs for the computation of sediment loads and the processing, storage, and tabulation of other quality-of-water data in late 1962. This work served as the base for techniques and procedures used Divisionwide with the establishment of Automation and Data Management Section in the QWB in 1963.

## North Dakota

Based largely on material provided *by* Quentin F. Paulson *and* Orlo A. Crosby

### Organization and Personnel

In 1965 the North Dakota WRD Council established an Administrative Services Section headed by Gordon M. Holtan, assisted by LaRue A. Baker. There were no QWB offices in North Dakota during this period. Water-quality work in North Dakota was done by QWB personnel headquartered in Lincoln, Nebr. In July 1966, the Branches were integrated as a Division District with Harlan M. Erskine as District Chief.

#### *Surface Water Branch*

The SWB District headquarters was in the Eltinge Building at 202.5 Third Street in Bismarck until 1964 when it was moved to the new Federal Building at Third Street and Rosser Avenue. Harlan M. Erskine was District Engineer. Jelmer B. Shjeflo, Assistant District Engineer, was in charge of field-data collection. Other members of the senior staff in Bismarck included Hugh C. McCreery, office engineer until 1963 when he retired; Charles E. Schoppenhorst, (McCreery's successor); and Orlo A. Crosby, who was in charge of the highway program and miscellaneous studies. Jack R. Little, a student-trainee at the beginning of this period, and William E. Harkness, engineering aid since 1962, were promoted to engineers in 1961 and 1965, respectively. Annabell M. Jundt (1956) and Doris A. Krein (1957–65) served as District Clerks. Marjorie C. Kocon was clerk-typist from 1957 on.

The District was made up of North and South Dakota. Rapid City, S. Dak., was Subdistrict headquarters for work in South Dakota.

Field headquarters were maintained at Dickinson throughout this period and at Grand Forks until 1963 when that field headquarters was upgraded to Subdistrict status. The Grand Forks Subdistrict was responsible for the field and office work for an area in northwest Minnesota and in northeast North Dakota. Because of the extensive work on the Missouri River system, a field headquarters was operated at Williston (1960–65), staffed at first by Douglas L. Ellenbecker and later by Richard C. and Elmer F. Beard, and at Stanton (1958–65), staffed at first by Melvin A. Marlenee then by Adam Guenthner, both WAE engineering aids.

George M. Pike was in Engineer-in-Charge of the Grand Forks office until 1965 when he transferred to Helena, Mont. Engineering technician Charles E. Cornelius was placed in charge after Pike transferred. Also on the Grand Forks staff at various times were Clifford F. Schneider (left in 1958), Oren O. Holmen (joined the staff in 1963), and James D. Bohn (left in 1965). Dennis K. Stewart was promoted from student-trainee to engineer in 1958 and left about 1964.

Those in charge of the Dickinson office were Elmer E. Schroeder (1956–58), Robert E. Hedman (1958–62), and John R. Little (1963–67). Their principal assistants were engineering technicians Anton M. Mack during the entire period and Douglas L. Ellenbecker for most of the period.

Other full-time technicians during all or part of the period at one of the several offices included Leonard Bachmeier, Morris S. Brostrom, John R. Eastman, Kirth A. Erickson, James D. Heidt, Ronald H. Keating, and Roger A. Pewe.

#### *Ground Water Branch*

Until 1964, the GWB District office was in the Bureau of Mines Lignite Research Laboratory on the University of North Dakota campus in Grand Forks. Joseph W. Brookhart was District Geologist until his death in June 1960. Hans M. Jensen was Acting District Engineer for several months until Edward Bradley transferred in as District Geologist. In 1963, Bradley moved to Washington, D.C., and Quentin F. Paulson was Acting District Geologist until the District headquarters was moved to Bismarck (a Subdistrict office from 1962). Later in 1963, Delbert W. Brown was transferred from Tallahassee, Fla., to be District Geologist. The Grand Forks office then became a Subdistrict office with Paulson as Geologist-in-Charge.

Others serving in the District, then Subdistrict, Grand Forks office were: Donald G. Adolphson, Earl A. Ackroyd, Donald Akin (former District Engineer, then WAE during this period), Claud H. Baker, Jr., Evelyn M. Barker, Oscar B. Eckhoff, David L. Hill, Charles J. Huxel, Suzanne L. Jones, Thomas E. Kelly, Robert L. Klausing, John E. Powell, Philip G. Randich, Susan G. Shatraw, Barbara M. Shipe, and Henry Trapp.

At the time the District headquarters was moved to Bismarck, a field headquarters was established at Fargo staffed by Klausing, in charge, and by Hill.

Other members of the District staff in Bismarck at various times during this period were Luverne L. Albright, Clarence A. Armstrong, LaRue A. Baker, James L. Hatchett, Wayne A. Pettyjohn, Marjorie C. Pokladnik, Jeannette E. Wagner, and James D. Wald.

### Funding and Cooperation

Combined funding for surface-water and ground-water operations for most years of this period is shown in the table below. Sources of funds were the Federal (Fed) program, cooperative (Coop) funds (or services provided by State or local agencies), and funds from other Federal agencies (OFA). Federal program funds supported a few gaging stations, ground-water observation wells, and chemical-quality sampling of surface water for irrigation.

The approximate distribution of funds by Branches in FY 1958 was 66 percent SWB, 24 percent GWB, and 10 percent, water-quality activities. In FY 1965, the final year when funds were identified by Branch, SWB funds had decreased to 32 percent of the total, GWB funds had increased to 60 percent, and the remaining 8 percent supported chemical and sediment water-quality work. Program growth was largest in the county ground-water studies, supported by the State Water Conservation Commission (WCC).

North Dakota District funds, fiscal years 1958, 1961–66
[In thousands of dollars]

| Fund source | 1958 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966* |
|---|---|---|---|---|---|---|---|
| Coop | 91.0 | 208.0 | 202.9 | 192.1 | 405.5 | 414.6 | 426.7 |
| OFA | 110.0 | 204.3 | 181.2 | 158.3 | 153.5 | 167.9 | 164.1 |
| Fed | 12.6 | 24.2 | 16.8 | 36.2 | 33.4 | 36.6 | 22.0 |
| Total | 213.6 | 436.5 | 350.9 | 386.6 | 592.4 | 619.1 | 612.8 |

*Planned expenditures. Source: District program documents.

#### *Cooperating Agencies*

Early in this period, the WCC was the principal State cooperator for both Branches, primarily for the continuing statewide stream-gaging program and for studies of the geology and ground-water resources of counties and local areas. Part of the WCC funds for ground-water studies were derived from counties and cities in the State. By FY 1962, a small Coop program was in effect with the State Geological Survey (GS), supplementing WCC cooperative studies in three counties. Part of the WCC contributions and all of the GS contributions were in the form of direct services to the ground-water program rather than in cash. Continuing cooperation was also in effect with the State Highway Department that supported the operation of a network of crest-stage gages and other peak-discharge activities to provide data for the hydraulic design of highway-stream crossings. A cooperative program to provide streamflow data to the Oliver County Board of Commissioners began in 1965.

#### *Other Federal Agencies*

The U.S. Army Corps of Engineers, with its responsibility for hydroelectric power generation and maintenance of navigation channels on the Missouri River, was the major contributor of OFA funds, largely for streamflow records but also for some sediment data. Missouri River Basin Development funds were an important source of funding for the District's participation in the prairie potholes study (see Part IV, "Prairie Pothole Project"), for the data-collection activities of both Branches in North Dakota, and for significant amounts for chemical and sediment work. The Department of State funded the collection of streamflow and water-quality records at the Canadian boundary. The Fish and Wildlife Service supported a study of the ground-water resources of the James River Valley near Jamestown and the collection of hydrologic data elsewhere. The BOR, the SCS, the Public Health Service, and the Air Force also paid for hydrologic-data assistance at times during this period.

### Summary of Program

Collecting and publishing streamflow and reservoir records continued to be the backbone of the SWB program. Conducting studies of the geology and ground-water resources of areas, usually counties, was the principal GWB activity.

#### *Water Records*

Streamflow Records.—The gaging-station network grew from 89 continuous-record streamflow stations in 1956 to 107 in 1966. Records of stage were collected at six or seven lakes and reservoirs during the period. The maximum number of low-flow partial record stations operated during this period was six stations in 1960. There were 77 crest-stage gages operated in 1966, an increase of 17 during the period.

Ground-Water Records.—The ground-water observation-well program increased dramatically, with 66 wells reported in 1958, and 377 in 1965. In 1958, 2 wells were equipped with recorders and 64 were measured occasionally. In 1965, 18 wells were equipped with recorders and 359 were measured somewhat regularly but infrequently. Many were observation wells monitored during the course of ground-water investigations being made in various parts of the State.

Water-Quality Records.—In 1962 there were 16 sites where samples were taken daily or monthly for chemical analysis and 2 stations where the water temperature was measured daily. In 1969 there were 13 sites where daily or monthly chemical-quality samples were taken, 1 station where suspended-sediment samples were taken daily, and 14 stations where temperatures were continuously recorded. Additional samples were obtained for the study of the hydrology of prairie potholes.

Other Data Activities.—An analysis of the frequency and magnitude of floods in North and South Dakota, based on data from 1900 to 1950, was made by J. A. McCabe and Crosby and released to the open file in 1959.

From 1959 to 1962, Bradley supervised reconnaissance test drilling to determine the irrigation potential of the Little Muddy aquifer in northwestern North Dakota.

A major effort was made in 1960–61 to update the measurements of drainage-areas in the State. McCreery and Crosby compiled new drainage-area data using State highway-planning and USGS topographic maps and correlated the results, where appropriate, with their Canadian counterparts.

In 1965, Crosby and Robert E. West (of the Pierre, S. Dak., office), compiled records of flood stages and discharges for small streams in North and South Dakota as a progress report for the period July 1, 1954, to September 30, 1964, on the cooperative programs with the highway departments of both States (open-file rept. 1965). Crosby documented the floods of June 24 and 25, 1966, in southwest-central North Dakota (open-file rept., 1966).

Records of hundreds of wells and test holes, including water-quality data, were recorded as part of the areal ground-water program, particularly in the county ground-water studies during this 1957–66 period of history. The records were included in ground-water basic-data reports published by the State WCC and the GS. Many of the test-hole records included geophysical and lithologic logs.

#### *Special Studies*

Among the special studies conducted, all or in part, within FY 1957–66, was the study of the hydrology of prairie potholes in North Dakota (see Part IV, "Prairie Pothole Project"). Although the project was initially that of GHB staff in Denver, there was significant participation by North Dakota Branch members including Shjeflo and Paulson (Circ. 472, Shjeflo and others, 1962).

Harkness reported on the runoff to and evaporation and seepage from Froelich Reservoir near Selfridge (open-file rept., 1966).

In 1957, the ground-water program was heavily involved in small, detailed investigations at municipalities in the State that were experiencing difficulties in obtaining adequate supplies of water. By the early 1960's, however, these studies were largely being done by the WCC and the GWB District; then began a systematic appraisal of the State's ground-water resources on a county-by-county basis.

The municipalities for which ground-water studies were completed during the period, the principal investigators, number and year of the WCC and GS publication include: Upham, by Paulson (No. 26, 1957); Westhope, by Powell (No. 27, 1959); Rolla, Minto, Powers Lake, Maddock, and Hunter, by Brookhart and Powell (No. 28, 1961); Richardton, by Powell and Paulson (No. 29, 1960); Walhalla, by Adolphson (No. 30, 1960); Drake, by Adolphson (No. 31, 1961); Sanbern by Huxel (No. 32, 1961); Gackle, by Adolphson (No. 33, 1961); Northwood, by Jensen (No. 34, 1961); Alexander, by Jensen (No. 35, 1961); Ashley, by Randich (No. 37, 1962); Lehr, by Adolphson (No. 38, 1962); Hatton, by Adolphson (No. 39, 1962); Beulah, by Bradley and Jensen (No. 40, 1962); Parshall, by Schmid (No. 41, 1962); Bowbells, by Jensen (No. 42, 1962); Tiogas and Hofflund Flat, by Paulson and Powell (No. 43, 1962); Leeds, by Randich and Bradley (No. 44, 1962); Max, by Armstrong (No. 45, 1963); Berthold, by Randich (No. 46, 1963); Reynolds, by Jensen (No. 47, 1962); Lakota, by Powell and Jones (No. 48, 1962); Hoople, by Jensen and Bradley (No. 49, 1963); Linton-Strasburg, by Randich (No. 50, 1963); Hillsboro, by Jensen and Bradley (No. 55, 1963); and Devils Lake, by Paulson and Akin (No. 56, 1964).

The results of the county ground-water studies were published in three parts, (Part I, "Geology;" Part II, "Ground water basic data;" and Part III, "Ground water resources"). Those that were completed during or soon after the close of this period were, by county name, WCC and GS Bulletin number, Part number, investigator, and year of publication include: Kidder (Bull. 36), Part I, by GS personnel (1962); Part II, by Randich, Petri, and Adolphson (1962), and Part III, by Bradley, Petri, and Adolphson (1963); Stutsman (Bull. 41), Part I, by Winters (1963), Part II, by Huxel and Petri (1963), and Part III, by Huxel and Petri (1965); Burleigh (Bull. 42), Part I, by Kume and Hansen (1965), Part II, by Randich (1965), and Part III, by Randich and Hatchett (1966); Barnes (Bull. 43), Parts I (1967), II (1965), and III (1966), by Kelly; and Eddy and Foster (Bull. 44), Part I, by Bluemle (1965), and Parts II (1966), and III (1968), by Trapp; Divide (Bull. 45), Part I, by Hanson (1967), and Parts II and III by Armstrong (1967); Richland (Bull. 46), Parts I (1967) and II (1966), by Baker, and Part III, by Baker and Paulson (1967); and Cass (Bull. 47), Parts I (1968), II (1966), and III (1968), by Klausing. By 1968, all or parts of the results of similar studies of Williams (Bull. 48), Traill (Bull. 49), Renville and Ward (Bull. 50), Wells (Bull. 51), and Grand Forks (Bull. 53) Counties were published.

Other activities of the GWB staff included ground-water studies at selected ballistic-missile sites by Brown in 1965 and 1966, and the preparation of a lay-reader report describing the State's ground-water resources by Paulson (GS Misc. Ser. 16 and WCC Inf. Ser. Bull., 1962).

Maderak, of the Lincoln, Nebr., QWB staff, investigated the quantity and characteristics of sediment and quantity and kind of dissolved materials transported by the Heart River (WSP 1923, 1966). Also working out of the Lincoln office, Hugh T. Mitten, Cloyd H. Scott, Philip G. Rosene investigated changes in water quality of the lakes in the Devils Lake Basin resulting from variations in runoff and fluctuating lake levels (WSP 1859–B, 1968).

### Other District Activities

An International Joint Commission directive of May 31, 1959, created the International Souris River Board of Control to oversee compliance with measures governing distribution of waters of the Souris River. Harlan Erskine served as alternate member of the Board and was responsible for the data needed to effect proper water distribution.

## Ohio

*By* Stanley E. Norris assisted *by* Charles R. Collier *and* Lawrence C. Crawford

### Organization and Personnel

Programs were developed, administered, and executed by the Branches until July 1965, when Ohio became a Division-level District.

### *Surface Water Branch (1957–65)*

The SWB District office was at 1509 Hess Street, Columbus, not far from the Ohio State University. Lawrence C. Crawford, District Engineer until his retirement in 1961, was succeeded by John J. Molloy, who transferred from Pennsylvania. Orison H. Jeffers, Assistant District Engineer from 1957 until his retirement in 1962, was succeeded by Harold P. Brooks, who served for the remainder of the period.

Margaret M. Jordan served as secretary throughout this period, but in 1960 was assigned to a newly-formed Administrative Services Section headed by William V. Rowse. The Section served the Ohio WRD Council until 1965, when it became part of the reorganized WRD District.

Other key personnel during the 1957–65 period included engineers Harry A. Carlson, William P. Cross, Richard E. Hedges, William J. Schneider, and Earl E. Webber. Frank N. Workmaster was a technician of long and respected service to the District. Engineer Ronald I. Mayo transferred from Juneau, Alaska, to join the District in 1960.

A Subdistrict office at New Philadelphia was headed by Earl H. Curtis throughout the period. His assistants included Glenn D. Francis and Ted S. Graff. Helen E. Boyd served as secretary. Lester M. Hicks and Anthony V. Thomasina, technicians, joined the unit about 1960. Donald J. Ensminger worked out of a field office in Norwalk during this period.

Others who served on the SWB staff for more than a year during this period included Donna L. Belt, William D. Borghese, Katherine O. Eisel, Paul M. Plummer, Rodney H. Roeske, Lawrence L. Stewart, and Harriet A. Vance.

Housed in the same building with the SWB District office in Columbus were two research sections administered, respectively in 1957 by the SWB and the GHB in Washington, D.C. By 1961 these activities had been reduced to a single SWB "Field Unit." By the end of the period it had become the Instrument and Development Unit, reporting to the Branch Area Chief, MCA. These research and/or development units were headed successively by Arthur H. Frazier, Keith S. Essex, and Edgar G. Barron. Key personnel included Harold E. Cox, George F. Smoot, Harold O. Wires, and Samuel E. Rickly.

### *Quality of Water Branch (1957–65)*

The QWB office and laboratory were located in the east end of Columbus, at 2822 East Main Street, not far from the municipal airport. George W. Whetstone served as District Chemist from 1956 to 1964, when he transferred to Headquarters in Washington, D.C. Charles R. Collier was his assistant and succeeded him until reorganization of the Ohio Branch Districts into a Division District on July 1, 1965. Other key personnel in 1957 included chemists Paul G. Drake, John H. Hubble, Robert A. Krieger, Leslie B. Laird, and Garland Stratton. Merle E. Schroeder returned to the Columbus office in 1961 from Little Rock, Ark., where he had been District Chemist since 1955.

Other technical personnel who later joined the staff included Roger J. Archer, Timmy R. Cummings, Russel F. Flint, Robert J. Madison, John J. Musser, Ranard J. Pickering, Earl L. Skinner, and Herbert H. Stevens. Additionally, the QWB staff members who served for more than a year included Thomas F. Beckers, Don M. Brooks, Norma H. Carver, Jesse H. Klinger, Seymour Merrin, Beverly M. Myers, Melville W. Smith, Mary M. Underwood, Gracie F. Ward, Marjorie Mae Miller (later Zielke), Joe C. Wallace, and Joseph B. Wile.

In 1956, the QWB District operated with 14 chemists and engineers and 3 technicians; in 1960, with 11 professionals and 9 technicians and aides. There were 20 employees in 1966 in water-quality and sediment-laboratory functions: 10 professionals and 10 technicians. Most of the technicians worked in the sediment laboratory.

Water-quality studies and laboratory analyses for WRD activities in the States of Indiana, Illinois, Kentucky, Michigan, West Virginia, and Wisconsin were performed by the Ohio QWB District. Those States obtained their own water-quality staffs after reorganizing into WRD Districts in the 1960's. Sediment investigations and laboratory work also were conducted for WRD activities in the States of Indiana, Kentucky, Michigan, West Virginia, and Wisconsin.

In 1963, an Automatic Data Processing Center was established in the Columbus QWB office, where basic-data reports for the States of Arkansas, Illinois, Indiana, Kentucky, Louisiana, Michigan, Mississippi, Ohio, Pennsylvania, Tennessee, Texas, West Virginia, and Wisconsin were processed for publication.

### *Ground Water Branch (1957–65)*

The GWB District headquarters was in the Federal Building, 85 Marconi Boulevard, in downtown Columbus. Stanley E. Norris was the District Geologist until Division-level operations began in 1965. He then became Chief of the Areal Studies Section, which included the former GWB personnel. Other key personnel included Jack Baker, George D. Dove, Alvin V. Feulner, Andrew M. Spieker, John D. Winslow, and part-time employee Professor George W. White, head of the Geology Department, University of Illinois. In 1960, Winslow had left, Jon L. Rau had joined the staff, and Baker became a part-time employee. In 1961, Professor R.P. Goldthwait of Ohio State University joined the staff as a part-time employee. In 1962, both Spieker and Rau changed to part-time status, the former to pursue graduate studies at Stanford University and the latter to teach at Kent State University. Richard E. Fidler joined the staff in 1963. Bonnie J. Bricker was the District secretary.

#### *Water Resources Division (1965–66)*

John J. Molloy became District Chief in July 1965 when the Branch Districts were reorganized into a Division District. His chief assistant was Charles R. Collier. William J. Rowse continued as Chief of the Administrative Services Section Council. Norma Jean Garver, formerly of the QWB, became secretary to the District Chief.

The newly appointed District Chief moved his office from the Hess Street location to the GWB office in the Federal Building. With him were Collier and Garver. The other units (formerly Branches) remained in their original locations; however, the search began for a central location to house all personnel and activities under one roof. This occurred in 1967.

Other members of the Division-level staff, who are not listed as Branch members were Peter W. Antilla, Gene A. Bednar, Daniel P. Bauer, Lee E. Donald, Robert R. Fawcett, A. Brice Gordon, Rosalie T. James, Margaret M. Jordan, Robert L. Smith, Marjorie N. Strickling, and A. Jared Zima.

#### *WRD Project Office (1963–66)*

In 1963, a project office responsible to the Area Hydrologist (MCA) was established in Gahanna, a Columbus suburb, headed by Morris Deutsch. From a "one-man office" the unit expanded until by 1966, Deutsch had as assistants hydrologists Paul R. Jordan and George D. Dove, the latter having transferred from the GWB District staff, and technician Joe C. Wallace from the QWB District. The unit prepared water-resources reports on several subbasins of the Great Lakes Basin.

### Funding and Cooperation

The funds for water studies in Ohio came mainly from the cooperative program (Coop) and from other Federal agencies (OFA). A few thousand dollars of Federal funds were used mainly for operation of several key stream gages, sediment and water-quality stations, and observation wells.

Total funding for the 1957–66 period is shown in the following table:

Ohio District funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958* | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965* | 1966* |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 318 | 396 | 373 | 412 | 362 | 388 | 481 | 452 | 488 |
| OFA | 82 | 117 | 90 | 89 | 98 | 102 | 167 | 147 | 123 |
| Fed | 21 | NA | NA | NA | NA | NA | NA | 20 | 26 |
| Total | 361 | | | | | | | 619 | 637 |

Source: From a Headquarters compilation from unknown sources, except *. *From District program documents.

#### *Cooperating Agencies*

The chief cooperating agency in Ohio was the Ohio Department of Natural Resources (DNR), mainly the Division of Water, whose chief, C. Vernon Youngquist, was a former District Engineer of the SWB and who functioned throughout the period as coordinator of WRD programs in the Ohio River Basin. Other principal cooperators included the Miami Conservancy District, an organization headquartered in Dayton whose function was maintenance of flood-control measures centering around five local dams built after a devastating flood in the Dayton area in 1913. Other cooperating agencies were the Departments of Highways and of Health for most of the period and, at various times, there were relatively short-term programs with counties, cities, and other public entities. For most of the period there was a cooperative water-quality program with the Ohio River Valley Water Sanitation Commission (ORSANCO).

From 1952 to 1958 the QWB cooperated with the Ohio Division of Wildlife in stream-improvement studies in the Little Miami River Basin.

#### *Other Federal Agencies*

Programs in behalf of other Federal agencies included those for the U.S. Army Corps of Engineers (stream-gaging and basin studies); Bureau of Mines (mine-drainage studies); AEC (ground-water investigations); Army, Air Force; FWPCA (chemical quality studies); and Agricultural Research Service (sediment-trap efficiency studies).

## Summary of Program

The collection, processing, and publication of water records continued to be a strong but basically level component of the District program. Program growth was in interpretive studies. Topical hydrologic studies, such as those of floods and low-flow frequencies, stressed statistical analysis of available water records to improve product usefulness for design and water-management needs. Emphasis in areal and site studies gradually shifted during the period from the traditional characterization of hydrologic conditions to water-management practices and environmental impacts.

### *Water Records*

Data activities representative of this period are from information reported in "Water resources investigations in Ohio, 1962."

Streamflow Records.—In 1962, at approximately midterm of this period of history, a total of 143 continuous-record streamflow stations were being operated, consisting of 48 classified as primary (long-term hydrologic), 23 as secondary (short-term hydrologic), and 72 as serving water-management needs. Additionally, there were 113 partial-record stations, of which 31 were crest-stage gages, 64 were low-flow partial-record stations, and 18 were combined crest-stage and low-flow stations.

Ground-Water Records.—There were 213 observation wells maintained in 1962 of which 12 were considered key wells and equipped with continuous recorders. For project use, water levels were observed regularly in 74 wells and an additional 127 observation wells were maintained for other purposes. Continuous recorders were operated at 111 of the project and other wells.

Water-Quality Records.—In 1962, a fairly representative year, samples were collected daily for chemical analyses at eight sites, and records of suspended sediment were also obtained daily at eight sites. Temperatures were observed daily at 12 sites and continuously recorded at 10 sites.

The first recording of multiparameter water-quality characteristics occurred in November 1962 when a water-quality monitor was installed on the Cuyahoga River at Center Street in Cleveland, in cooperation with the Ohio Department of Health. This program increased later to a maximum of 51 monitors in operation throughout the State.

Other Data Activities.—A flood occurred in Ohio in 1959, causing inundations in cities and damage not seen since 1913. Division Chief Leopold made an emergency trip to Columbus to assess the situation. About 30 engineers and technicians were then assigned to Ohio from other districts for 3 months to gather field data under the direction of Richard H. Tice. The flood was documented by Cross and Brooks (Circ. 418, 1959).

### *Special Studies*

Among the principal water-resources investigations during FY 1958–66 were studies of the ground-water resources of counties including Madison County, by Norris (ODNR Bull. 33, 1959); Licking County (ODNR Bull. 36, 1960) and Fairfield County (ODNR Bull. 60, 1962) by Dove, and Portage County, by Winslow and White (PP 511, 1966). An analog model was used in the study by Fidler of the potential development and recharge of ground water in Mill Creek Valley, Butler and Hamilton Counties (WSP 1893, 1970).

Several important studies were made of the water resources of other areas or sites in the State including those at Dayton, where vertical leakage through till as a source of recharge to a buried valley aquifer was investigated by Norris (ODNR Tech. Rept. 2, 1959); in the Fairborn area, near Dayton, where the ground-water resources of the valley train deposits were studied by Walton and Scudder in 1955–56 (ODNR Tech. Rept. 3, 1960); of the Piqua area, proposed for Ohio's first commercial atomic reactor, where the hydrogeology of the area was investigated by Norris and Spieker (Bull. 1133–A, 1961); and at the AEC Feed Materials Production Center near Fernald where a study of ground-water movement and contamination was made (Rept. to AEC, 1962); and in the Dayton area, where the ground-water resources were investigated by Norris and Spicer (WSP 1808, 1966).

Studies of other areas include those by Spieker and Watkins of the hydrogeology of the lower Great Miami River Valley (PP 605 A, B, C, and D, 1968); of the hydrogeology of the Scioto River Valley near Piketon in south-central Ohio, by Norris and Fidler (WSP 1872, 1969); and of the hydrogeology of the Berea and Cussewago Sandstones in northeastern Ohio, by Rau (HA–341, 1969). The recharge characteristics of a watercourse aquifer system at Springfield were investigated by Norris and Eagon (Ground Water, v. 9, no. 1, Jan.–Feb. 1971).

Statewide compilations of information relevant to the ground-water resources of Ohio were a glacial map of Ohio, compiled by Goldthwait, White, and Forsyth (Miscellaneous Geologic Investigations Map I–316, 1961) and maps depicting the saline ground-water resources of Ohio, prepared by Sedam and Stein (HA–366, 1970).

Floods, regionally and topically, were reported on. Floods at Columbus were documented by Edelen (HA–52, 1962), and the magnitude and frequency of floods in Ohio was reported by Cross and Mayo (ODNR Bull. 43, 1969). Reports on other aspects of streams were written on the flow duration of Ohio streams, by Cross and Hedges (ODNR Bull. 31, 1959) and on low-flow frequencies and storage requirements for selected Ohio streams, by Cross (ODNR Bull. 37, 1963). Bauer reported on the time-of-travel of water in the Great Miami River from Dayton to Cleves (Circ. 546, 1968).

Special reports on streamflow quality included those on the quality of surface water in Ohio, 1946–58, by Hubble and Collier (ODNR Inven. Rept. 14, 1960); an analysis of water quality of the Mahoning River in Ohio, by Bednar, Collier, and Cross (WSP 1859–C, 1968); and on the water quality of the Appalachian Region, by Collier and Whetstone (HA–198, Sheet H, 1965).

### Other District Activities

During most of the period of this report, Whetstone served as the Survey representative on the Water Users Committee of the Ohio River Valley Water Sanitation Commission. The Committee focused on water-quality monitoring of the Ohio River and on standardization of analytical techniques among the various municipal and industrial laboratories along the river.

## Oklahoma

Based on material provided *by* James W. Irwin, John W. Odell, Richard P. Orth, *and* Charles W. Sullivan

WRD activities in Oklahoma were developed, administered, and executed by the Branches until July 1967 when the Branch Districts were reorganized as a Division-level District.

The GHB was represented in Oklahoma by a one-man project office during the early part of this period. The Branches, with the exception of General Hydrology, functioned as a WRD Council, with the chair rotating annually between the District Engineer, the District Geologist, and the District Chemist. Although the principal responsibilities of the GHB were separate from those of the other Branches, there was collaboration between GHB and members of other Branches in certain technical investigations and coauthorship of reports of common interest.

### Organization and Personnel

#### *Surface Water Branch*

The SWB District, headquartered in Oklahoma City, was at 210 NW 5th St. from 1957 to 1959, at 1101 N. Broadway from 1959 to 1960, and in the Federal Building and U.S. Courthouse, 200 Northwest 4th St., during the remainder of this 1957 to 1966 period.

Alexander A. Fischback, Jr., former District Engineer, West Virginia, replaced Sherman K. Jackson as District Engineer in March 1957, after Jackson was transferred to Denver, Colo., as Division Hydrologist, RMA. In October 1957, Charles W. Sullivan replaced John Horton as Assistant District Engineer following Horton's reassignment to the Director's Office at National Headquarters. Leo L. Laine, Hydraulic Engineer, functioned as a technical specialist and Katherine C. Wall was District Clerk during the entire period.

Among the other engineers on the staff at some time during this period were George R. Dempster, Jr., Clarence R. Gilbert, David L. Weiss, and Arthur O. Westfall. Other members of the SWB staff for more than a year during this period were Alfred C. Collins, Robert K. Corley, Marilyn R. Dickey, Linda L. Fithian, Clarence E. Gaines, Donald L. Hart, Paul S. Moore, William J. Murphy, Jr., Melvin J. Parham, Warner B. Pearce, Charles C. Rose, Douglas D. Spence, and Mary W. White.

Field headquarters were maintained at several locations, each a one-man office. In Elk City were DeRoy L. Bergman (to 1964), Alvin K. Clark, III (1964–65), and Lionel D. Mize (1965 on). In Pryor was Dale V. Mitchell, and in Liberal, Kansas, was Charles R. Haddock, both for the entire period.

#### *Ground Water Branch*

From prior to 1957 until 1961, the GWB District was headquartered in Norman, 20 miles south of Oklahoma City, in a building on the University of Oklahoma campus that also housed the Oklahoma Geological Survey. In 1961, the District office was moved to the Federal Building in Oklahoma City where SWB District headquarters was located.

Alvin R. Leonard served as District Geologist until 1964, when he transferred to Oregon. He was succeeded by James W. Irwin, who transferred in from the Operations Section of the GWB at National headquarters.

Professional members of the GWB staff in the early part of this period and prior to the move to Oklahoma City included geologists Leon V. Davis, Ira W. Marine, Harry H. Tanaka, and Porter E. Ward; engineers Lee C. Burton, Jerrold R. Hollowell, Carl E. Steele, and Wayne Steele, and technician Don L. Hart, Jr. (son of Don L. Hart in SWB). By 1962, the professional staff had been reduced by transfer and resignation to Leonard, Tanaka, and Hollowell. Don Hart, Jr., was still on the roster. In 1963, Perry R. Wood transferred from Sacramento, Calif., and in 1966 Melvin V. Marcher arrived from Anchorage, Alaska. Alice F. Moses was a member of the staff during this entire period.

Field headquarters were maintained at several locations for brief periods in order to facilitate project operations. In the Oklahoma City field headquarters was Bill L. Stacy (1957); in Woodward, Marvin E. Davis (1957); and in Elk City, Robert K. Smith (1961 on).

### *Quality of Water Branch*

In 1957, the QWB District headquarters and laboratory were in World War I "temporary" buildings that served as a warehouse/service area for the General Services Administration at 2800 S. Eastern Street in Oklahoma City. It was not until the reorganization after the close of this period that the office and laboratory were moved to join the other Branches in the Federal Building and U.S. Courthouse in downtown Oklahoma City.

Tyrus B. Dover was District Chemist until late 1958, when he became the first QWB Area Chief, MCA. He remained in Oklahoma City until 1960; then he moved to St. Louis. In 1958 he was succeeded by Richard P. Orth, formerly of the Sacramento, Calif., QWB District. Orth served as District Chemist for the remainder of this period and was assisted successively by John J. Murphy and Timmy R. Cummings, who served in dual roles as Assistant District Chemist and laboratory supervisor. Ralph F. Pascoe became laboratory supervisor shortly before the end of this period. Other members of the QWB staff for more than a year were chemists Gene A. Bednar, James W. Clark, Louise Degaris, Buddy W. Harbin, and Clyde O. Pate, technicians Dale M. Ferree, Jerome F. Haag, Thomas E. Waldrep, and Marjorie J. Webster, and typists-stenographers Inez M. Graham and Kathryn Sue Spenser. In addition, there were two Oklahoma Water Resources Board employees assigned full time to the District to collect water samples and several University of Oklahoma chemistry students employed part-time.

### *General Hydrology Branch (1958–62)*

The GHB maintained a one-person project office in Oklahoma City from 1958 to 1962 that shared space and facilities, including clerical services, with SWB District headquarters. Frank W. Kennon, engineer, was project chief.

Kennon studied the hydrologic effects of 22 flood-retarding structures in the Sandstone Creek watershed in western Oklahoma. The structures were built by the SCS, which requested the study to help answer questions that arose in the small-dam versus large-dam controversy.

## Funding and Cooperation

Funds for WRD operations in Oklahoma were largely from the cooperative (Coop) programs, lesser amounts from other Federal agencies (OFA), and much less from the Federal (Fed) program. Federal funds supported the operation of a few gaging stations, observation wells, and sampling sites and, in 1958, several special projects that were outside normal District operations, such as the completion of the Lake Hefner evaporation study, land-use evaluation in the Sandstone Creek watershed, and a demonstration report on the water resources of the State (see Part IV, "Water Resources of States").

As shown in the following table, the total WRD program was fairly stable; however, the GWB program funds ranged from a high of $107,000 in 1958 to a low of $66,000 in 1965 and, for these 9 years, made up about 23 percent of the WRD total. SWB funds varied between $150,000 and $215,000 per year from all sources and was about 50 to 60 percent of the total. QWB funds were between $70,000 and $100,000 per year and averaged about 20 percent of total WRD program funds. For the GHB operations in Oklahoma, only FY 1958 funding records are available. Its funding for that year, at 5 percent of the total, was $17,000.

Oklahoma WRD Program funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 208 | 154 | 220 | 301 | 230 | 242 | 228 | 204 | 263 |
| OFA | 83 | - | - | - | 105 | 128 | 126 | 83 | 77 |
| Fed | 45 | - | - | - | 10 | 9 | 18 | 18 | 24 |
| Total | 336 | - | - | - | 345 | 379 | 372 | 305 | 364 |

Source: District program documents, except figures for FY 1959–FY1961, which are from Headquarters compilations of lesser reliability.

### *Cooperating Agencies*

The Oklahoma Water Resources Board (OWRB, Forrest Nelson, Director) was the principal cooperator during this period for statewide water-resources investigations.

The Oklahoma Geological Survey (OGS, Charles J. Mankin, State Geologist) continued its cooperative support of ground-water investigations that began in 1937.

In 1963, a cooperative program with the Oklahoma Highway Department was started to provide peak-runoff data from drainage areas of from 1 to 10 square miles to provide data for the hydraulic design of bridges and culverts. Small streams at about 100 sites in the State were equipped with crest-stage recorders in support of this program.

The Oklahoma State Health Department provided funds through the cooperative program for water-quality sampling by the QWB.

Oklahoma City cooperated in the operation of several gaging stations to acquire data for the design and operation of municipal water facilities.

#### *Other Federal Agencies*

Other Federal agencies that provided major funding to the Survey to obtain hydrologic information for certain planning or operational needs of those agencies were the U.S. Army Corps of Engineers, the BOR, and the SCS. The Corps funded the GWB to study the hydrology of the alluvium of the Arkansas River and funded the SWB to operate several gaging stations. The Corps also assisted in the collection of surface-water samples for chemical analysis and furnished streamflow records collected by its personnel for review and publication by the Survey. The BOR and the SCS repaid the District for operating certain streamflow, sediment, and chemical-quality sampling stations.

Other Federal agencies that requested and funded short-term assistance included the Public Health Service, Bureau of Indian Affairs, and Air Force. The Agricultural Extension Service at Oklahoma State University, through its county agents, collected ground-water samples and other data in support of the QWB District's ground-water-quality program.

### Summary of Program

Collecting, processing, and publishing streamflow and reservoir data continued to be the mainstay of the SWB District's program. The GWB continued its program of countywide ground-water studies, began a series of hydrologic studies of 2-degree quadrangles, and continued monitoring ground-water levels through its extensive network of observation wells. The QWB's major program effort was the continued development and operation of a network of stations to define the chemical character of surface water in the State. Its ground-water-quality program was small and mainly confined to western Oklahoma.

#### *Water Records*

Water records are summarized from information reported in "Water resources investigations in Oklahoma, 1962."

Streamflow Records.—In June 1962, 132 continuous-record streamflow stations were operated in the State, of which 48 were classified as primary (long-term hydrologic), 38 as secondary (short-term hydrologic), and 66 as water management (specific purpose).

Ground-Water Records.—During 1962, observations of ground-water levels were made at 420 wells. The frequency of measurement of these wells was annually at 237, quarterly at 38, monthly at 129, and continuously at 16 wells. In addition, 310 wells were measured semiannually, 55 monthly, and 20 continuously for projects and special investigations. Selected water-level records for western Oklahoma were released to the open file.

Water-Quality Records.—During 1962, chemical-quality data and measurements of temperature were obtained daily at 29 stream sites and sediment data at 1 site. In addition, chemical-quality data were collected periodically (nine or more samples per year) at 49 stream sites and at miscellaneous times (eight or fewer samples per year) at 63 stream sites. During 1965 and 1966, data activities accelerated and samples were obtained at 275 irrigation, stock, and domestic wells in 38 counties.

Other Data Activities.—In addition to normal USGS publication, data and text material were prepared by QWB staff for use by the OWRB in its annual reports titled "Chemical character of surface waters of Oklahoma," for the years 1946–63.

The Water Quality Act of 1965, P.L. 89–234, required each State to publish water-quality standards for interstate streams. The QWB District furnished data, supervised the statistical analyses of the data, and wrote the text that described the general character of surface waters for the published standards.

#### *Special Studies*

Laine was the principal investigator of the surface-water resources of several stream basins in Oklahoma during this period. All reports of these studies were released to the open file. Included were the Washita River Basin (1958), North Boggy Creek in the Muddy Boggy Creek Basin (1958), Little River Basin in central Oklahoma (1959), Illinois River Basin in Arkansas and Oklahoma (1959), Cottonwood Creek in the Cimarron River Basin in central Oklahoma (1962), Kiamichi River Basin in southeastern Oklahoma (1963), and, with John J. Murphy, the Beaver Creek Basin in south-central Oklahoma (1962). Most also contained descriptions of the chemical character of the water by Tyrus B. Dover, Richard P. Orth, or Timmy R. Cummings.

Kennon reported on his study of the hydrologic effects of small reservoirs in Sandstone Creek in Beckham and Roger Mills Counties (WSP 1839–C, 1963). He concluded that although water losses attributable to the reservoirs were about 20 percent of natural flows, streams below the dams changed from ephemeral to perennial with corresponding changes in riparian vegetation, conveyance, and shape. As a part of Kennon's larger study, significant channel changes were also reported in Sandstone Creek near Cheyenne by Bergman and Sullivan (PP 475–C, 1963).

The geology and ground-water resources of counties and local areas were studied and reported on by members of the GWB staff including southern McCurtain County, by Davis (OGS Bull. 86, 1960); Canadian County, by Mogg, Schoff, and Reed (OGS Bull. 87, 1962); Beaver County, by Marine and Schoff (OGS Bull. 97, 1962); the Rush Springs Sandstone in the Caddo County area, by Tanaka and Davis (OGS Circ. 61, 1963); Woodward County, by Wood and Stacy (OWRB Bull. 21, 1965); the terrace deposits of central Beckham County, by Burton (OWRB Bull. 25, 1965); the alluvial deposits of the Washita River between Clinton and Anadarko, by Don Hart, Jr., (OWRB Bull. 26, 1965); the alluvium of Otter Creek Basin, by Hollowell (OWR Bull. 27, 1965); Harmon County and adjacent areas of Greer and Jackson Counties, by Steele and Barclay (OWR Bull. 29, 1965); and Cleveland and Oklahoma Counties, by Wood and Burton (OGS Circ. 71, 1968).

Beginning in 1965, the shift was made from county or small area ground-water studies to water-resources appraisals at the reconnaissance level, with emphasis on ground water, and of 2-degree quadrangles. Among the first of these was the Fort Smith Quadrangle by Marcher (OGS HA No. 1, 1969). Others in this series were begun in 1967 and 1968 by Marcher, Don Hart, Jr., and David B. Sapik.

Another significant report was that of the chemical character of surface waters of Oklahoma, 1962–63, by Cummings (OWRB Bull. 30, 1966).

### Other District Activities

Keystone Reservoir, built by the Corps of Engineers on the Arkansas River downstream from its confluence with the Cimarron River, began filling in 1964. Orth and others found that the highly saline inflow from the Cimarron River was stratified and anaerobic at lower depths in the reservoir. Orth discussed his findings with representatives of Federal and State water agencies. Later, the Corps began releasing water from upper and lower depths simultaneously to minimize odor and damage to downstream aquatic life.

Oklahoma was selected as one of several Districts to prepare a report on the water resources of the State, written with the informed layman as its audience (see Part IV, "Water Resources of States"). "Water for Oklahoma" was an interbranch effort involving Dover, Leonard, and Laine (WSP 1890, 1968).

During the late 1960's, the GWB and QWB assisted the OWRB in a series of public meetings held in about 70 county seats. The purpose of the meetings was to acquire local input to water-resources development. Irwin and others of GWB and Orth of QWB made presentations at the meetings, which became known as "The Forrest Nelson Minstrel Shows." This activity resulted in 12 regional reports by the OWRB. Each report contained descriptions of ground water and quality of water that were prepared by members of the Branches.

## Oregon

Based on material provided *by* Roy B. Sanderson, Kenneth N. Phillips, Reuben C. Newcomb, *and* Leslie B. Laird, with subsequent assistance from Alvin R. Leonard

Programs in Oregon were planned, developed, and carried out by the individual Branches throughout this 1957–66 period of WRD history. Oregon became a Division-level District on July 1, 1966, with Stanley F. Kapustka as District Chief.

### Organization and Personnel

#### *Surface Water Branch*

The Oregon SWB District began the period 1957–66 headquartered in the Interior Department Building at 1001 NE Lloyd Boulevard in Portland. The headquarters office was moved in 1960 to 830 NE Holladay Street and again in 1962 to the old Post Office Building, 511 NW Broadway.

Kenneth N. Phillips served as District Engineer with Wallace A. Brownlie, Rufus W. Childreth, Harry Hulsing, and Albert M. Moore as his principal assistants. Alta G. Conrad headed the clerical and secretarial staff. Albert B. Goodwin joined the District staff in Portland in 1959 after Hulsing transferred to the California District.

In 1962, after 42 years with the Geological Survey and 14 years as District Engineer in Oregon, Phillips retired. But he immediately returned to work as a reemployed annuitant to devote his time and energy to a "closed-lake" study being made with the QWB. His successor, effective in September 1962, was Roy B. Sanderson, who had completed a 2-year tour of duty in the Office of the Chief, SWB.

In October 1962, District personnel and friends of Goodwin were shocked and saddened to learn that he had succumbed to a heart attack while assisting Phillips collect field data for the "closed-lake" study.

With Brownlie's transfer to Hawaii early in 1962, Sanderson's remaining principal staff in Portland were Moore, Nicholas A. Kallio and Childreth, with Conrad in charge of the clerical unit. The arrival of David D. Harris, a former Oregon District employee, from the Colorado District in April 1963 helped alleviate the manpower shortage.

Because of program changes and an increasing emphasis on hydrologic studies, some Portland office personnel were reassigned to different duties and sections. A Basic Records Section was established with Kallio in charge, and a Hydrologic Studies Section was set up with Harris in charge, assisted by John Friday and Charles H. Swift. Childreth was placed in charge of the Portland Subdistrict, the largest of the Oregon Subdistricts.

The La Grande Subdistrict, with Francis J. Cleaver in charge, was staffed with three to four hydrographers throughout the period. Cleaver and his staff took great pride in being the first Subdistrict to complete its records after the end of the water year. For this and other commendable aspects of his work, Cleaver was given a Superior Service Award.

The field headquarters in Eugene was elevated to Subdistrict status in 1961. It was staffed with three to five hydrographers with David L. Weiss in charge until January 1960 when he was transferred to the Oklahoma District. John L. Ebling was in charge for the remainder of the period.

The Salem Subdistrict was unique in that it was staffed by only one engineer, Gordon J. Backe, throughout the period. Backe worked closely with the State Engineer's hydrographers and was responsible for the quality of the State-furnished surface-water records published by the Survey.

The Medford Subdistrict, DeWayne L. Miller initially in charge, was generally staffed with three hydrographers and a clerk-typist. In February 1958 Miller drowned while measuring the Applegate River near Ruch. Miller's replacement was Albert B. Harris, who arrived from the Utah District in August 1958 and remained in charge of the Medford Subdistrict for the remainder of the period.

Other full-time employees who served in surface-water programs for more than about 2 years at one or more locations in the District included James M. Abbott, Donald J. Baldrica, Howard L. Bjork, Blanche C. Crombie, Russell W. Cruff, G. Louis Ducret, Jr., Richard M. Edmond, Wilmer D. Eicher, Rae E. Gardner, Donald H. Giles, William A. Hart, Peter V. Jeffs, Philip M. Kielhorn, H. Duane King, Richard L. Kraus, Margaret L. Mercer, Parley Merrill, James L. Moore, Eugene A. Oster, John K. Page, Forrest N. Pitts, Neil B. Sherwood, G. Bryant Smith, Edward H. Stolte, Charles E. Swan, John R. Taylor, and Mary Jean Warwick.

The Portland Current Records Center continued to function as an office of the Branch Area Chief, PCA, throughout the period with Hollis M. Orem in charge, assisted by George E. Philipsen, Edward H. Stolte, and Edith M. Moore.

### *Ground Water Branch*

The GWB District headquarters was located in the Interior Department Building in the Lloyd Center in Portland until 1961 when it was moved to the Post Office Building at Broadway and Glisan where it remained until after the reorganization of mid-1966.

In 1957, a field headquarters for District work at the Hanford Atomic Energy Reservation was in Richland, Wash., staffed by Florian J. Frank and several drillers and helpers. The Hanford work was completed in 1958, the Richland office was closed, and Frank transferred to Idaho to work at the National Reactor Testing Station near Arco.

The GWB program in Oregon was directed by Reuben C. Newcomb until Bruce L. Foxworthy transferred from Tacoma, Wash., in 1959. Foxworthy was District Geologist until 1964 when he moved to Mineola, N.Y. Acting District Geologist Eugene R. Hampton was in charge until mid-1966, when the District was integrated into Division-level operations. In 1957 Glenmore M. Hogenson transferred to California. In 1959 Stuart G. Brown moved to Arizona and Donald Price arrived from Utah. In 1965 newly recruited Donald C. Helm started work. At about the end of this period of history, Frank returned to Portland.

Changes in the clerical staff saw Ruth L. Smith retire in 1959, Jean W. Zinzer resign in 1961, and Nyra A. Johnson succeed Zinzer. Both Zinzer and Johnson were recruited from the Forest Service stenographer pool, a situation for which the Forest Service officials voiced their disapproval (but not very loudly, because they enjoyed trying to recruit our engineers).

After Newcomb transferred from District operations to a research project in 1960, he occupied adjacent office space and worked with the same clerical staff.

### *Quality of Water Branch*

In 1957, the QWB District headquarters was located in the Interior Department Building in offices adjacent to those of the SWB and GWB. Its laboratory, however, was in Troutdale (about 15 miles east of Portland) in space provided by the U.S. Army Corps of Engineers in their Materials Testing Laboratory. In 1959, the laboratory and District office were combined in the basement of the 830 Holladay Building in Portland.

In 1962, a field office was established in Pasco, Wash., to handle data collection for the radionuclide study in the upper reaches of the Columbia River. In 1964, the Pasco office functions were expanded to include project investigations and additional hydrologic data collection. Phillip R. Boucher supervised the Pasco operations during this period.

In 1957, the Oregon QWB District was under the direction of Herbert A. Swenson, District Chemist; John F. Santos served as Principal Assistant. The District responsibilities included QWB field activities in Idaho, Oregon, Washington, and part of Montana; however, the activities in Montana were reassigned to the Worland, Wyo., office in FY 1959.

In January 1958, Swenson transferred to the QWB headquarters in Washington, D.C., and was replaced by Leslie B. Laird, from Columbus, Ohio. Laird served as District Chemist until August 1964, when he transferred to Tacoma to become Chief of the new Division-level Washington District. David W. Hubbell was the Acting District Engineer from August 1964 until July 1965 when Lawrence G. Bodhaine arrived from Denver, Colo. Bodhaine was the District Engineer until mid-1966 when the Branch activities in Oregon were reorganized and Stanley E. Kapustka transferred from California to become District Chief.

In 1957 the staff of the QWB District consisted of two professionals and a part-time technician but grew in response to two particular program surges to reach a total of 30 people in 1963. Robert C. Williams arrived from Wyoming in 1960 to head a study of the sediment protection of forested watersheds in the State. In 1965, five people transferred to Tacoma in connection with the establishment there of a Division-level District; however, the Portland laboratory continued to perform water-quality analyses for WRD programs in Washington State until 1966.

During the period 1957–66, at least eight long-time QWB employees started their careers in the Portland office: Jerry D. Stoner (1958); Charles T. Bryant (1959); Norman F. Leibbrand (1959); Patrick A. Glancy (1961); Charles A. Onions (1962); Edmund A. Prych (1963); Johnson J.S. Yee (1963); and James B. McConnell (1964).

Other full-time QWB employees who served more than about 2 years with the District included Mona J. Anagnostis, Earl R. Anthony, Charles B. Behlke, Virginia N. Burke, George R. Dempster, William L. Haushild, Sandra L. Huffman, Anna S. Homer, Karna K. Lewis, Robert J. Madison, Margaret M. Marchington, Robert E. Sommer, Jr., John M. Stalp, Herbert H. Stevens, Jr., and Albert S. Van Denburgh.

## Funding and Cooperation

Funds for surface-water investigations in Oregon were from the cooperative program (Coop), other Federal agencies (OFA), and the Survey's Federal program (Fed). The Coop funds were the most stable from year to year and, for most years, provided the largest amounts. OFA funds were provided by those Federal agencies that required hydrologic assistance in support of their planning, operating or regulatory functions. Funds were also provided by licensees of the FPC for streamflow records where required by the terms of the licenses. Federal program funds normally supported a few gaging stations and sampling sites where the Federal interest was strong but were also available for special investigations such as the "closed lakes" studies, following catastrophic events such as the floods of December 1964 and January 1965 in Oregon and adjacent States, and for special needs such as the cost of the boat, *SURVEYOR*, built for gaging The Dalles.

Financing for the ground-water work was mainly: (1) cooperative programs with the State Engineer, which was about $10,000 per year, each side, (2) cooperation with local governmental agencies (such as the city of Florence), and (3) an entirely Federal program for areas of primarily Federal interest, such as the Umatilla River Basin (WSP 1620, 1964), the Fort Rock Basin (PP 383–B, 1964), and some observation wells. The research project on the water-bearing characteristics of the Columbia River basalt had its first papers on subprojects published during this decade; these were on general features of the ground-water occurrence and on the effects of tectonic structure (PP 383–C, 1969)

Funds for water-quality work in the Pacific Northwest were very limited in 1957, consisting of $27,000 from Federal funds for the collection of basic records, only about 20 percent of which was in Oregon. Oregon State agencies supported a small amount of data collection but had almost no interest in interpretive studies. In 1960, the first major program increment occurred when a cooperative program was started with Washington State Division of Water Resources and the State Pollution Control Commission. This program, the first broad-scope water-quality study by any agency in Washington, provided information upon which the State's water-quality standards were ultimately based. This program increased Portland District water-quality funding to over $100,000 in 1960; staffing increased to 12.

The second major program increase occurred in 1962 when the AEC funded a study of radionuclide transport by the Columbia River from the Hanford Works through the Columbia estuary.

Growth of the Columbia River radionuclide studies as well as cooperative programs in Washington State increased the District's total quality-of-water program from more than $300,000 in 1962 to almost $700,000 in 1964. Funding dropped to about $500,000 in 1965.

Precise records of funding from all sources and all years are not available; however, the following table contains reliable figures for 1958 and 1965. Internal program documents are available for those 2 years only. The remaining amounts shown in the table are from unofficial accounting documents and are considered reliable within about 10 percent. The table, even with shortcomings, indicates the general scale of funding for WRD programs in Oregon during this period of history.

Oregon District funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 179.4 | 210 | 222 | 263 | 280 | 282 | 324 | 325.3 | 350 |
| OFA | 61.5 | NA | NA | NA | NA | NA | NA | 370.2 | 435 |
| Fed | 81.7 | NA | NA | NA | NA | NA | NA | 144.5 | NA |
| FPC | 28.2 | 27 | 29 | 32 | 39 | 38 | 41 | 40.5 | 42 |
| Total | 350.8 | | | | | | | 880.5 | |

The cooperative program in Oregon was unique in that the District placed a Survey employee in the principal cooperator's office (State Engineer) to supervise the computation of streamflow records collected by the State but published by the Survey. This arrangement was a contributing factor to the excellent relationship shared with the State Engineer (Chris Wheeler) and his employees. Other cooperators such as the various irrigation districts and counties (particularly Lane County) were staunch supporters of the Survey's work and published records.

Power development in Oregon resulted in the need for many streamflow records by other Federal agencies, particularly the Corps of Engineers. These demands combined with special needs such as the *SURVEYOR* and the acoustic velocity meter at The Dalles resulted in the transfer of considerable funds from other Federal agencies. Negotiations for these funds were generally conducted with one individual from each agency who in turn "rode herd" on the request through his agency of government. The Oregon District is indebted to Mark Nelson, Corps of Engineers; Harold Hafterson, Bureau of Reclamation; and Fritz Limpert, Bonneville Power Administration, for their foresight and efforts in obtaining funds for hydrologic investigations, instrumentation, and data.

## Summary of Program

Collecting, processing, and publishing water records continued as the major SWB effort; however, there was an increasing emphasis on interpretive studies during this period.

The GWB work continued along the general lines of Arthur M. Piper's 20-year program that had been followed during the preceding postwar decade. The main goals of the plan were (1) statewide coverage of the general occurrence of ground water, (2) detailed reports on the more important water-use areas, and (3) technical research and reports on many of the ground-water-related problems. The program was financed adequately for about four investigators, which was about half the force needed, but it accomplished a great deal toward a comprehensive understanding of the basic ground-water conditions. Besides the project investigations, the collection of field data statewide on ground-water levels and the chemical composition of ground water was continued during the period.

Progress was made on the statewide ground-water reconnaissance studies, and more detailed work was proceeding in some project areas. Among the latter were investigations into the occurrence of ground water in Ghyben-Herzberg lenses and perched conditions in coastal dunelands, under confined and unconfined conditions in volcanic rocks, and in a bank storage situation along the Columbia River. The paper by Brown and Newcomb on bank storage (WSP 1539–I, 1961) was the first on that subject—the occurrence of which had been described and named by O. E. Meinzer in the early decades of the century.

During this period and its predecessor decade, a great advancement had been made in knowledge of the ground-water resources of Oregon. The question of where (its locations), had been largely answered. The questions of quantity and quality had yet to be conclusively answered in many parts of the State.

### *Water Records*

Streamflow Records.—The number of gaging stations operated by the District was 434 in 1964, of which 91 were classified as long-term hydrologic, 23 were short-term hydrologic, 229 were for water-management purposes, and 91 recorded peak stages.

Ground-Water Records.—Ground-water levels were measured four to six times per year in 707 wells, monthly in 34 wells, and continuously in 3 wells during 1964. From 1953 through 1959, the Portland laboratory performed about 1,300 adjusted complete chemical analyses of water samples. For the period 1960–66, almost 20,000 analyses were made.

Water-Quality Records.—Chemical-quality data were obtained at sites on 12 streams and sediment-transport data at 20 sites during 1964.

Other Data Activities.—During December 1964 and January 1965, Oregon and areas in adjacent States were subjected to record-breaking floods that caused extensive property damage and the loss of 47 lives. The District suffered extensive damages to or losses of gaging facilities. In many areas in Oregon, peak discharges occurred that were the greatest of record. Harris spearheaded the effort to determine peak flows by indirect methods. With Arvi O. Waananen and Robert C. Williams, Harris described the flood and documented the water and sediment discharges (WSP 1866–A&B, 1971).

Personnel of SWB, GWB, and QWB were actively involved in the Willamette Basin Comprehensive study from 1964 to 1966. This study was initiated by the Columbia River Basin Interagency Committee in January 1963 and evolved into the Willamette Basin Task Force, a Federal-State-local interagency group that involved representatives of 20 Federal, 17 State, and 2 local agencies. Its mission was to develop a comprehensive plan for the development of the land and related water resources of the Willamette River Basin. Among its 13 committees was the Hydrology Committee, chaired by Alvin R. Leonard, who transferred to Portland in early 1965 to fill that assignment. The Hydrology Committee, made up of representatives of six Federal and two State agencies, was responsible for preparing the Hydrology Appendix to the main report on plan formulation. Leonard wrote the ground-water chapter and several other section of the appendix; Eugene A. Oster prepared a runoff map of the basin that was also published as HA–274 (1968); Swift made special streamflow data analyses; and Moore compiled stream-temperature data collected by the Survey and by other agencies that was also published as Circular 551 (1968). He had previously investigated the correlation and analysis of water-temperature data for Oregon streams (WSP 1819–K, 1967). Onions wrote the sediment-discharge section and Madison provided the chemical-quality section of the appendix. David D. Harris supervised time-of-travel studies in the basin, the results of which were published in HA–273 (1968).

District staff who contributed to other Task Force appendices included Hampton, who helped prepare the geology and physiography sections of the Study Area Appendix, and Kallio, who contributed to the Flood Control Appendix.

The Oregon District was one of the first districts to utilize fluorescent-dye tracers to determine (1) traveltimes and travel rates of water, (2) discharge where standard methods of measuring were not applicable, and (3) dispersion characteristics of streams. By the end of this period of history, dye tracers had been used to collect hydrologic data on 2,350 miles of stream channels in the Long Tom, Umpqua, Willamette, and John Day River Basins, and in the Carmen-Smith power tunnel.

The first of these investigations and the one creating the most interest was conducted on three streams in the Umpqua River Basin being considered for dam sites. Traveltime of the hypothetically reduced flow, and resultant effects on water temperatures, on fish habitat, and on pollution abatement were essential considerations in the dam-site studies.

Indicative of the interest in the Umpqua study, other Federal and State agencies contributed manpower, transportation, and equipment for the investigation. Henry C. Riggs and Thomas J. Buchanan came from Branch headquarters with two fluorometers to assist in the project. With Harris, Childreth, and all personnel from the Eugene Subdistrict plus personnel from State and other Federal agencies, Sanderson put together a 23-man team, and in an "around-the-clock" operation, time of travel was measured in 233 miles of streams in 53 hours. Despite discharges exceeding 17,000 $ft^3/s$ only 23 gallons of dye was used. Harris supervised the remainder of the dye-tracer studies in Oregon. The results were presented by Harris and Sanderson in a paper published by the AWRA (Water Resources Bull., vol. 4, no. 2, June 1968).

Records of discharge for the Columbia River at The Dalles are vital to the management of the complex water-development projects in the Columbia River Basin. The destruction of the cableway in 1953 from which discharge measurements were made required that measurements be made by boat or from a distant bridge, neither of which produced accurate results. The problem became more severe after the Dalles Dam was completed in 1957 and the gage had to be relocated to a site that was in backwater from Bonneville Dam.

As a replacement cableway was not feasible, a specially designed and constructed boat was determined to be the best streamflow-measuring platform. To obtain financing, estimated at $54,000 of which the Survey was to provide $9,000, Sanderson appeared before the Columbia Basin Water Management Committee and obtained supplemental funding commitments from the U.S. Army Corps of Engineers, Bonneville Power Administration, and the BOR.

Kallio was named project chief for developing the measuring boat. He was assisted by Sanderson, Childreth, Swift, and H.L. Bjork.

Plans for the jet-powered measuring boat, later christened *SURVEYOR*, and its equipment were to include numerous innovative features including (1) a 350-pound weight to anchor the current meters to the river bottom rather than suspending them from the boat; (2) a spring arrangement at the open well to compensate for vertical movement of the boat caused by wave action; (3) simultaneous use of two current meters positioned at 0.2 and 0.8 of the depth; (4) simultaneous registration of meter revolutions and elapsed times by electromechanical counters and timers; (5) lights on the pilot's instrument panel to note deviation-from-vertical of the sounding line as it emerged from the open well and used to correct for positioning; and (6) a radio-signal phase-comparison system (Tellurometer) to fix distances for stationing. The design was underway as this period of history ended.

Results of studies elsewhere by Winchell Smith and Harold O. Wires indicated an acoustic velocity meter might prove feasible at The Dalles. Success by the Westinghouse Corporation in its development led to a decision by the Survey to finance an installation of such a meter at The Dalles. Preliminary work was initiated and some phases completed by the end of this period.

#### *Special Studies*

Phillips, Newcomb, Herbert A. Swenson, and Leslie B. Laird coauthored "Water for Oregon" (WSP 1649, 1965), an attractive, well illustrated, and interesting publication written for the nontechnical reader. (See Part IV, "Water Resources of States.")

In 1959 Robert C. Williams began a study of sedimentation in three small forested watersheds in the Alsea River Basin (Circ. 490, 1964).

The Columbia River radionuclides study that began in 1962 was one of the first studies in the world of transport of radionuclear compounds by a major river system. William L. Haushild was the project chief of the study of the river above the estuary, and David W. Hubbell led the estuarine investigations. They were supported by an outstanding staff including Chintu Lai, Edmund A. Prych, and Herbert H. Stevens. These studies produced an array of Survey publications and technical journal articles. The studies also required the development and application of some unique equipment and techniques, one of which was an electromechanical vibrating corer. This equipment, developed largely by Prych and Hubbell, collected cores of underwater sediment deposits in the estuary. The corer design was later utilized by the Corps of Engineers and still later developed into a commercial product by a private company. (See Part IV, "Columbia River Radionuclide Studies.")

Newcomb's principal efforts in 1960 and 1961 were to complete several reports such as those for the Walla Walla River Valley (State Dept. Cons., Div. Water Resources Water Supply Bull. 21, 1965) and the Hanford Atomic Energy Reservation (PP 717, 1972). Price produced reports on areas such as French Prairie (WSP 1833, 1967) and the Burnt River Basin (WSP 1839–I, 1967).

Foxworthy and others wrote several reports on artificial recharge through wells in volcanic rock aquifers (Price, Hart, and Foxworthy, WSP 1594–C, 1965; Foxworthy and Bryant, WSP 1594–E, 1967; and Foxworthy, WSP 1594–F, 1970).

Kallio studied the effect of vertical motion on current meters (WSP 1869–B, 1966).

Results of the studies by Phillips (SWB) and Steve Van Denburgh (QWB) of the "closed-basin lakes," Crater, Davis, and East Lakes, were published in WSP 1859–E (1968), and of Abert, Summer, and Goose Lakes, and other closed-basin lakes in south-central Oregon in PP 502–B (1971).

#### Vignette

The Columbia River nuclide-transport studies almost didn't get started. In the spring of 1961, the AEC held an interagency meeting in Portland outlining their needs for information related to the impact of Hanford Works activities on the Columbia River and the Estuary. The AEC Division Chief personally requested Laird to submit an investigation proposal, which Laird did after consulting with S. Kenneth Love, Chief, QWB. Within days, Director Nolan received a letter from the Commissioner of AEC "accepting the USGS proposal for the investigation of the Columbia River." Nolan hit the ceiling and demanded that "this Laird be brought to Washington to be informed that only the Director could accept programs from other Federal agencies." Some judicious suggestions by

Headquarters staff led to a "field investigation committee" visiting Portland. This committee, consisting of Raymond Nace, Associate Division Chief; Adrian Williams, Assistant Chief SWB; Warren Hastings, Assistant Chief, QWB; and others, reviewed the proposal onsite, and it was approved with only the deletion of the part of the proposal dealing with nuclide transport in the biologic phases—because "WRD doesn't have any aquatic biologists and it is not appropriate for the Division to hire them." Laird was warned not to "do that" again however, there was a broad grin on the face of Warren Hastings who imparted the terms of "probation."

## Pennsylvania

*By* Robert E. Steacy; Harold Meisler assisted *by* Eugene P. Patten; *and* Norman H. Beamer assisted *by* Benjamin L. Jones, Harry E. Koester, David McCartney *and* John W. Wark. Reviewed *by* John R. George

WRD operations in Pennsylvania during the period 1957 to 1966 were by the Branches. The Pennsylvania WRD Council actively coordinated the operations of the three Branches and began developing multidiscipline projects. Integration of Branch operations as a Division-level District was in July 1966 when Norman H. Beamer, District Chemist, QWB, was named District Chief.

### Organization and Personnel

#### *Surface Water Branch*

The SWB District headquarters office was initially located in Room 490 of the Pennsylvania State Education Building in Harrisburg. John J. Molloy was the District Engineer, supervising a staff of 10 full-time Federal and about 7 State employees. Of the Federal employees, four were engineers, and five were technicians and aids. Merle E. Huber was the District Clerk.

Molloy transferred to Columbus, Ohio, on April 2, 1962, and was succeeded by Robert E. Steacy, formerly Assistant District Engineer. Leland W. Page succeeded Steacy as the Assistant District Engineer. In 1962, the District office was moved to 1224 Mulberry Street in space provided by the State. The staff then numbered 19 Federal employees and no State employees.

By 1966, Steacy and Page were assisted by a full-time staff of six engineers, nine technicians and aids, two clerical employees, and several part-time helpers. Among those on the staff during the entire period were engineers David Barton and William F. Busch, technicians Donald C. Bartoo, Samuel E. Craighead, and Russell W. Reichle and clerk Merle E. Huber. Others who served in Harrisburg for more than about 2 years included Alice R. Brinton, John W. Buchanan, David D. Dickstein, Jr., Horace W. Evans, Henry C. Ganster, Ignatius A. Heckmiller, Clayton D. Kauffman, Thomas W. Kelly, Joseph B. Lescinsky, Harry C. Luman, Richard W. McMillan, and Lewis C. Shaw.

District operations were supported by Subdistricts headquartered at Pittsburgh and Philadelphia.

The Pittsburgh Subdistrict was responsible for the office and field work in the area of Pennsylvania that drains into the Ohio River; about a third of the State. It was the launching pad for several SWB engineers who later became District Engineers in other States, including Harlan M. Erskine in West Virginia, then North and South Dakota, and Fay N. Hansen in Louisiana.

In 1957, the Pittsburgh Subdistrict office was located in the Victory Building at 9th Street and Liberty Avenue. Robert D. Schmickle was Engineer-in-Charge. On his staff were three engineers, three technicians and aids, and a clerk. Schmickle was succeeded in 1961 by Ernest A. Burti. In 1964, the office was moved to the New Federal Building. At the close of this period, Burti had the full-time help of two engineers, three technicians and aids, a clerk, and several part-time employees. Burti and engineer Joseph F. Amorosa were the longest-tenured members of the Pittsburgh staff; both having been there in 1957. Others who served in Pittsburg included Raymond E. Bartoo, Martin B. Coll, John F. Ficke (WAE), Mary E. Glasgow, Henry J. Oswick, Carl J. Rossow, Charles M. Schubert, and Donald Senovich.

The Philadelphia Subdistrict, located at 5940 Old York Road, was established in 1965 in response to a large, new cooperative program with the city of Philadelphia, with Earl L. Smith as Engineer-in-Charge.

#### *Ground Water Branch*

The GWB office occupied rooms on the second floor of 100 N. Cameron Street, Harrisburg. Desirable features of the location included light traffic, convenient free parking, a view of a large outcrop of Martinsburg Shale, and proximity to colleagues and facilities of the sediment lab of the QWB on the first floor. Furthermore, the principal cooperator, the Pennsylvania Geological Survey (PGS), along with its outstanding geological library, was only a 10-minute walk away. Alas, that wonderful library was largely destroyed in the infamous Susquehanna River flood of 1972 when, ironically, the PGS occupied space vacated by the WRD at 100 N. Cameron Street.

David W. Greenman served as District Geologist until September 1958. In November 1958, he transferred to Lahore, West Pakistan. Joseph E. Barclay transferred from Tallahassee, Fla., in September to take charge in Harrisburg, remaining at the helm for the rest of the period. Grace A. Dreisigacker was the District Clerk for the entire period. Alice T. Poslosky assisted Dreisigacker until 1960; Margaret L. Kosevic assisted from 1960 on.

Although most personnel worked out of Harrisburg, small field offices operated for several years in Greenville (1957–61), Doylestown (1960–63), and Meadville (1964–65 on). The number of full-time employees was 16 in 1957 and 15 in 1966 but ranged from 11 to 13 during most of the period. Employees who remained in the District through all, or nearly all, of the period included Harold Meisler, Charles W. Poth, and William C. Roth. William N. Lockwood transferred to the Hydrologic Laboratory in Denver, Colo., in 1958; Donald R. Rima left in 1959 to become District Geologist in Delaware; Perry R. Wood transferred to the California District in 1962 after 2 years in Harrisburg; Eugene P. Patten and Gordon D. Bennett left in 1960 and 1962, respectively, to join Greenman's ground-water project in Pakistan; in 1964, Louis D. Carswell transferred to the New Jersey District in Trenton, and Stanley M. Longwill transferred to the Analog Model Unit in Phoenix, Ariz. (As an interesting side note: one of Bennett's ancillary duties in Pakistan was to provide technical instruction to the counterpart Pakistani staff. The class notes on his ground-water hydraulics lectures were published as a USGS Techniques of Water Resources Investigations in 1976, and he subsequently received the prestigious Meinzer Award of the Geological Society of America for the work.)

Those in the District during the latter part of the period were Charles R. Wood (1960 on), Herbert E. Johnston (1960 on), Albert E. Becher (1962 on), Jerrald R. Hollowell (1962 on), Paul R. Seaber (1963 on), Este Holiday (1964 on), George R. Schiner (1964–65 on), and Grant E. Kimmel (1964–65 on).

#### *Quality of Water Branch*

The Pennsylvania QWB District, until the reorganization of 1966, was composed of the States of Pennsylvania, New Jersey, and Delaware. This account is limited to operations within Pennsylvania. The hub of chemical-quality investigations was at Philadelphia and that for sedimentation at the Subdistrict office at Harrisburg.

The District headquarters and chemical-quality laboratory remained at Philadelphia in the Customs House, 2nd and Chestnut Streets, during the entire period. Norman H. Beamer, as District Chemist, was in charge of QWB operations in the 3-State District until his selection in July 1966 as District Chief, Pennsylvania. Catherine M. Casey was not only the District secretary but efficiently performed the myriad duties that in later years were the functions of an administrative officer.

The water-quality laboratory was initially headed by Michael J. McGonigle assisted by Edward F. McCarren, then early in this period, David McCartney became the Laboratory Chief and directed the lab and field chemical programs in Pennsylvania for the next several years. Beamer said, "Dave's background in SWB (as a WAE) and his outstanding ability to direct the testing of instruments, the difficult construction work, and to work directly with the universities in Philadelphia and the many industries specializing in instrumentation were great assets to the programs." (Bernard A. Malo succeeded McCartney as lab chief late in this period.) "Tom White and his fine staff of technicians did an outstanding job. Production increased from 19 complete analyses per month to over 30 per month."

Others who served in the District at times during the period for more than about 2 years included Roland Brown, Anna S. Homer, Leo T. McCarthy, Jr., David W. Moody, Gertrude W. Moore, James E. Poole, Kathryn P. Russell, Frederick L. Schaefer, Russell E. Shehan, and Richard G. Stoler.

The Harrisburg Subdistrict office and sediment laboratory were at 100 North Cameron Street during the entire period. The laboratory became the largest laboratory of its type east of the Mississippi River and processed samples from many eastern QWB Districts and special projects. The laboratory performed about 10,000 sediment-concentration analyses per year as well as hundreds of particle-size analyses on suspended-sediment and bed-material samples. As the Subdistrict responsible for District sediment activities, its staff operated throughout the 3-State District in the sedimentation field and also did the chemical-quality sampling in its area of the State.

Those in charge of the Harrisburg Subdistrict were James K. Culbertson (1956–58), John W. Wark (1958–60), and John R. George (1960–66). They were responsible for day-to-day operations of the office and laboratory. Allen B. Commings, hydrologic technician, was in charge of laboratory operations during this period. The laboratory and office staff varied between 6 and 10 people. Other members of the Harrisburg staff at various times during this period of history were James E. Biesecker, Arlene J. Hartzell, Benjamin L.

Jones, Harry E. Koester, Wayne C. Loper, Thomas G. Newport, Arthur N. Ott, Alice T. Posolskey, and Allen A. Spotts.

#### *General Hydrology Branch*

A one-man project office staffed by Sam Shulits, engineer, was maintained at University Park throughout the period.

### Funding and Cooperation

Funds that supported water-resources investigations in Pennsylvania were largely from the cooperative (Coop) program. Investigations for other Federal agencies (OFA) and support for several gaging stations and observation wells from Federal program funds (Fed) made up less than 20 percent of the budget. Several power companies that held FPC licenses provided support for a few gaging stations.

As shown in the table below, program growth was generally steady during most of this period and greatly increased during the last 3 years. The overall program growth of nearly 80 percent was due largely to increased emphasis on interpretive studies. The growth in the SWB program from FY 1958 to FY 1966 was about 80 percent, and that of the GWB program decreased slightly. The QWB program grew from $125,500 to $273,000 or nearly 120 percent during the FY 1958 to FY 1966 period.

Pennsylvania District funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Fed | 49.9 | - | 23.8 | 25.4 | 24.3 | 33.4 | 23.8 | 46.0 | 36.0 |
| Coop | 387.0 | - | 444.3 | 486.9 | 582.1 | 546.5 | 693.9 | 763.0 | 784.5 |
| OFA | 88.5 | - | 61.1 | 66.3 | 74.2 | 79.7 | 96.5 | 108.6 | 119.3 |
| FPC | 3.2 | - | 3.5 | 3.7 | 3.7 | 3.7 | 4.0 | 4.0 | 4.0 |
| Total | 528.6 | - | 532.7 | 582.3 | 684.3 | 663.3 | 818.2 | 921.6 | 943.8 |

Source: District program documents; none available for 1959.

#### *Cooperating Agencies*

The Department of Forests and Waters (DF&W) was the principal cooperator during this period for streamflow and chemical-quality activities, statewide, while the Pennsylvania Geological Survey (PGS) was the cooperator for ground-water studies. The PGS was under the direction of Carlyle Gray until 1959, when he was succeeded by Arthur A. Socolow.

The State Departments of Agriculture, Commerce and Highways, several counties and numerous towns and cities, notably Philadelphia, were cooperators in both short-term and continuing water-resources studies.

Of his cooperators as individuals, Beamer had this to say: "Men like Samuel Baxter, Philadelphia Water Department Commissioner, Joseph Radzuil, Philadelphia Water Department Research, and Maurice Goddard, Secretary of the Pennsylvania Department of Forests and Waters were examples of the many cooperators who helped the Survey to be progressive and productive in its investigations and studies in the Commonwealth of Pennsylvania."

#### *Other Federal Agencies*

Among other Federal agencies that sought and received technical assistance were the U.S. Army Corps of Engineers, Departments of the Air Force and Army, FWPCA, National Aeronautics and Space Administration, and the Bureau of Outdoor Recreation of the DOI.

### Summary of Program

Although the basic-data program continued to be a strong and stable component of District activities, the major program growth was in interpretive studies. Leopold and other members of the Headquarters staff appeared to take a special interest in Pennsylvania programs and established or assisted in the design of multidiscipline hydrologic studies in the State.

The main thrust of the ground-water program during the period 1957–66 was to analyze and develop understanding of the hydrology of specific hydrogeologic units or rock types. Hence, studies dealt individually with coastal-plain sediments, carbonate rocks, shales and sandstones of early Paleozoic age, rocks of Triassic age, rocks of the Appalachian Plateau, crystalline rocks of the Piedmont, and Pleistocene valley-fill sediments.

#### *Water Records*

Data activities are summarized from District program documents and from "Water Resources Investigations in Pennsylvania, 1962," the approximate midyear of this period.

Streamflow Records.—A review of the stream-gaging program was completed in 1957 that indicated a need for more information on runoff from small streams, particularly those in urban areas. As a means of meeting this need, Molloy began adding about five additional secondary gaging stations each year to the program utilizing unique pipe wells designed by Ignatius A. Heckmiller. In addition, low-flow data were obtained annually at about 100 sites and peak-flow data at about 30 crest-stage sites, statewide. The program was funded by discontinuing the operation of long-term stations that the review indicated were no longer needed. Discontinuing cooperatively financed long-term stations generated some complaints by users of the records, in which cases, certain stations were reestablished as water-management stations with 100-percent financing by the user agencies. The new secondary stations were moved to new sites as soon as sufficient record was obtained. From 1958 to 1965, the effects of the program on streamflow data collection were: the number of primary stations remained the same, at 66; secondary stations increased from 29 to 70; water-management stations increased from 75 to 78; crest-stage stations increased from 29 to 63; and low-flow measuring sites increased from 95 to 106.

Ground-Water Records.—Water levels were measured continuously at 12 wells, weekly at 24 wells and monthly at 9 wells. Water-level measurements in project wells are not included in these figures.

Water-Quality Records.—In 1962, The QWB reported 39 active chemical-quality monitoring stations of which 20 were sampled daily and 19 were sampled monthly.

Other Data Activities.—Flood data were compiled by Busch and Shaw for a report on the magnitude and frequency of floods in Pennsylvania (open-file rept., 1960). Steacy and Heckmiller documented floods on the Susquehanna River at Harrisburg (HA–57, 1962).

Major impacts on the water-quality program occurred in the late 1950's as Federal regulations required compliance and the State of Pennsylvania responded with new laws of its own. Pennsylvania made it impossible for many cities to make civic improvements without first upgrading sewage-treatment facilities. The most dramatic response was from the city of Philadelphia, which instituted the largest, most comprehensive urban water-quality study ever involving the Geological Survey. All streams in the city were continuously gaged at one or more sites, equipped with automatic water-quality samplers, and sampled for biological and chemical quality.

The Philadelphia Laboratory was the first WRD laboratory to install atomic absorption equipment (Perkin Elmer 303) for the measurement of the bulk of metallic ions. It was also the first laboratory to use plastic bottles for the collection of all samples in the field.

In 1958, the first continuous conductivity recorder was installed on the Delaware River downstream from Wilmington, Delaware.

By 1960, the District had developed a monitor that could continuously record temperature, dissolved oxygen, pH, specific conductance, and turbidity. This work, in Philadelphia, was considered by some to be the forerunner of WRD's instrumentation research and development group, later headed by George F. Smoot.

#### *Special Studies*

The time of travel of water in the Ohio River from the Shippingport nuclear powerplant near Pittsburgh to Cincinnati was investigated by Steacy. The decision to remove "Shippingport" from the report title, to avoid the appearance of creating anxiety over the nuclear plant operations, was made after the report was submitted for approval (Circ. 439, 1961).

Among the special studies by members of the GWB during this 1957–66 period were: the ground-water resources of the Coastal Plain of southeastern Pennsylvania, by Greenman, Rima, and Lockwood, that included a detailed delineation of the hydrogeologic units on maps and fence diagrams (PGS Bull. W–13, 1961); the geology and hydrology of the Stockton Formation in Montgomery County, southeastern Pennsylvania, by Rima, Meisler, and Longwill (PGS Bull. W–14, 1962); the hydrogeology of the carbonate rocks of the Lebanon Valley, by Meisler (PGS Bull. W–18, 1963); and the geology and hydrology of the Mercer quadrangle in western Pennsylvania, by Poth (PGS Bull. W–16, 1963).

Greenman and then State Geologist Carlyle Gray strongly believed that any ground-water investigation much beyond the reconnaissance level required subsurface information that could be obtained only by borehole geophysical methods. Although a small electric logger was available in the District, it was wholly inadequate for what the two geologists envisioned. Accordingly, in 1957, the State Survey and the District shared the considerable costs of buying a state-of-the-art logger capable of providing quantitative information on a number of parameters in and about the borehole. Initially, the logger was used in support of Districtwide ground-water investigations, but questions regarding interpretation of the logs, or ideas about possible new interpretive procedures drove the project increasingly into a greater research mode. A trailer containing centrifugal and submersible pumps was added to provide the ability to conduct hydraulic testing and flow metering at virtually any site. A series of investigations by Bennett and Patten produced a number of new techniques useful for interpreting both geophysical logs and the hydraulics of wells (WSP 1536–A, 1960; WSP 1536–G, 1962; WSP 1544–C, 1962; and WSP 1544–D, 1963).

Also, studies were made of the geology and hydrology of the Neshannock quadrangle in the Appalachian Plateau of northwestern Pennsylvania, by Carswell and Bennett (PGS Bull. W–15, 1963); of the ground-water resources of Olmsted Air Force Base at Middletown for the Corps of Engineers, by Meisler and Longwill (WSP 1639–H, 1961); of the hydrology of the New Oxford Formation in Adams and York Counties, that included a tabulation of all municipal water supplies and an evaluation of the quality of the ground water, by P. Wood and Johnston (PGS Bull. W–21, 1964); and of the hydrology of the Brunswick Formation in Montgomery and Bucks Counties adjacent to Philadelphia, by Longwill and C. Wood (PGS Bull. W–22, 1965).

Additionally, investigations were made of the occurrence of brines associated with oil and gas deposits in western Pennsylvania, by Poth (PGS Bull. M–47, 1962). From an analysis of water-level records by Poth explained the uses of these data and what water-level fluctuations mean and how they relate to water supply (PGS Bull. W–20, 1963 and 1972).

Studies were also made of the geology and hydrology of the Martinsburg Shale in Dauphin County, by Carswell and Hollowell (PGS Bull. W–24, 1968); of the hydrogeology of the New Oxford Formation in Lancaster County east of the Susquehanna River, by Johnston (PGS Bull. W–23, 1966); of the hydrogeology of the carbonate rocks of the Lancaster quadrangle, by Meisler and Becher (PGS Bull. W–26, 1971); and of the hydrology of the metamorphic and igneous rocks of central Chester County in an area underlain by crystalline rocks and undergoing rapid suburban development, by Poth (PGS Bull. W–25, 1968).

The ground-water resources of the Susquehanna River Basin were investigated by Seaber and Holiday to provide geologic and hydrologic information needed by the Corps of Engineers and other agencies to evaluate the role of ground water in the formulation of a comprehensive plan for the conservation and development of water and related land resources of the Susquehanna River Basin (open-file repts., 1965, 1966, 1968, and 1969). Streamflow and water-quality information, including sedimemt data, were also provided.

Studies were also made of the ground-water resources in the Loysville and Mifflintown quadrangles, by Johnston (PGS Bull. W–27, 1970); of the hydrology of the Pleistocene sediments in the Wyoming Valley as a source of water supply, by Hollowell (PGS Water-Res. Rept. 28, 1971); and of the geology and ground-water resources in the Shenango and Stoneboro quadrangles, by Schiner and Kimmel (PGS Water-Res. Rept. 33, 1976).

Investigations were begun in the early 1950's and continued through much of this period to evaluate the effects of soil-conservation practices on sediment yield in several small watersheds in central Pennsylvania. Results of the work on Corey Creek were reported by Jones (WSP 1532–C, 1966). Similar investigations were made in Bixler Run near Harrisburg and Bald Eagle and Marsh Creeks northwest of Harrisburg.

Early in the period a multidiscipline investigation was undertaken in the Swatara Creek Basin near Harrisburg. The objective of the project was to use the skills of a chemist, an engineer, and a geologist to evaluate the chemical and physical quality of surface water in the Swatara Creek Basin. The project team, McCarren, Wark, and George, reported the results of the investigation in an open-file report (1964).

Additionally, Biesecker and George investigated the quality of streamwater in Appalachia as related to coal-mine drainage (Circ. 526, 1965) and Biesecker, Lescinsky, and C. Wood reported on the water resources of the Schuylkill River (DF&W, Water Res. Bull. C, 1968).

Wark said "Looking back upon the period 1957–66, and in particular the first half, several accomplishments come to mind; there were application of reconnaissance techniques to appraisals of sedimentation characteristics of large river basins and the use of portable water-quality recorders to determine temporal variations and their relation to precipitation and streamflow."

#### An Observation by John R. George

"The text doesn't do justice to Norm [Beamer]'s water-quality program, either statewide, regionally, or with the city of Philadelphia. Long before my arrival in 1956, Beamer had made a major impact on the acquisition of river-quality information in Pennsylvania. In my 23 years since leaving Pennsylvania, I cannot reflect on the availability of similar high-quality data bases for either Southeastern or Western rivers. His abilities to discern water-quality problems and obtain State support for the collection of important data had, I am convinced, a lead role *** in the U.S. Congress' passage of Public Law 92–500."

## Rhode Island

*By* Robert M. Beall *and* reviewed *by* current staff members Herbert E. Johnston, David C. Dickerman *and* Joseph S. Rosenshein, *and* retirees William B. Allen, Ralph C. Heath, Solomon M. Lang, *and* George C. Taylor

The WRD program in Rhode Island was administered by the Ground Water and Surface Water Branch District offices in New York and Massachusetts, respectively, from 1957 to early 1965. Interbranch collaboration was effected through the WRD Council.

Consolidation and integration of functions occurred with the creation of the WRD Central New England District in February 1965, at which time District supervision of the ground-water program was transferred from New York to Massachusetts. Surface-water data collection within the State became the responsibility of the Providence staff, which continued to carry out the ground-water program in Rhode Island.

### Organization, Personnel, and Activities

#### *Surface Water Branch (1957–65)*

The Rhode Island SWB program was conducted by personnel from the Boston District Office, supervised by Charles E. Knox, District Engineer. Initially, there were 10 gaging stations in the program for which discharge records were analyzed and prepared for publication in Boston, principally by the assigned field engineer, Norman J. Roy. Roy continued as the field engineer until October 1965.

Richard A. Brackley, headquartered in Boston, built and operated three short-term gaging stations and made low-flow discharge measurements at six other sites in support of an interbranch study of the upper Pawcatuck River Basin from 1957–60.

Additional partial-record, low-flow and crest-stage, stations were established in the early 1960's and the gaging-station network expanded, both to support basin and areal studies. Continuous stream-temperature recording was initiated at three gaging stations in 1961.

#### *Ground Water Branch (1957–65)*

(Author's Note: "A cooperative agreement between the Rhode Island Development Council [RIDC] and the Survey provided for bedrock and surficial geologic mapping by the Geologic Division [GD] that was designed to be used in general support of ground-water mapping and studies. The geologic mapping was done by personnel of the Geology Department of Brown University, who were part-time Survey employees, and by the staff of the Boston office of GD. As the ground-water resources occur chiefly in the glacio-fluvial deposits, the bedrock mapping was of limited value to the ground-water studies. The surficial geologic mapping, however, was directly applicable to those studies.

"In 1958, the new cooperator, the State Water Resources Coordinating Board [WRCB], requested accelerated publication of ground-water information. A new series of quadrangle ground-water maps was begun, each with an explanatory text. At the same time it was decided to phase out the Geological Bulletin [GB] series, except for special reports or reports still in the pipeline. By the end of 1965, some 21 ground-water maps had been published by the RIWRCB, completing coverage of the entire State. Thus, by the late 1950's, the geologic mapping and ground-water programs had gone their separate ways in both field activities and publications.")

The Rhode Island GWB program was under the general direction of the New York District Geologist, George C. Taylor, Jr., headquartered at Mineola from March 1957 until September 1960. Joseph E. Upson II, Taylor's predecessor, remained in Mineola until October 1963 as a representative of the GWB Area Chief, ACA, and continued to provide advice and support to the program in Rhode Island. Following Taylor's 1960 transfer to WRD Headquarters, Albany was designated as the New York-Southern New England District Office and Ralph C. Heath became District Geologist for the remainder of the period.

The GWB maintained a field headquarters in Providence located in the Post Office Annex Building, renamed the Federal Building and U.S. Post Office in 1960. Also in 1960, the Providence office became a Subdistrict office with William B. Allen continuing as Geologist-in-Charge.

Allen was Geologist-in-Charge until June 1964 and transferred to Michigan in October 1965. George R. Schiner served as acting Geologist-in-Charge until October 1964, when Joseph S. Rosenshein transferred in from Indiana to take charge following graduate school at the University of Illinois. Ruth E. Hawthorne entered on duty as the office clerk in January 1957 and continued in that capacity throughout the period.

In mid-1957, the professional staff consisted of Allen; engineer Solomon M. Lang (returned to New Jersey, October 1957); geologist Glenn W. Hahn (resigned, September 1962); geologist Jean A. Smith-Wosinski (resigned, April 1958); and Karl E. Johnson (initially an aid, reclassified as a geologist, 1960, left in 1962). Geologist Samuel J. Pollock, formerly of GD, was on the staff from May 1958 to February 1960. Following a Headquarters detail, he joined the GWB staff in Boston. Technician Herbert E. Johnston entered on duty in February 1959, was converted to geologist in May 1959, and transferred to Pennsylvania in February

1960. Also on the staff were geologists Arnold J. Hansen, Jr. (joined early in 1961, transferred out in January 1964); George R. Schiner (arrived from Minnesota, August 1962, moved to Pennsylvania, October 1964); and Joseph B. Gonthier (hired, January 1963).

Immediately prior to reorganization as a Subdistrict office of the WRD Central New England District, Rosenshein's staff had dwindled to geologist Gonthier, technicians David D. Dickerman and Eugene L. Peterman (WAE), and clerk Hawthorne.

An informal working relationship with the GD, exercised largely through its Boston personnel and through the Geology Department of Brown University, continued through the 1957–66 period although with decreasing effect in the 1960s. Professor Alonzo W. Quinn, Department Chairman until 1961, directed many of the geological studies that provided the framework for the earlier ground-water studies. He and several University personnel were part-time employees of the GD under an agreement with the RIDC and its predecessors. After the establishment of the RIWRCB in 1958, Professor Quinn served as a member of the Board. By the late 1950's, the geologic studies were carried out principally by the Boston staff of GD and were essentially terminated by 1964. Curtis R. Tuttle from the Boston office of GD assisted in the field phase of the Upper Pawcatuck River Basin study in 1958–59.

#### *Quality of Water Branch (1957–65)*

Water-quality studies in Rhode Island were under the direction of Felix H. Pauszek, District Chemist, New York-New England, Albany, N.Y. Water samples collected by local SWB and GWB personnel were analyzed in the Albany Laboratory. Laboratory assistance was also provided by the Rhode Island Department of Health.

#### *Central New England District (1965–66)*

The creation of the Central New England District in February 1965 chiefly involved the transfer of general supervision of GWB activities in Rhode Island from Heath in Albany to Knox in Boston. Rosenshein remained in charge, assisted through the remainder of the period by Gonthier, Peterman (WAE), and Hawthorne, who by this time had more than twice the length of service in Providence than anyone else on the staff. Dickerman was given responsibility for surface-water field operations in Rhode Island beginning in October 1965, in addition to his other duties. Assistance was provided from time to time by SWB personnel in Boston, particularly in the joint GWB-SWB basin studies. Water-quality analytical services continued to be provided by the QWB laboratory in Albany and, intermittently, by the Rhode Island Department of Health.

### Funding

Cooperative (Coop) funds provided about 95 percent of the operating budget except in FY 1958 when a special allotment of $10,000 in Federal (Fed) funds was made for a "statewide report." Federal funds in that year were about 19 percent of the budget but otherwise ranged between 2 and 4 percent. In 1958 also, there was a small allotment of Federal funds for a chemical-quality reconnaissance at four sites in connection with the New England-New York Interagency Committee studies. This was to be completed in June 1958.

The "statewide report" itemized in the 1958 program analysis was scheduled for completion in October 1958 and showed equal $5,000 allotments for the SWB and GWB parts. According to Lang (oral commun.) the funding was actually for 3 years of his effort (1955–58) as a solo ground-water researcher on small glaciated basins. Lang said, "It was apparent that the [funds were] not sufficient to carry out an appropriate study so I volunteered to move back to New Jersey in October 1957 so that the money could be used for a drilling contract instead of my salary. I arranged for the drilling contract, then moved on."

Federal funds supported the operation of two gaging stations throughout the period and 14 observation wells through 1963, after which the number was reduced to 3 and finally absorbed in the cooperative program. Continuous temperature recording at the two "primary" stations was federally funded in FY 1962 and FY 1963.

As noted in the table below, the U.S. Army Corps of Engineer funds, the only other-Federal-agency (OFA) source, amounted to less than 2 percent in 3 of the 4 years that they were provided. A small amount of money was provided by the Corps for chemical-quality sampling at four sites in 1960 and at two sites in 1961. Beginning in 1963, the Corps supported the construction and operation of a gaging station.

Rhode Island program funds, fiscal years 1958, 1960–66
[In thousands of dollars]

| Fund source | 1958 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|
| Coop | 52.2 | 76.0 | 63.8 | 70.8 | 70.8 | 82.8 | 84.1 | 69.3 |
| Fed | 12.6 | 2.2 | 2.4 | 2.4 | 2.4 | 1.9 | 1.9 | 2.3 |
| OFA | - | .2 | .1 | - | 3.5 | 1.2 | 1.2 | 1.3 |
| Total | 64.8 | 78.4 | 66.3 | 73.0 | 76.7 | 85.9 | 87.2 | 72.9 |

Source: Data in files of the Branch of Planning Support, WRD. The table does not include Coop funds which were in the program of geologic mapping by Geologic Division.

## Cooperating Agencies, Program Elements, and Report Products

### *Surface-Water Activities*

The Rhode Island Division of Harbors and Rivers (H&R) within the Department of Public Works (DPW) continued to cooperatively finance the operation of 8 of the 10 gaging stations through FY 1964. In that year, 7 stations were added to the State network with installation financing provided by the Water Resources Coordinating Board (WRCB), Walter J. Shea, Chairman, also principal cooperator for the ground-water program. Three of the seven were short-term stations supporting GWB areal studies. Operating funds for 14 stations were provided by DPW, H&R, in 1965, and for 13 stations in FY 1966, at which time their support was transferred to the State Department of Natural Resources (DNR).

The DPW Division of Roads and Bridges (R&B) initiated a cooperative study of the flood characteristics of small drainage basins in 1965, in which three more stations were installed as well as 11 crest-stage stations and precipitation recorders at 5 sites. By 1966, two more stations were added to the project, including one from the DNR program. Carl G. Johnson in Boston was the project chief.

DPW, H&R, funded the installation of a continuous stream-temperature recorder at one site late in 1961, supplementing the two installed with Federal program funds. The collection of these three records was thereafter included in the WRCB program.

The surface-water components of the several ongoing joint GWB-SWB projects were included in the cooperative agreement with the WRCB for those studies.

### *Ground-Water Activities*

The sole cooperating agency at the beginning of the period, 1957, was the RIDC. This cooperation was supplanted in 1958 by the RIWRCB, which became the cooperator for the remainder of the period.

The core ground-water program consisted of a limited observation-well network and the mapping and description of ground-water occurrence on a quadrangle basis. In addition, special topical studies and areal appraisals were carried on throughout the period.

The basic observation-well network numbered from 3 to 6 recording sites plus periodically measured wells that ranged in number from 9 to 26.

The initial plan for combined reports on geology and ground-water resources encountered difficulties. Consequently, the GD separately published its results in some 28 USGS Geologic Quadrangle Maps and in 7 USGS Bulletins. Meanwhile, the GWB staff prepared ground-water reports and maps that were published initially by the RIDC and later by the RIWRCB. By 1959, RIDC Geological Bulletins (titled "Ground-water resources of ***") had been published for seven quadrangles and two urban areas. These were followed by a series of 21 ground-water maps, published by the RIWRDC, and completing coverage of the State by 1965. The dominance of this project activity is reflected in its designated share of the GWB Coop funding which ranged from about 30 to 75 percent of the Subdistrict budget between 1958 and 1964, phasing out in 1965.

A small allotment of cooperative funds in 1958 provided for the continuation of a short series of RIWRCB Hydrologic Bulletins (HB) reporting on water levels from a larger number of observation wells than that being published by the USGS. The latter had been reduced to a few key wells having significant periods of record. RIWRCB HB 1 (Allen and Lang, 1957), provided well data and limited analysis for 1956; HB 2 (Hahn and Wosinski, 1960), for 1957; HB 4 (Johnson, 1961), for 1958 and 1959; and HB 5 (Hansen and Schiner, 1963), for 1960–62.

The federally funded glacial-outwash studies led to a cooperatively funded interdisciplinary study of the availability of ground water in the upper Pawcatuck River Basin which got underway in 1957. Most of the field work was completed by 1960. A compilation of data by Allen, Hahn, and Tuttle was published in 1963 (GB 13). The final report by Allen, Hahn, and Brackley was published in 1966 (WSP 1821).

Other cooperatively financed studies during this period included an investigation of the ground-water resources of an area in the vicinity of Wallum Lake, by Hahn (WRB Geo. Bull. 12, 1962); an appraisal of the ground-water resources of Block Island, by Hansen and Schiner (WRB Geo. Bull. 14, 1964); a 1961–66 study of the hydrologic characteristics and sustained yield of principal ground-water units in the Potowomut-Wickford area, by Rosenshein, Gonthier, and Allen (WSP 1775, 1968); and a compilation of hydrologic data for the South Branch Pawtuxet River Basin, by Gonthier (WRB HB 6, 1966).

A study of the availability of ground water in the lower Pawcatuck River Basin was started in 1966 by Gonthier and Johnston, assisted by Glenn T. Malmberg from the Boston office.

### *Other Program Elements and Report Products*

A paper on ground-water problems in New York and New England and based on the Ipswich River

Basin in Massachusetts, the Blackstone River Basin in Massachusetts and Rhode Island, and the Pawcatuck River Basin in Rhode Island was written by Upson (ASCE HY Jour., June 1959).

The federally funded study of small glaciated basins resulted in two cooperatively published reports: HB 3, by Lang, Bierschenk, and Allen (1960) on the hydraulic characteristics of glacial outwash, and Geological Bulletin (GB) 11 by Lang (1961), an appraisal of 17 ground-water reservoirs within the State.

Water resources of the Providence area, by Halberg, Knox, and Pauszek, one of the national series of industrial-area reports, was published in 1961 (WSP 1499–A).

At the close of the period, Rosenshein commenced work on the Survey's contribution to the interagency North Atlantic Water Resources (Type 3) Study.

## South Carolina

Based largely on material provided *by* Woodrow W. Evett, Frances J. Whetstone, *and* George E. Siple *and* reviewed *by* Neil C. Koch

Programs were developed, administered, and executed by the Branches throughout most of this period, except for the QWB that had neither office nor staff in South Carolina. Analytical services were provided by the QWB laboratory in Raleigh, North Carolina. The Branches were integrated as a Division-level District in January 1966 with the transfer of Rolland W. Carter from Washington, D.C., as District Chief.

### Organization and Personnel

#### *Surface Water Branch (1957–65)*

The SWB District headquarters remained at 210 Creason Building in Columbia until 1961 when it was moved to 121 Veterans Administration Regional Office Building where it remained through this 1957–65 period of history.

Albert E. Johnson continued as District Engineer until he retired in 1965. Rolland W. Carter then transferred from Washington, D.C., and served in the newly created District Chief position through the remainder of this period. Frederick W. Wagener, the Assistant District Engineer until he retired in 1964, was succeeded by John S. Stallings, who transferred from Alabama.

The career of Leslie L. Finley was cut short when he was killed in a fall from a gaging-station platform, June 23, 1960. In 1964, Woodrow W. Evett transferred to Nepal and Hillary H. Jeffcoat joined the staff. Although the full-time staff numbered no more than 12 during these years, engineers William M. Bloxham, Francis A. Johnson, Benjamin H. Whetstone, technician William T. Utter, and clerk Frances J. Whetstone served for the entire period. Others who served more than about 2 years were Leslie L. Finley, Hillary Jeffcoat, Lyda B. Mayer, and Blanche S. Robey.

#### *Ground Water Branch (1957–65)*

In early 1957, the GWB staff in South Carolina numbered three people. George E. Siple, District Geologist, was aided by geologist Richard E. Taylor and clerk Claudia E. Turner. Taylor was called to military duty in 1957 and was replaced by Neil C. Koch. In 1960, Anne C. Gibert joined the GWB staff and served as secretary and administrative aid for the remainder of this period. Ira W. Marine, geologist, was transferred from Oklahoma in 1961 and established the field headquarters at Aiken. William E. Clark, engineer, transferred from the Florida District in 1964 and joined Marine at Aiken, where both remained through this period of history.

Office space for the District headquarters was furnished by the University of South Carolina in a dormitory on Bull Street in Columbia. Financial accounts for GWB operations were maintained by the SWB District Clerk.

#### *Water Resources Division (1966)*

Rolland W. Carter became South Carolina's first Division District Chief on January 1, 1966. The District headquarters were those of the former SWB in the Veterans Administration Regional Office Building in Columbia. His full-time staff of 13 included five engineers and two geologists, including the engineer and geologist in Aiken, two technicians, and four clerical employees. Timmy R. Cummings soon arrived as the reorganized District's first in-house chemist.

#### *Funding and Cooperation*

A summary of funds by source for each Branch District during the 1957–66 period is shown in the following tables. The cooperative program (Coop) and other Federal agencies (OFA) made up the bulk of funds. The Federal program (Fed) funds supported a few key gaging stations and, briefly, part of the observation well network. Funds from the FPC paid the cost of operating gaging stations where streamflow records were required under the terms of power-company licenses.

The significant increase in funds at the end of this period was due to several interpretive projects getting underway in SWB and large increases in the Savannah River Plant (SRP) work of GWB for AEC. The SRP investigations more than doubled in the latter half of this period.

South Carolina District funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| SURFACE WATER BRANCH | | | | | | | | | |
| Coop | 62.5 | *60.7 | 57.2 | 60.6 | 64.5 | 63.7 | 62.9 | 65.0 | 84.0 |
| OFA | 20.0 | *22.5 | 26.5 | 22.9 | 22.9 | 26.1 | 32.3 | 23.8 | 28.4 |
| Fed | 9.8 | *10.0 | 11.4 | 13.8 | 11.1 | 12.0 | 13.4 | 15.0 | 18.1 |
| FPC | 6.4 | 6.5 | 8.8 | 9.8 | 9.8 | 10.0 | 11.6 | 12.5 | 13.2 |
| Total | 98.7 | 99.7 | 103.9 | 107.1 | 108.3 | 111.8 | 120.2 | 116.3 | 145.7 |
| GROUND WATER BRANCH | | | | | | | | | |
| Coop | 20.0 | - | 22.0 | 23.3 | 23.9 | 23.9 | 28.2 | 22.3 | 24.6 |
| OFA | 6.0 | - | 4.0 | 8.5 | 23.0 | 34.0 | 29.0 | 36.6 | 47.8 |
| Fed | .6 | - | .9 | .6 | .6 | .6 | 0 | 0 | 0 |
| Total | 26.6 | - | 26.9 | 32.4 | 47.5 | 58.5 | 57.2 | 58.9 | 72.4 |
| WATER RESOURCES DIVISION | | | | | | | | | |
| Total | 125.3 | - | 130.8 | 139.5 | 155.8 | 170.3 | 177.4 | 175.2 | 218.1 |

*Estimated. Source: SWB funds are from District program documents, except those for FY 1959, which were estimated. GWB funds were compiled by Robert Logan of the South Carolina Water Resources Commission.

#### *Cooperating Agencies*

Water-resources investigations were funded by several State agencies, including the Highway Department, the Public Service Authority, the Development Board, and the Water Pollution Control Authority of which the Development Board was the principal cooperator for both Branches. In fact, ground-water investigations would have quite likely been limited to areas of local Federal or other-Federal-agency interest along the coast were it not for the support of the State Development Board.

The city of Spartanburg continued its program to monitor streamflow in and out of Rainbow Lake and Lake William C. Bowen.

#### *Other Federal Agencies*

The U.S. Army Corps of Engineers, Savannah District, funded the operation of a number of gaging stations in the Savannah River Basin. The SCS, until 1965, funded studies of the performance of flood-retarding reservoirs in the Twelvemile Creek Watershed Demonstration Project. The U.S. Navy at Charleston supported operation of the tidal-flow station on the Combahee River until 1960.

The greatest financial support to the GWB from another Federal agency was from the AEC for hydrologic assistance at the SRP. The AEC also provided funds to SWB for monitoring the discharge and temperature of streams emerging from the SRP containment areas. The U.S. Navy and National Park Service provided a much lower level of funding for short-term ground-water investigations. The Navy requested the GWB District to study saltwater intrusion into the principal aquifer that provided water to the Parris Island Marine Base, the Naval Hospital, and the Naval Air Base. The investigation for the Park Service was to determine the availability of potable ground water available beneath Ft. Sumter in Charleston Harbor.

The GWB District staff assisted the Corps of Engineers in the preparation of an environmental impact statement on the effect of diverting most of the water that flowed from Lake Moultrie into the Cooper River, to an alternative discharge point in the Santee River.

### Summary of Program

The SWB programs in South Carolina remained oriented primarily toward collecting and publishing streamflow data until the arrival of Carter and the beginning of Division-level operations when new programs were added and expansion commenced. Work at the SRP was the major GWB activity during most of this period

#### *Water Records*

Streamflow Records.—At the end of the period 1957–66, 66 continuous streamflow stations were reported as being in operation, of which 23 were classified as "primary," 19 were "secondary," and 24 were operated for water-management purposes. Records of stage were obtained daily at seven reservoirs. Additionally, there were 63 stations where peak stages were recorded and 149 sites where low-flow measurements were made.

Ground-Water Records.—In 1966, the District reported 26 observation wells where water levels were measured daily or continuously and 48 wells where water levels were measured periodically.

Water-Quality Records.—Also during 1966, daily sediment records were obtained at one site and samples for chemical analysis were obtained at 93 stream sites. Temperatures were observed daily at 11 stream sites and less frequently at 213 sites. Periodically, samples for chemical analysis were taken at 50 wells and temperatures were measured at 53 wells.

Other Data Activities.—Daily records of precipitation were obtained at 62 sites in 1966.

A few analog-to-digital water-stage recorders were installed at gaging stations.

The SWB began preparations for a statewide flood frequency report, updated its records of drainage-area size, and intensified its low-flow, partial-records program.

The GWB office was, for many years, the only repository in the State for water-well and oil-well samples. The samples were eventually turned over to the State Geologist, Norman K. Olson.

The South Carolina GWB District may have been first WRD operation east of the Mississippi River to utilize gamma-ray logs. The logging services were supplied by the Denver-based Hydrologic Laboratory. The South Carolina District also pioneered in the use of remote-sensing techniques—both black and white and infrared imagery. Aerial surveys were made along the east side of the Savannah River both within and southeast of the plant. The imagery indicated areas of discharge by wells or springs into the river by revealing changes in the temperature of the water in contrast to that of the air.

### *Special Studies*

The major studies of the South Carolina GWB District were those associated with planning, constructing, and operating the Savannah River Plant (SRP) of the AEC in Aiken and Barnwell Counties. The District's involvement began prior to the beginning of this period of history when Siple prepared a reconnaissance report on the site for the AEC.

Siple, Marine, and, later, Clark were involved in a study that began in the early 1960's to determine the feasibility of storing high-level radioactive wastes in caverns excavated in crystalline bedrock, about 900 to 1,000 feet beneath the surface (Marine and Siple, E.I. DuPont de Nemours and Company, Savannah River Laboratory, DP–844, 1964). Siple also reported on these studies in PP 501–C (1964). Marine examined the hydraulic correlation of fracture zones in the rock (PP 550–D, 1966) and later reported on the permeability of the fractured crystalline rock at the SRP (PP 575–B, 1967).

About 1964, the District was asked to determine the probable movement of contaminated material between two production areas within the plant. Clark, recently arrived from Florida, supervised this study, drilled additional test holes, and conducted aquifer tests. The study was scheduled to be completed in mid-1969.

Deep holes drilled at the SRP revealed indications of a buried Triassic basin. The extremely low permeability of this rock suggested to Siple that it might be a favorable host rock for the storage of radioactive wastes. Siple and Marine presented a paper on the discovery of this basin at the Athens, Georgia, meeting of the Southeastern Section of the Geological Society of America in 1966. They also reported on the basin in the Geological Society of America Bulletin and designated it the Dunbarton Basin.

Siple's report on geology and ground water at the SRP and vicinity was published in 1967 (WSP 1841).

Although the SRP projects were important in their technical content and to the Nation, there were other ground-water studies underway in South Carolina that were important to State and local agencies. These included the investigation by Siple of the ground-water resources of York County (SDB Bull. 33, 1966) and by Koch of the ground-water resources of Greenville County (SDB Bull. 38, 1966).

As this period was ending and integration of Branch activities was becoming effective, an interdisciplinary team consisting of F. Johnson (engineer), Siple (geologist), and Cummings (chemist) made a reconnaissance of the water resources of Pickens County. Their report, significantly, was Report No. 1 of the newly formed State Water Resources Committee (1968).

### Vignette

Assistant District Engineer Frederick W. Wagener is well remembered by SWB District personnel as one who gave freely of his time to assist and teach the young engineers in all phases of the stream-gaging program. He was a stickler for recording incidents, and one which he enjoyed relating occurred when he was on reconnaissance for a gaging-station site on the Edisto River in coastal South Carolina. In an attempt to determine the elevation of an earlier flood, he asked a local farmer if he could point out the height of the 1916 flood crest (known as the highest flood of modern times). "Sure can. Come with me," answered the farmer. He took Wagener up a bluff, the only high ground in the vicinity, and pointed to the porch floor of an old farm house. Wagener could see that a flood crest at that elevation meant that most of the flat, coastal area would have been flooded. "Are you sure?" Wagener asked. "Sure, we lived in this house at the time down along the river. Since the water came up to the floor, my daddy had the house moved up here on this hill to prevent it being flooded again."

One of the more humorous events of the period occurred when the Congaree River was in flood stage and District Engineer Johnson asked for help from the GWB staff to measure the discharge from the Gervais Street bridge in Columbia. While Siple (a geologist) was working with the surface-water crew, a reporter came by and took a story from Johnson. But the next day's headlines and pictures stated "Geologists Gage Flood"—with pictures on the front page. Needless to say, Johnson got rather steamed up about that.

## South Dakota

*By* Edmund F. LeRoux assisted *by* current staff members Rick D. Benson, Ella M. Decker, Richard E. Fidler, John R. Little, *and* the author's wife *and* typist, Deannie, with subsequent assistance from Kenneth I. Lindskov

### Organization and Personnel

#### *Surface Water Branch*

Until July 1966, when the South Dakota District began functioning on a Division basis, the SWB operations in South Dakota were administered and supervised as part of the Bismarck, N. Dak., District, comprising the States of North and South Dakota. Harlan M. Erskine served as District Engineer in Bismarck during the years 1957–66.

The Branch Subdistrict office, located in the old Federal Building in Pierre, was responsible for field work and computation of streamflow records in South Dakota. Field offices at Rapid City and Yankton were under the administrative and technical supervision of the Pierre office.

Personnel assigned to the Pierre office during the period included Kenneth I. Darmer, Engineer-in-Charge, 1957 to 1960 when he transferred to Albany, N.Y.; John E. Wagar from Ellenville, N.Y., Engineer-in-Charge, 1961–66; Howard L. Dixson, James H. Eade, Warren H. Erkskine, Barney J. Granstra, Darwin W. Heyd, Eugene B. Hoffman, Terry K. Lockner, and Robert E. West. Marie L. Peterson served as file clerk, typist, secretary, and records checker during the entire period.

The Rapid City field headquarters was located on the second floor of the old Prep Building on the campus of the South Dakota School of Mines. As there was only one stairway to the second floor, small chain ladders were kept in boxes near the windows to be used in case of fire. The office was supervised by Leonard B. Yarger during this entire period. His staff at various times included James H. Eade, E. Robert Hedman, Terry K. Lockner, Bobby E. Mapes, Larry R. Schutterle, Opal A. Stinson, Edna M. Sutherland, Robert C. Ugland, and Anselm T. Wolf.

The Yankton field office was staffed by Archie A. McCollam (Engineer-in-Charge, 1957–60), Donald J. Pangburn (Engineer-in-Charge, 1961–66), and Oliver C. Hetick.

Field personnel from the Pierre office serviced gaging stations and computed streamflow records for the central and eastern part of the State; Rapid City was responsible for the far western part and streams in the Black Hills; and the Yankton office handled the southeastern part of the State and a station on the Missouri River at Yankton that was operated for the U.S. Army Corps of Engineers.

The primary purpose of the Yankton office was to make frequent (often daily) flow measurements of the Missouri River downstream from Garrison Dam at Yankton. Measurements were made from a narrow, double-deck bridge on U.S. Highway 81. The heavy truck traffic, limited clearance, and high winds resulted in some spine-tingling moments for the field men. The approach of a hay mover toward the bridge would result in complete abandonment of the measurement and a restart after the hay had passed.

#### *Ground Water Branch*

Although SWB operations in South Dakota were under the supervision of the Bismarck, N. Dak., District office, the GWB in South Dakota was organized and operated as a single State District. The District office was located above the Osborn Clothing Store at the corner of Third Street and Dakota Avenue in downtown Huron. In 1958 or 1959 the office was moved to the basement of the Post Office—a large, dark, cold, crowded room with little ventilation. Herbert J. Bandelman, the draftsman, had his table and drafting equipment set up in the public hallway outside the office. In 1960 the office was moved to more spacious and airy quarters on the second floor of the Post Office Building. All GWB staff in South Dakota were headquartered in Huron.

James R. Jones was the District Geologist until 1958 when he transferred to Libya. He was replaced by John E. Powell, who transferred from Grand Forks, N. Dak. Other members of the staff at various times during this period included Donald G. Adolphson, Margaret A. Bloomberg, Adela H. Brown, Richard G. Curtis, Robert W. Davis, Charles F. Dyer, Michael J. Ellis, Joyl D. Friese, Arllow J. Goehring, William B. Hopkins, Lewis W. Howells, Suzanne L. Jones, Donald

G. Jorgensen, Neil C. Koch, Francis C. Koopman, Audian L. Larson, Edmund F. LeRoux, Dale C. Lewis, Jerry C. Stephens, Ronald S. Stulik, Kenneth E. Vanlier, and Richard A. Wilkens.

During the period 1957 to 1961, the District staff ranged from 7 to 9. During the 1962-to-1966 period, a redirection of the ground-water program from data collection toward areal studies and a significant increase in funding resulted in a staff of from 12 to 14 people.

South Dakota District funds, fiscal years 1958, 1962–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 67.0 | - | - | - | 177.7 | 180.4 | 186.0 | 191.4 | 193.1 |
| OFA | 151.1 | - | - | - | 145.2 | 173.9 | 173.8 | 201.9 | 194.0 |
| Fed | 8.0 | - | - | - | 7.0 | 7.2 | 10.1 | 9.2 | 9.3 |
| Total | 226.1 | - | - | - | 329.9 | 361.5 | 369.9 | 402.5 | 396.4 |

Source: District program documents. Figures for 1959–61 were not available.

### *Quality of Water Branch*

QWB operations in South Dakota were under the administrative and technical supervision of the Branch office in Lincoln, Nebr. An Area Office in the Prep Building on the campus of the South Dakota School of Mines in Rapid City was staffed by Arvo R. Gustafson in 1957 and 1958, and by Roger A. Bush in 1959. The office was closed in 1960 and field work after that time was done by the Branch staff from Lincoln.

### *Water Resources Division Council*

The unusually extreme separation of the headquarters of the Branches that operated in South Dakota—SWB at Bismarck, N. Dak.; GWB at Huron, S. Dak.; and QWB at Lincoln, Nebr.—made the planning and coordinating functions of a WRD Council in South Dakota vital to the work of the three Branches in the State. The Council met semiannually or oftener. Although seemingly cumbersome, the organization worked well, primarily because of the unselfish and cooperative attitude of the principals comprising the Council.

## Funding and Cooperation

Cooperative (Coop) program funds accounted for about 30 percent of the District program in FY 1958, increased to 54 percent in FY 1962, and averaged about 50 percent for the remainder of this period. The other principal source of funding was from other Federal agencies (OFA) at about 50 percent of the District program. A small amount of funds from the Survey's Federal program (Fed) was used to support several Federal-interest benchmark stations and for a gaging-station network evaluation.

### *Cooperating Agencies*

Water-resources studies in South Dakota were in cooperation with the State Geological Survey, the State Water Resources Commission, and the State Highway Commission.

The first cooperative ground-water studies in South Dakota began in 1955 when the Water Resources Commission requested an investigation of the wasteful, uncontrolled flow from artesian wells throughout the State.

In 1958, the State Geological Survey entered into a cooperative agreement with the USGS for ground-water studies with emphasis on counties in the eastern part of the State.

The cooperative program, begun in 1955 with the State Highway Commission to acquire special flood data from a network of about 60 crest-stage gages in 16 areas of the State, continued, as did the long-standing program to provide streamflow information, Statewide, with the State Water Resources Commission.

### *Other Federal Agencies*

During the period 1957–66, from 20 percent to 40 percent of the total South Dakota WRD budget was from the Missouri River Basin (MRB) program. Most of the work was that of collecting streamflow and water-quality data, primarily in the James River Basin. The MRB funds also supported a small ground-water observation-well network in the area of the proposed Oahe Irrigation Project until the early 1960's and ground-water studies at Indian reservations in the State.

During 1957–66, the Corps of Engineers was the primary OFA source of funding for obtaining streamflow records in South Dakota. The gaging-station records of interest to the Corps were on the Missouri River and its tributaries.

The National Park Service requested, and reimbursed the Survey for water-supply assistance at Jewel

Cave National Monument in 1958 and at Mt. Rushmore National Monument in 1966.

From 1962 to 1964, the BOR funded the collection of ground-water data in the Shadehill Reservoir area and for streamflow records on streams and canals in the Belle Fourche Irrigation Project and at the Pactola Dam construction site.

The Public Health Service and the Bureau of Indian Affairs funded several small ground-water supply studies at villages on the Pine Ridge, Rosebud, and Standing Rock Indian Reservations.

The U.S. Fish and Wildlife Service and the SCS supported the collection of streamflow records at various sites throughout the State.

## Summary of Program

In 1958, the program in South Dakota comprised 59 percent surface water, 23 percent water quality, and 19 percent ground water. More than 90 percent of the work was to collect, compile, and publish basic water data. By 1962, following a nearly fourfold expansion of the ground-water areal-studies program and a 50-percent reduction in the water-quality data program, basic-data collection accounted for only about 65 percent of the program. In 1966, the figure had dropped to about 60 percent.

### *Water Records*

Data activities are those reported in "Water Resources Investigations in South Dakota, 1962."

Streamflow Records.—In 1962, 59 long-term hydrologic stations, 10 short-term hydrologic stations, and 29 specific-purpose or water-management stations were operated in South Dakota. Most of the long-term hydrologic stations were a part of the State cooperative or the Missouri River Basin program. Most of the water-management stations were maintained to provide records needed by the Corps of Engineers or the BOR.

Ground-Water Records.—The size of the ground-water observation-well network varied considerably because of the many wells measured for the duration of 2- to 3-year special studies. However, in 1961 the more-or-less permanent observation-well network consisted of 134 wells measured annually, 12 measured monthly, and 20 equipped with continuous water-level recorders. Most of these observation wells were maintained in cooperation with the Water Resources Commission to inventory and monitor artesian wells statewide and to monitor wells in the glacial aquifers east of the Missouri River.

Water-Quality Records.—Samples for chemical-quality analysis of surface water in 1962 were obtained monthly or more frequently at nine sites, and on a reconnaissance basis in selected areas throughout the State. Fluvial-sediment data, which include information on suspended-sediment discharge and on particle-size distribution of suspended sediment and bed material, were obtained at three sites.

### *Other Data Activities*

Data on floods in North and South Dakota, compiled by John A. McCabe and Orlo A. Crosby, provided the basis for a report on the magnitude and frequency of floods in both States (open-file rept., 1959). The SWB also collected, compiled, and analyzed data for publication in WSP's dealing with floods in 1957, 1960, 1962, and 1965.

### *Special Studies*

The county-by-county ground-water (later expanded to water-resources) studies of the counties east of the Missouri River concentrated on determining the availability of surface and ground water, the operation of the hydrologic system, the quality of the water, and the effects on the hydrologic system of developing the water resources. For each study area, State Geological Survey personnel were engaged in geologic mapping, test drilling in the glacial deposits, and mapping the sand and gravel resources. Although, at times, there may have been minor personality and technical conflicts between USGS and State personnel, the system worked admirably. Over the years it resulted in a very close working relationship between the two agencies and what has been described by many as one of the best cooperative programs in the Nation.

Each county study was scheduled to be completed in 3 or 4 years and to produce reports on the hydrology, the geology, and on the sand and gravel resources. The reports were published by the State Geological Survey in its Bulletin series. The first of these, begun in 1959, was for Sanborn County, by Steece and Howells (Bull. 17, 1967). This was followed in the period 1960–66 by Beadle County, by Howells and Stephens (Bull. 18, 1968); Clay County, by Stephens (Bull. 19, 1967); Campbell County, by Koch (Bull. 20, 1970); and Bon Homme County, by Jorgensen (Bull. 21, 1971).

In 1959 a low-budget study began of the geology and occurrence of ground water in the Dakota Sandstone in South Dakota. The project was proposed and initiated by Dyer and later directed by LeRoux. The project was continuing in 1966.

Dyer made an investigation in 1959 of the surface geology and ground-water resources at Jewel Cave National Monument in the Black Hills near Custer, S. Dak. (WSP 1475–D, 1961).

Studies of the water resources in the glacial drift in eastern South Dakota was begun in 1960 under the direction of Ellis. The results were published as Hydrologic Atlases (Ellis and Adolphson, HA–195, 1965; and Ellis, Adolphson, and West, HA–311, 1969).

The quality of the water in 26 lakes in the eastern part of the State was studied during 1964 and 1965 by Petri and Larson. The results of their investigation were published by the State Water Resources Commission (Rept. of Invest. No. 1, 1967).

In 1966, Powell and Adolphson teamed with James J. Norton, Geologic Division, in a 3-year study to locate additional sources of ground water for the Mt. Rushmore National Memorial. Their findings were published in WSP 1865 (1973).

Seven ground-water studies were completed or initiated on the nine Indian reservations in South Dakota during this period. A reconnaissance was first made of the Cheyenne River and Standing Rock Indian Reservations in north-central South Dakota during 1958-61 under Powell's supervision. Wilkens and Rosene then evaluated the ground-water resources at nine town sites in the Cheyenne River Indian Reservation (open-file rept., 1959) and Ellis and Adolphson investigated the ground-water resources at three towns in the Standing Rock Indian Reservation (open-file rept., 1965).

Under the Missouri River Basin program, the Bureau of Indian Affairs requested a comprehensive investigation of the geology and ground-water resources of the Rosebud and the Pine Ridge Indian Reservations in southwestern South Dakota. Ellis, the project leader, was assisted by Adolphson and Ficken for the Rosebud study, begun in 1961 (HA–355, 1971) and by Adolphson for the Pine Ridge study, begun in 1964 (HA–357, 1971).

### Vignettes

#### *Weather*

The Dakotas' blizzard of March 1966 was one of the worst on record—heavy snow, temperature about 20 below, and winds of at least 40 miles per hour. As might be expected, the blizzard coincided precisely with a Division conference to be held in Bismarck, N. Dak. On the morning of the first day of the blizzard, Ed LeRoux drove from Huron to Pierre in bright sunshine. He met Darwin Heyd of the Pierre office and after lunch, headed north on Highway 83 in a light snow. Within an hour, the temperature had dropped 25 degrees, the light, vertical snowfall had become heavy and horizontal. Being new to the Dakotas, LeRoux turned the car radio on to find out what was happening. What he heard did not calm his nerves—"Travel on Highway 83 north of Pierre is impossible." (Weren't they on Highway 83?) Three to four hours later, at speeds never exceeding 20 miles per hour they reached the Interstate, about 20 miles east of Bismarck. They were strongly tempted to stop at a small motel there but decided that as they would be heading west, with the wind, they could make it to Bismarck before dark. The next day in Bismarck, they learned that about a hundred people had spent the night at that small motel.

The conference at Bismarck's Grand Hotel was to include WRD people from surrounding States, Washington Headquarters, and the Denver regional office. Thankfully, everyone arrived safely. John Powell, who drove in alone from Rapid City, learned several days later that two high school basketball coaches had perished in their vehicle on that same road to Bismarck.

The next morning as the out-of-towners convened for the conference opening, it became apparent that no one from Bismarck, the host office, was present. The town was so completely buried in snow that no one could move. With the hosts missing and the town snowed in, the conference quickly degenerated into 3 days of poker, bull sessions, and conviviality. Fortunately, the hotel employees also were trapped in the hotel so the restaurant and bar were operating. The bar opened at 11 a.m. every morning except one when the bartender misplaced the key and the door had to be taken off the hinges. After 3 days of isolation, with food supplies dwindling and everyone suffering from cabin fever, the conferees were told that the roads out of town were cleared and they could leave.

#### *Personnel*

In 1964, when Ed LeRoux transferred to South Dakota from his position as Chief, Manpower Section, GWB, in the Washington office, he was appalled at the low GS grades of many of the field personnel. After working with these people in the field and seeing for himself their difficult and often unpleasant duties, he was convinced that something must be done to upgrade the positions. A request to the Regional Personnel Office sent an impartial Classification Specialist to observe the men in the field. It was not by chance that the District selected mid-November for the visit and the work selected for observation was water sampling from a boat on the Oahe Reservoir near Pierre and measuring the flow of the Missouri River. The day of the water-sampling trip dawned deceptively clear and sunny but cold and windy. The waves on the reservoir were not dangerous but did produce a freezing spray which coated the borrowed field clothes of the observer with ice. The flow-measuring site which was visited the next day was at an abandoned railroad bridge over the river. It was cloudy, colder, and windier than the day before. Completely uncomfortable.

The District didn't hear much from the Classification Specialist after he left South Dakota (not even a note of thanks for the hospitality). But, it did seem easier thereafter to justify promotions for field personnel.

## Tennessee

*By* Joseph S. Cragwall assisted *by* retired District personnel Bernard J. Frederick, Thomas J. Quarles, *and* W. John Randolph, *and* current District staff Lewis G. Conn, Betty Hill Keener, *and* William S. Parks. Reviewed *by* Alfred Clebsch, Jr., Elliott M. Cushing, George W. Edelen, Jr., John P. Monis, *and* Joe L. Poole

Programs were developed, administered, and executed by the Branches until September 1962, when Tennessee was designated as one of the first Division-level districts. By 1963, the District was functioning on a Division basis and continued so with subsequent evolutionary changes throughout the remainder of the 1957–66 period.

### Organization and Personnel

#### *Surface Water Branch (1957–62)*

The District office was in 823 Edney Building, Chattanooga, a major downtown office building occupied mainly by the Tennessee Valley Authority (TVA). William R. Eaton served as District Engineer until May 1958 when he was named Branch Area Chief (BAC), MCA. He was succeeded by Joseph S. Cragwall, reassigned from the Floods Section, SWB, Arlington, Va. J. Wyatt Gambrell served as Assistant District Engineer until his transfer to Virginia as District Engineer in August 1958, after which Milburn Hassler served in that position.

Thomas J. Quarles served as District Clerk and later as Administrative Assistant. Dorothy A. Potts served as secretary to both District Engineers. A special unit, known locally as the "H & H Section" (short for "Hydrology and Hydraulics," but better known locally as "Hell and Highwater"), was headed by Clifford T. Jenkins until he transferred to Colorado in 1959, and then by W. John Randolph who transferred in from Louisiana. Irby J. Hickenlooper, Charles Wells, and Alfred M.F. Johnson (at times) rounded out the District headquarter's staff.

Eaton operated as BAC from Chattanooga until he transferred to St. Louis in March 1961. His secretarial support was provided by Annie M. Harris (deceased 1960), and by Marilyn S. Wert, afterwards.

Paul R. Speer headed a field unit of SWB headquarters to coordinate and prepare streamflow compilation reports and regional flood-frequency studies (see Part IV, "Compilation of Surface-Water Records" and "Flood Frequency Studies"). Following retirement in 1964, he continued to work part time for 2 more years, assisted by Alma J. Jeffries and, at times after 1960, by Charles R. Gamble.

Bernard J. Frederick transferred to Chattanooga from New York in 1958 to conduct field experiments for the SWB Research Section on diffusion and dispersion in natural channels using radioactive isotopes and fluorescent dyes. In 1960, he moved to the newly established Subdistrict office at Oak Ridge, reporting administratively to the BAC-SWB, MCA.

Branch Subdistrict offices at Chattanooga, Knoxville, Nashville, and after 1960 at Oak Ridge, performed all field and office work within their respective areas. At Chattanooga, Milburn Hassler was Engineer-in-Charge until 1959 and Prentiss M. Frye, thereafter. Their staff, at various times, included Howard L. Edmiston, F. Derward Edwards, Charles R. Gamble, Alfred M.F. Johnson, Meta A. Martin, and John L. Simmons. At Knoxville, Elmer P. Mathews was Engineer-in-Charge assisted at times by Lewis G. Conn, Patrick N. Counts, Edith C. Flemming, Sarah M. Hartley, Lewis C. McWilliams, and John P. Monis. At Nashville, Woodford J. Perry was Engineer-in-Charge assisted at times by Edward B. Boyd, James D. Hathcock, Mary D. Perkins, McGlone Price, Robert L. Reed, and George H. Wood. A field headquarters within the Nashville Subdistrict area, staffed by Howard L. Edmiston, was operated at Jackson during 1960 and 1961. At Oak Ridge, Raymond M. Richardson was Geologist-in-Charge. On his staff at times were P. Hadley Carrigan, Bernard J. Frederick, William M. McMaster, Ranard J. Pickering, and Shirley A. Wilson.

#### *Ground Water Branch (1957–62)*

The District office was located at the Memphis General Depot until moved to Nashville in 1960. Elliott M. Cushing served as District Engineer until late 1957 when he was reassigned to head the federally funded regional Mississippi Embayment project (see Part IV, "Mississippi Embayment Project"). Paul H.

Jones was then named District Geologist, and after serving about 2 years, transferred to Idaho. Harry M. Peek, until he resigned in 1959, and then Cushing, served as acting heads of the District.

The District office was moved to 90 White Bridge Road, Nashville, in late 1960 with the arrival of Joe L. Poole as District Geologist. The Memphis location was continued as a Subdistrict office under the direction of Pao C. Sun, followed by Gerald K. Moore. Poole transferred to St. Louis to be BAC-MCA, in August 1962.

Mildred S. Hankins served as District Clerk at Memphis and Clara A. Reeves at Nashville. Other members of the Memphis or Nashville staffs during the period included Roy H. Bingham, James H. Criner, Charles W. Currey, Louis G. Dyche, Billie J. Ingram, Thurman H. Jackson, Melvin V. Marcher, Richard E. Lounsbury, and Dale J. Nyman. A field headquarters headed by Marcher was maintained in Nashville until becoming a part of the District office in 1960. Field headquarters were operated temporarily in Jackson by James W. Niehaus and in Martin by Bingham in 1958–1959.

A field headquarters at Oak Ridge, staffed by Raymond M. Richardson, was reassigned to the SWB and designated a Subdistrict of that Branch in 1960. A Subdistrict office in Knoxville, headed by Robert M. Maclay, was closed in 1958 with his transfer to Washington, D.C.

#### *Quality of Water Branch (1957–62)*

This Branch maintained no offices in Tennessee. Its District office at Raleigh, N.C., served Tennessee's needs before 1960; the Little Rock, Ark., District office, served them thereafter.

#### *Water Resources Division (1963–66)*

With designation of Tennessee as a Division-level District in late 1962, Cragwall was named District Hydrologist (later, "District Chief"). In June 1963, Donald R. Rima was reassigned from Newark, Del., to Nashville to serve as Assistant District Chief of the new organization. Rima also had technical direction of ongoing projects of the former GWB offices in Memphis and Nashville during the period of transition and consolidation that followed.

To be more centrally located in the State and closer to principal cooperating agencies, the District headquarters in Chattanooga was moved to Nashville in the summer of 1965, leaving a Subdistrict office in Chattanooga with Hassler in charge. Cragwall, Gamble, Potts, Quarles, Randolph, Donald W. Spencer (Chattanooga Subdistrict after 1963), and Wert moved to Nashville as part of the relocation. All offices in Nashville were consolidated with the relocated District office in the old Federal Building and remained there for the rest of the period.

The Memphis Subdistrict office was headed by Edwin A. Bell as Engineer-in-Charge from 1963 to the end of the period. John P. Monis served as Engineer-in-Charge of the Knoxville Subdistrict in 1963–64, and Bernard J. Frederick, from Oak Ridge, thereafter.

The Oak Ridge Subdistrict was closed in 1965 with completion of the Clinch River study. Carrigan entered graduate school at Colorado State University under the Government Employees Training Act; McMaster and Betty B. Hill, who had joined the staff in 1963, were reassigned to the Knoxville Subdistrict; Pickering transferred to Columbus, Ohio, QWB; and Richardson transferred to the AEC at Germantown, Md.

Additions to staff after the 1962 reorganization, but not heretofore listed, included Donald L. Brown, Charles R. Burchett, Gerald M. Christianson, Lewis G. Conn, Thelma H. Jackson, Owen T. Marsh, and William S. Parks in Nashville; James G. Lewis in Chattanooga; Donald W. Harkleroad, Vester J. May, and Gordon B. Smith in Knoxville.

#### *Other Organizational Arrangements*

The District Engineer, SWB, and later as the District Chief, WRD, represented the Division as coordinator of and principal contact for the basinwide program with TVA, covering parts of Alabama, Georgia, Kentucky, North Carolina, Tennessee, and Virginia.

The District was also assigned operational management of the Division's program with the AEC through the Oak Ridge National Laboratory (ORNL) to participate in the multiagency Clinch River study. Cragwall served throughout the study as the Survey's member of a steering committee of Federal and State officials that planned, oversaw, and reviewed the study.

Before the District reorganization in 1962, the Branches collaborated in planning and programming and in cooperating-agency liaison through the Tennessee WRD Council which had regularly submitted consolidated annual progress reports and proposed programs to principal cooperators since the mid-1950's.

### Funding and Cooperation

The District's program was funded from two principal sources, the cooperative program (Coop) and other Federal agencies (OFA). The Survey's Federal program (Fed) funds added support for a few gaging stations and observation wells and, in FY 1965, for a summary report on the hydrology of the Oak Ridge area. The Aluminum Company of America, a licensee of the FPC, required streamflow data throughout the period. As shown in the following table, total funds ranged from a low of $326,000 in FY 1958 to a high of $573,400 in 1964, the final year of AEC funding of the Clinch River study.

Tennessee District funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 198.4 | 222.8 | 213.5 | 227.5 | 210.9 | 218.8 | 304.3 | 332.5 | 386.2 |
| OFA | 118.5 | 115.0 | 120.2 | 198.2 | 236.3 | 272.8 | 255.4 | 157.7 | 149.9 |
| Fed | 7.2 | 11.6 | 8.6 | 13.4 | 9.1 | 17.0 | 12.3 | 34.4 | 14.3 |
| FPC | 1.9 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.4 | 1.4 | 1.4 |
| Total | 326.0 | 350.6 | 343.5 | 440.3 | 457.5 | 509.8 | 573.4 | 526.0 | 551.8 |

### *Cooperating Agencies*

The Tennessee Department of Conservation, through its Divisions of Water Resources (DWR) and Geology, was the principal cooperator throughout this period for statewide water-resources activities—the streamflow and ground-water data networks, areal hydrologic studies and hydrologic/geologic mapping.

The Tennessee Department of Highways and Public Works supported a statewide network of crest-stage gages, flood frequency studies, and preparation of reports on flood characteristics at specific stream sites. Beginning in 1966 this program was expanded with federally allotted highway research funds (100-percent repay by the cooperator) to support a network of flood-runoff stations on small streams.

The Tennessee Department of Public Health supported a network of low-flow partial-record stations and low-flow frequency analyses.

The city of Memphis continued and strengthened its program of ground-water monitoring and investigations in that metropolitan area.

A major urban program was begun in FY 1964 with the Metropolitan Government of Nashville and Davidson County to document current flood events, to assess the magnitude and frequency of floods, and to delineate depth and extent of flooding on the local streams within the metropolitan area.

The Tennessee Game and Fish Commission, and the cities of Knoxville (until 1959), Murfreesboro, Chattanooga (from 1959), and Oak Ridge (from 1965) each cooperated on collection of surface-water records at specific locations within their respective areas of interest.

### *Other Federal Agencies*

The TVA, through its Hydraulic Data Branch, supported a large part of the District's gaging-station network in the Tennessee River Basin. TVA's program also provided for special measurements to calibrate or verify dam-gate and turbine-release ratings and for sharing the cost of computer processing of all past streamflow records in the Basin.

The Nashville District of the U.S. Army Corps of Engineers funded a number of gaging stations in the Cumberland River Basin.

The AEC funded gaging stations and hydrologic studies at the ORNL, and, by transfer of funds through WRD headquarters beginning in 1961, the Survey's participation in the Clinch River study, completed in 1965.

The Air Force, through the Arnold Engineering Development Center, and the U.S. Fish and Wildlife Service required surface-water data throughout the period. The National Park Service received assistance for ground-water development in several parks in 1965 and 1966.

In 1965, the U.S. Public Health Service funded hydrogeologic and geochemical studies of a landfill for pesticide wastes in Hardeman County, east of Memphis. This work continued in 1966, and years following, funded by the newly created FWPCA.

## Summary of Program

Collecting, processing, and publishing water records continued to be a strong but basically level component of the District program. Application of network concepts sharpened data-collection objectives. Increasing applications of computer technology improved timeliness of data collection, processing, and publication.

Program growth was in interpretive studies. Topical hydrologic studies, such as those of flood and low-flow frequency, stressed statistical analysis of available water records to improve product usefulness for design and water-management needs. Emphasis on areal and site studies gradually shifted during the period from the traditional characterization of hydrologic conditions to water-management practices and environmental impacts.

### *Water Records*

Data activities are summarized as of 1965 from information reported in "Water Resources Investigations in Tennessee, 1965" or from annual District progress reports to cooperators.

Streamflow Records.—A total of 114 continuous-record stations were being operated in June 1965, consisting of 59 classified as primary (long-term hydrologic), 12 as secondary (short-term areal hydrologic), and 43 as serving water-management needs. By June 1965 about 75 percent of the stations had been equipped with the new analog-to-digital recorders.

As of June 1965 there were 111 low-flow partial-record stations and 101 crest-stage stations. Previously the low-flow network had included an additional 60 stations, largely in support of the Mississippi Embayment project.

Ground-Water Records.—The District reported 62 wells in the observation-well network in 1965, 51 of which were equipped with recorders and 11 were measured periodically. An additional 41 wells had been discontinued according to plan. This network was selected and designated as such in 1961, but water-level data had long been collected as part of systematic statewide collection of hydrologic and geophysical data and areal ground-water resources investigations.

A spring-flow network was formally designated for systematic measurement in 1962 and maintained thereafter at 13 to 18 springs. These data were published annually in "Surface Water Records of Tennessee."

Statewide collection of subsurface information—geophysical, geologic, and hydrologic—relevant to principal aquifers and in support of active or planned ground-water investigations continued throughout the period. This information was generally open-filed on a current basis and used as appropriate in subsequent maps and reports.

Water-Quality Records.—In 1965 the District collected temperature data at 114 surface-water stations and chemical-quality data at 27 stations. As of 1965, chemical-quality analyses were available at about 1,000 wells and springs.

A small program of chemical-quality sampling at gaging stations and observation wells was initiated in 1964. Sampling at stream-gaging stations was limited mostly to stations in the Cumberland and Lower Mississippi River Basins where quality information was previously lacking. In addition, 50 ground-water samples, mostly in project areas, were collected. This 1964 effort marked a modest beginning of a systematic network approach to water quality as a component of the State's hydrologic data base.

Other Data Activities.—In the early 1960's all streamflow records were processed on the Washington computer to obtain summaries of low- and flood-flow for selected periods of consecutive days and of flow duration. These summaries were compiled by Wood and Johnson for publication as a special Tennessee Division of Water Resources data report in 1965.

Beginning in 1964 the systematic collection of water-use data was initiated cooperatively with the State Division of Water Resources, and subsequently reported by Johnson and others in a water-use information series of the Division of Water Resources.

In 1965 the District measured base flow and collected water-quality samples in support of WRD's regional assessment of the effects of acidic mine drainage on stream quality in Appalachia (Circ. 526, 1966).

Throughout the period the District gave priority attention to measurement and documentation of notable flood events. The District made more than 40 indirect measurements at regular and crest-stage stations and miscellaneous sites of the floods of March 1963, which were reported in Barnes' 1964 open-file report, "Floods of March 1963, Alabama to West Virginia," and in WSP 1830-B (1968). Other outstanding floods of the period were summarized in the Survey's annual flood series of Water-Supply Papers, "Summary of Floods in the United States, during __." The District also participated with other Districts in the interchange of personnel as needed to measure floods elsewhere.

#### *Special Studies*

Among the principal studies that were conducted, all or in part, within FY 1958–66 were studies of the large springs of east Tennessee by Sun, Criner, and Poole (WSP 1755, 1963); of ground-water conditions in the Memphis area, by Criner, Sun, and Nyman (WSP 1779–0, 1964); of the geology and hydrology of the Claiborne group in a 7,200-square-mile area of western Tennessee, by Moore (WSP 1809–F, 1965); and of the ground-water resources of Madison County by Nyman and Moore (DWR, HA–1, 1963).

Members of the Tennessee District provided input to the Mississippi Embayment project (see Part IV, "Mississippi Embayment Project") by assisting with the preparation of two chapters of the report, Professional Papers 448–C (Moore with others), 1965, and 448–H (Speer, Perry, and others), 1965.

Details of the Clinch River study are provided in Part IV, including a list of published reports. Carrigan, Pickering, Frederick, and others from the District were major participants in this miltiagency study of the movement and fate of low-level radionuclides which were discharged for a number of years to the Clinch River from the ORNL reservation.

Other major studies during this period included an analysis of the potential hydrologic effects of pumping from the Lichterman well field in the Germantown-Collierville area of Shelby County, by Nyman (WSP

1819–B, 1965) and of potential changes, caused by changes in pumping rates and well locations, in the quality of water pumped from the 500-foot sand, a major aquifer supplying water to Memphis, by Bell and Nyman (WSP 1853, 1968).

There were several projects that were continued through the end of this period including the data collection and analysis in support of the study of floods from small streams in the Nashville-Davidson County metropolitan area. This study, under the leadership of Conn, began in 1964. A similar project, begun in 1965 and also continuing, was that of long-term data collection and analysis to develop more reliable estimates of flood magnitude and frequency on small streams, statewide. This project, under the leadership of Spencer, involved establishing gaging stations equipped with ADR recorders set to record stage as frequently as 5-minute intervals..

Flood investigations, sometimes referred to as the "Highway Program" in recognition of its Highway Department sponsorship continued under the leadership of Jenkins and Randolph. Maintaining the network of crest-stage stations, documenting outstanding floods, analyzing the magnitude and frequency of floods, and preparing hydrologic reports for specific highway-stream crossings were the principal activities. Jenkins reported on the magnitude and frequency of floods in Tennessee (Dept. of Highways, 1960). Randolph contributed to regional flood-frequency reports, WSP 1676 (1964) and WSP 1681 (1964). Through 1966, 175 formal and many informal highway-stream crossing reports were requested by and prepared for the Highway Department.

Geologic quadrangle mapping by Marcher, Marsh, Parks, and others continued in support of ongoing or planned hydrologic studies in Dyersburg, Dover, Highland Rim plateau, and western areas of the State. The maps were published as 7.5-minute quadangles by the State Division of Geology.

Also, the hydrology of the Oak Ridge area was reported by McMaster (WSP 1839–N, 1967) drawing on his own work there, Richardson's work during the 1960's in support of subsurface waste-disposal management, and the Knoxville Subdistrict's surface-water data collection in the area. McMaster earlier prepared a geologic map of the Oak Ridge area, and with H.D. Waller of ORNL, a geology and soils map of White Oak Creek Basin (ORNL repts., 1964.)

The surface- and ground-water resources in the upper Stones River Basin were described by Burchett and Moore (DWR, Water Resources Series No. 8, 1971). Rima and others assessed the potential contamination of the hydrologic environment from the disposal of pesticides in a landfill in Hardeman County (open-file rept., 1967).

(A list of water-resources publications for Tennessee through this period and beyond is contained in USGS Open-File Report 87–552.)

### Other District Activities

The District's first edition of "Index to Water Resources Investigations in Tennessee," February 1961, was used by WRD Headquarters as a model for other Districts. The overall style of presentation prevailed for a number of years beyond the 1957–66 period.

The District worked closely with MCA to produce a District-level long-range plan in a program activities-calendar matrix. The plan dated May 1964 displayed an array of projects for years 1965–71 and was accepted by principal cooperators as a blueprint for future programs.

Conjunctive with earlier long-range planning, Cragwall prepared a map of tributary river basins in Tennessee delineated as logical units for water-resources investigations, development, and management (DWR, 1963). The map included a tabular summary of drainage area, total geographic area, and geographic area within Tennessee for each basin unit. (Author's note: This basin map may well have served as progenitor of the national series of State Hydrologic Unit maps prepared by OWDC in the 1970's as a Federal interagency effort.)

Responding to requests for current water information increased greatly during this period. A funded project was established in FY 1965 to support this activity. More than 500 special-information requests were serviced in that year, excluding standing requests from cooperating agencies.

District staff participated in working-group subcommittees with other agency personnel and public members to prepare material for the Tennessee Legislative Council's "Final report—Water Resources and Related Lands Study," 1963. District input was concerned mainly with describing the State's water situation, problems, and information needs.

Annual District conferences were held throughout the 1957–66 period, first by SWB and later by the WRD District. These meetings, attended by virtually all personnel each year, were primarily technical and programmatic in content, but they provided the opportunity for Divisionwide team building during the early reorganization years.

## Texas

Condensed from material provided *by* Allen G. Winslow, Clarence T. Welborn, *and* Herberto B. Mendieta assisted *by* Charles W. Boning, Harold D. Buckner, Bernard C. Massey, Julie A. Menard, *and* Mary Jane Winslow. Reviewed *by* Edward R. Leggat *and* Clarence R. Gilbert

The three Branches operating in Texas were headquartered at 302 W. 15th Street in Austin until 1958 when they were relocated to 807 Brazos Street. The activities of the Branches were coordinated through the Texas WRD Council which was chaired at various times by each of the three District Branch supervisors. In February 1965, the Branches were consolidated and began to function on a Division level under the leadership of Trigg Twichell, the first Texas Division District Chief. In 1965, the offices were moved to the Federal Building at 300 E. 8th Street.

As Branch consolidation occurred late in this period of history, it made little impact on-going programs and staff assignments during the remaining year of this period of history. Consequently, this account of the District history is presented largely on basis of Branch activities and staff.

### Organization and Personnel

#### *Ground Water Branch*

Raymond W. Sundstrom served as District Engineer until 1960 when he was reassigned to a field unit of the GWB Area Chief in Austin where he remained until 1962 when he was transferred to Cairo, Egypt. Allen G. Winslow was appointed District Geologist in early 1961 and served until 1965 when the Division District was established. Other key personnel assigned to the District office for all or part of the 1957–66 period were Ted Arnow, Edward R. Leggat, Edward A. Moulder, and Leonard A. Wood. Leio J. Krueger was the District Secretary. GWB Subdistrict offices were located at El Paso, Houston, and San Antonio.

The El Paso office, located at Fort Bliss, was directed by Edward R. Leggat, Geologist-in-Charge until 1960 when he was reassigned to the District office. He was succeeded by Marvin E. Davis. Others assigned to El Paso at various times during the period were Glenn L. Audsley, John D. Gordon, and Marlin E. Lowry.

At Houston, Leonard A. Wood was Geologist-in-Charge until 1959 when he transferred to Austin. Robert B. Anders was then in charge until 1965 when the office was merged with the SWB Subdistrict to form the Division Subdistrict office. Others at Houston during the period were Rita B. Franklin, Robert K. Gabrysch, Gene D. McAdoo, Wellborn L. Naftel, and John B. Wesselman.

At San Antonio, Ben M. Petitt, Jr., was Engineer-in-Charge until 1959 when he was succeeded by Sergio Garza. Garza continued in charge until the 1965 reorganization when the office was merged with the SWB Subdistrict to form the Division Subdistrict office. Others on the San Antonio GWB staff at times during the period included Olga Hernandez, Thomas V. Kinsey, Gene D. McAdoo, Richard D. Reeves, Paul L. Rettman, Orvie Wayne Rhea, and Gerald L. Thompson.

The GWB maintained field headquarters at various times and places during the period, usually staffed by one person. The field headquarters and staff were: (Alice), Curtis C. Mason; (Alpine), Kenneth J. DeCook and Marvin Davis; (Bandera), Richard D. Reeves; (Beaumont), Curtis C. Mason; (Brady), Curtis C. Mason; (Crockett), George R. Tarver; (Dumas), Walter H. Alexander; (Fort Stockton), Clarence A. Armstrong and Raymond G. Mitchell; (Katy), Clyde A. Wilson; (Kerrville), Frank C. Lee; (McAllen), Oscar C. Dale; (Mt. Pleasant), Matthew E. Broom; (Paris), Clarence A. Armstrong; (Pecos), William Ogilbee; (Plainview), James G. Cronin, Thomas G. Humphrey, Gene D. McAdoo, and Paul L. Rettman; (Pleasanton), Hobart B. Harris; (Seminole), Paul L. Rettman; (Sherman), Ernest T. Baker; (Stamford), Gene McAdoo; (Uvalde), Frank A. Welder; (Victoria), Richard F. Marvin; (Wharton), Robert K. Gabrysch; and (White Deer), Archie T. Long and Gene D. McAdoo. Many of these also served in other offices in Texas at other times.

Other full-time personnel who served in the Texas GWB District for more than about 2 years included Roger C. Baker, Anna Mae Beck, James G. Cronin, Verda M. Dougherty, Mava Lynn Eckert, Clarence C. Follett, Kay P. Hailey, Bobby Dean Jones, Pamela Jo McGlammery, Brian N. Myers, Richard D. Reeves, and George H. Shafer.

#### *Quality of Water Branch*

Burdge Irelan was the District Chemist until 1961 when he was reassigned to Yuma, Ariz. He was replaced by Charles H. Hembree, District Geologist, until 1965 when the Branches were consolidated. Other key District-office personnel during all or part of this 1957–66 period were James F. Blakey, Herman R. Feltz, Leon S. Hughes (Assistant District Chemist), Donald K. Leifeste, Herberto B. Mendieta (in charge of the laboratory), Jack Rawson, Wanda J. Shelby, and Clarence T. Welborn (in charge of the sediment program). All the QWB staff in Texas were headquartered in Austin. The Austin staff also performed field and laboratory services for the Louisiana District, which was often referred to as "the Louisiana Subdistrict."

Other full-time employees who served more than about 2 years included Eleanor S. Chitwood, Helen Jean Connell, Donald E. Donaldson, Alton J. Dupuy, Reba Nell Farrell, Marvin W. Flugrath, Guy W. Gifford, Harvey L. Kunze, James N. Rabey, and Guadelupe Ramus.

This is the period that the late Leon S. Hughes called "the golden years." It was a period of the largest expansion in water-quality programs in the Texas District. Water quality became an integral part of the planning and conduct of water programs and in the initiation of new types of studies that are continuing, many years later.

#### *Surface Water Branch*

The SWB District office was located in Austin throughout the period. Trigg Twichell served as District Engineer until 1965 when he became District Chief of the consolidated WRD District. The Assistant District Engineer was Seth D. Breeding. He retired in 1959 and was succeeded by William H. Goines. Evelyn M. Ogden served as Secretary to the District Engineer during the period. Other key SWB District headquarters staff during the period included Clarence R. Gilbert, Richard U. Grozier, Patrick H. Holland, and I. Dale Yost.

Other full-timers who served in the Austin District or Subdistrict office for more than about 2 years were Mary L. Bauer, Neal A. Bothmer, Harold O. Buckner, Charles S. Carney, Evangeline R. Carrillo, Shirley H. Hunter, Edward W. Jeffes, Geraldine C. Jenkins, Henry G. Krauss, Donald L. Leslie, Louis L. McDaniels, Pamela Jo McGlamery, Homer H. McGrand, Sylvester Pleasant, Jr., Francis S. Price, Henry C. Pritchett, Patricia L. Reinhardt, James N. Sansom, Ben G. Sauer, Stanley P. Sauer, and James T. Smith.

District field operations were handled through subdistrict headquarters located in Austin, Fort Worth, Houston, San Angelo, Wichita Falls, and San Antonio.

Arthur E. Hulme was Engineer-in-Charge of the Austin Subdistrict until 1963 when he was reassigned to the newly created San Antonio Subdistrict. Other key Austin Subdistrict staff included Joe M. Alexander, Cross Dodd, Patrick H. Holland, and Wallace D. Robbins. William H. Espey, Jr., and Norman E. Hutchinson also served on the staff for several years. With the creation of the San Antonio Subdistrict office, the Austin Subdistrict became a field headquarters with Willard B. Mills in charge.

The Engineer-in-Charge of the Fort Worth Subdistrict, during this period, was John H. Montgomery, assisted by Robert L. Allen. Other key personnel included Clarence R. Gilbert, Bernard C. Massey, and Ralph H. Ollman. Others serving short periods of time included Leslie B. Andrus, Billie B. Hampton, Roger Hartung, Thomas H. Hays, Gary E. Largent, Walter A. Lear, Erich E. Lotto, Jr., George H. Lowe, F. Altina Pillers, Frederick H. Ruggles, and Elmer E. Schroeder (earlier at Houston).

The Houston Subdistrict was headed by Hal K. Hall, Engineer-in-Charge, until 1963 when he transferred to Kansas. Robert E. Smith transferred from Georgia as Hall's successor. Other key personnel included Emil G. Kaminski and Steven L. Johnson. Others who served for more than about 2 years included Karen L. Carroll, Robert H. Dolman, Donald E. Ferguson, Leonard L. Lamar, Vernon B. Sauer, Maybelle H. Schneider, and Freddie L. Stroman. Katherine J.H. Eiby was Subdistrict Secretary. In 1965, with the integration of the Districts, former GWB staff members Gabrysch and John B. Wesselman were assigned to the Subdistrict, Gabrych as Assistant Subdistrict Chief.

Gilbert H. Hughes was Engineer-in-Charge of the San Angelo Subdistrict until 1960 when he left the District. He was replaced by Grozier for the remainder of the period. Other personnel included Harold W. Albert, Joe M. Alexander, Frank A. Anderson, Harold D. Buckner, Wallace R. Carnes, Loma Hoffman, and William H. Martin.

At Wichita Falls, John G. Joerns was Engineer-in-Charge of the Subdistrict throughout the period, assisted by Marshall E. Jennings, Willie F. Hastings, Jean L. Hans, Emil G. Kaminski, Gordon H. Martin, Bertha D. Nesbitt, Willard B. Mills, and Virgil L. Spiers.

In 1963, Arthur E. Hulme was transferred from Austin to San Antonio as Engineer-in-Charge of the newly created SWB Subdistrict office. Others at San Antonio included Marshall B. Jennings, Billie J. Lawson, Ira G. Rathbun, William E. Reeves, Paul B. Rohne, Jr., Stanley R. Rosenquist, and Ronnie E. Steger. With the reorganization in 1965, the SWB Subdistrict became a Division Subdistrict and the former GWB members in San Antonio, Sergio Garza, Reeves, Paul Rettman, John A. Tomlinson, and Olga Hernandez, were assigned to the new Division Subdistrict.

In 1962 a SWB field headquarters was established at Laredo staffed by Alfredo Gonzalez.

### *Administrative Services Section*

The Administrative Services Section in Austin provided centralized budget, fiscal, and personnel-management services to the Branch District offices throughout the period. Tinnie C. Schmitt served as Chief of the Section until her retirement in 1965. She was assisted by Pearl E. Ebner, Donna M. LaPointe, Billie J. Lawson, and Shirley A. Davis. In 1965, after reorganization of the District, the Section was led by James R. McLaughlin, assisted by Raymond Max Slaughter.

### *Other Organizational Arrangements*

In addition to his duties as SWB District Engineer, and later as District Chief, Trigg Twichell represented the Director, Geological Survey, on DOI's Region 6 Field Committee and was the Federal representative in negotiations between Kansas, Oklahoma, and Arkansas to form an interstate compact for the allocation of Arkansas River water.

Seth D. Breeding served part-time as SWB flood specialist until he retired in 1959.

William E. Clark was Engineer-in-Charge of an office of the Staff Engineer GWB until 1959 to provide coordination of the Federal observation well program. He was assisted by Verda M. Dougherty, Johnny F. Svoboda, and Evangelina R. Carrillo.

In 1962, a field unit of the GWB Area Chief was established in Austin to conduct the Permian Basin project. David W. Greenman, project chief until 1963 when he resigned, was succeeded by Peter R. Stevens. Others on the project staff were William F. Hardt and George L. Knapp.

Frank W. Kennon was in charge of a field unit of the SWB Area Chief from 1962 to 1965.

## Funding and Cooperation

District activities were financed through cooperative agreements between the Geological Survey and the Texas Water Development Board (WDB), formerly the Texas Water Commission (TWC), or the Texas Board of Water Engineers), the Texas Highway Department, and many other agencies. During this period, there were nearly 70 local or regional agencies of government represented in the cooperative program, including more than 20 cities and more than 40 counties, river authorities, water districts, and interstate-stream compact commissions.

Among the other Federal agencies that helped fund the District program were the U.S. Army Corps of Engineers, Bureau of Reclamation, Soil Conservation Service, National Park Service, U.S. Air Force, U.S. Army, and Federal Water Pollution Control Administration (formerly Public Health Service). There were also some Federal funds allocated by the Survey.

Total funds available for the operation of the Texas District increased steadily from $915,400 in 1957 to $1,790,200 in 1966. Table 1 shows the breakdown of the three principal sources of funds—The Federal program (Fed), the Federal-State Cooperative program (Coop) and the other Federal agencies program (OFA). Tables 2, 3, and 4 show the breakdown of the sources of funds available for the individual disciplines.

### *Available Funds*

During 1957–66 the largest program element, by far, was the stream-gaging program. The ground-water programs remained nearly constant until 1966 when the program experienced a large increase in interpretive studies. The surface-water and quality-of-water programs increased steadily throughout this period of history.

Texas District funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| SURFACE WATER BRANCH | | | | | | | | | |
| Fed | 33.2 | 42.5 | 48.6 | 34.3 | 27 | 40.7 | 32.1 | 31.4 | 36.3 |
| Coop | 360.5 | 376.4 | 349 | 377.4 | 536.6 | 543.6 | 654 | 714 | 763.5 |
| OFA | 105.8 | 115.1 | 239.2 | 209.1 | 154.9 | 206.2 | 209.4 | 191.4 | 222.9 |
| Total | 449.5 | 534 | 636.8 | 620.8 | 718.5 | 790.5 | 895.5 | 936.8 | 1022.7 |
| GROUND WATER BRANCH | | | | | | | | | |
| Fed | 68 | 35.6 | 21 | 11.5 | 2.1 | - | - | 15 | 62.6 |
| Coop | 404 | 400 | 410 | 388.6 | 374 | 358.4 | 380.2 | 387.4 | 443.6 |
| OFA | 10.7 | - | 6.9 | 4.7 | .8 | 19.1 | 3 | 2 | 12.7 |
| Total | 421.5 | 435.6 | 437.9 | 404.8 | 376.9 | 377.5 | 383.2 | 404.4 | 518.9 |
| QUALITY OF WATER BRANCH | | | | | | | | | |
| Fed | 7.6 | 5.8 | 6.3 | 5.4 | 5.3 | 5.5 | 5.3 | 5.3 | 17.2 |
| Coop | 57 | 74.7 | 85.4 | 97.4 | 124.2 | 135 | 161.9 | 170.1 | 191.1 |
| OFA | 14 | 18.9 | 10 | 10.4 | 8.3 | 8 | 11.6 | 37.3 | 40.3 |
| Total | 78.6 | 99.4 | 101.6 | 113.3 | 137.8 | 148.4 | 178.8 | 212.7 | 248.6 |
| WATER RESOURCES DIVISION | | | | | | | | | |
| Fed | 47.6 | 83.9 | 75.9 | 51.2 | 34.4 | 46.2 | 37.4 | 51.7 | 116.1 |
| Coop | 821.5 | 851.1 | 844.4 | 863.4 | 1034.8 | 1037 | 1196.1 | 1271.5 | 1398.2 |
| OFA | 130.5 | 134 | 256.1 | 224.2 | 164 | 233.3 | 224 | 230.7 | 275.9 |
| Total | 999.6 | 1,069 | 1,176.3 | 1,138.9 | 1,233.2 | 1,316.4 | 1,457.5 | 1,553.9 | 1,790.2 |

## Basic-Data Programs

### *Streamflow*

The hyrdrologic network of stream-gaging stations provided multiple-use data for planning the development and management of Texas' water resources. In addition, streamflow data were collected at a number of gaging stations primarily for the operation of flood-control projects, hydroelectric-power projects, municipal and industrial supply facilities, and interstate compact administrations. The statewide stream-gaging program was under the general direction of Breeding and Goines with direct supervision by those in charge of the SWB Subdistricts.

From 1958 to 1966, the numbers of streamflow stations operated by the Survey in Texas increased from 258 to 400; reservoir stations from 38 to 63; and partial-record stations, from 74 to 212. During 1966, 4,760 discharge measurements were made at the 400 stream-gaging stations, 922 measurements were made at partial-record stations and 831 measurements of floodflow or baseflow were made at other sites.

### *Ground-Water Observation-Well Program*

Programs of water-level and quality-of-water observation were maintained in areas of extensive ground-water development including the Houston-Galveston, Orange County, San Antonio, and El Paso areas. In 1962, of 1,101 water-level observation wells, 1,052 were measured periodically and 49 continuously. The chemical-quality observation program included 343 periodically sampled wells. Two land-surface subsidence observation wells were maintained near Houston. About 3,500 additional water-level observation wells were maintained cooperatively by the WDB. Thirty of these wells were observed continuously. The statewide program was under the general supervision of Clarence R. Follett.

The WDB provided water-level records for about 700 wells and the District provided records for about 900 wells for Survey publication. Observations were made in about half of the 254 counties in Texas.

### *Surface-Water Quality*

In the quality-of-surface-water field-sampling program from 1958 to 1966, sites at which daily samples were collected increased from 32 to 65; special or periodic samples from 12 to 19 sites; miscellaneous samples from 30 to 306 sites (including samples taken during several low-flow studies); and temperature observations from 30 to 68 sites. Laboratory production increased from 1,800 adjusted complete analyses in 1957 to about 5,000 adjusted complete analyses in 1966.

Though this was a period of increased salaries at all levels, the cost per adjusted complete analysis reduced slightly every year during that period. Precision or accuracy was maintained with the objective of a cation-anion balance of 1 percent. Results were approved only after rechecks and review by a second analyst.

In 1964, the laboratory added an atomic absorption spectrophotometer, and the analysis for heavy metals became much easier. Techniques had not been completely developed for the determination of trace elements in water so it fell on the Texas laboratory to solve some of the problems and even develop new methods for the determination of arsenic and selenium.

In 1965, with the move into a new Federal Building, more adequate space made operations more efficient. Though the purchase of automatic analytical equipment was prohibited pending the decision to establish central laboratories, the District laboratory increased its efficiency by considering each determination as a series of unit operations and finding how seconds or minutes could be saved with better nonautomatic instruments and improved techniques.

All laboratory work and some water-quality field investigations were done for the Louisiana District until 1958 when Wanda Shelby (nee Jones) was temporarily assigned to Louisiana to help establish a laboratory. Later some sediment-laboratory work from Louisiana was resumed in Texas.

Significant events during the period included the extensive field work to cover key stations during the record floods of April-June 1957 (Yost, WSP 1652–B, 1963). The sediment sampling throughout the rise and fall of the flood of the Colorado River at San Saba showed that the peak sediment discharge preceded the peak of the flood.

In 1958, results of a study of oil-field brine pits and the salinity of Salt Creek near Graham were influential in a ruling by the Texas Railroad Commission that banned this means of brine disposal and subsequently reduced stream salinity.

In 1960, during studies of oil-brine pollution in the Neches River Basin, it was shown that the brine also reacted with the clays to produce an acid water.

### *Sediment*

The sediment program was operated from the District office in Austin under the supervision of Clarence T. Welborn. All field and laboratory work was performed by the personnel of the former QWB at the

District office until 1965 when the consolidated District was organized. Sediment samples were then collected by District and Subdistrict personnel. The laboratory work was continued at District headquarters.

At the beginning of the period, there were four daily and one partial-record sediment stations. At the beginning of FY 1966, three daily suspended-sediment stations were being operated on streams, and one at a reservoir where an inflow-outflow study was being conducted on a floodwater-retarding structure. The reservoir station and two of the stream stations were operated in connection with the District studies of small watersheds. Later in 1966, six more daily sediment stations were added, two of which were for expanded small-watershed studies and four were operated as a part of the International Hydrological Decade program.

A partial-record suspended-sediment network of 26 stations was also established in 1966. The partial-record program, operated with Federal funds, was designed to obtain reconnaissance-type data that could be used to delineate where sedimentation problems existed and where more detailed records should be collected.

During the period, the Texas District provided particle-size analyses and determinations of sediment concentrations to the Louisiana District.

### Special Studies

The accounts of special studies by the Texas District that follows is not intended to be exhaustive but is representative of the broad range of investigations undertaken by the District during this period. Many special studies were completed by 1966 and others continued beyond that year. Additional information on the reports that resulted from studies during this period may be contained in "Bibliography of USGS reports on the geology and water resources of Texas, 1887–1974" (Water-Resources Invest. Rept. 20–75, 1975).

Among the continuing projects was that of obtaining special flood measurements to supplement data collected at regular stream-gaging stations, especially when extreme runoff occurred in ungaged areas. This was supervised by Goines.

Low-flow investigations continued to be made on streams in order to (1) quantify the interchange between ground water and streamflow, (2) determine the changes in quality and flow resulting from inflow of streams draining different hydrologic, geologic, and environmental settings, and (3) identify natural and manmade sources of contamination of the surface waters. Among the reports containing the results of such studies was that written by Harvey L. Kunze and James T. Smith documenting their base-flow studies of the upper Guadelupe River Basin (WDB Rept. 29, 1966).

Studies of ground water in areas of large-scale ground-water development continued during this period of history, including the Houston, Galveston, San Antonio, El Paso, and Trans-Pecos areas, the Southern High Plains, and the High Plains north of the Canadian River. The results of these projects were published chiefly in reports of the Texas Water Development Board. For example, that for the Houston area, by Gabrysch, was published as WDB Rept. 63 (1967).

Appraisals continued to be made county-by-county to determine the occurrence, availability, dependability, quality, and quantity of the ground-water resources of each county, with particular reference to the sources of water suitable for public supply, industrial, and irrigation uses. The results of these studies were published in reports of the Texas Water Development Board (WDB), or in the USGS Water-Supply Papers or open files. During this period, studies were conducted in the counties listed below. Representative reports are identified by source and year of publication or release to the open files. The county, principal investigator and publication, if shown, were: Atascosa, W.H. Alexander (WDB Rept. 37, 1967); Austin, C.A. Wilson (WDB Rept. 68, 1967): Bandera, R.D. Reeves; Bastrop, C.R. Follett; Bee, B.N. Myers (WDB Rept. 17, 1966); Brewster, R.T. Littleton; Brooks, B.N. Myers (WDB Rept. 61, 1967); Caldwell, C.R. Follett (WDB Rept. 12, 1966); Calhoun, R. Marvin; Camp, M.E. Broom; Carson, G.D. McAdoo; Chambers, J.B. Wesselman; DeWitt, C.R. Follett; Dimmit, C.C. Mason; Ellis, G.L. Thompson (WDB Rept. 62, 1967); Franklin, M.E. Broom; Frio, W.H. Alexander (WDB Rept. 32, 1967); Gaines, E.R. Leggat (WDB Rept. 15, 1966); Gonzalez, G.H. Shafer (WDB Rept. 4, 1965); Grayson, E.T. Baker (WSP 1646, 1963); Gregg, M.E. Broom; Guadalupe, G.H. Shafer; Hale, J.G. Cronin (WSP 1539-U, 1963); Hardin, E.T. Baker; Harrison, M.E. Broom (WDB Rept. 27, 1966; Houston, G.R. Tarver (WDB Rept. 18, 1966); Jackson, E.T. Baker (WDB Rept. 1, 1965); Jasper, J.B. Wesselman (WDB Rept. 59, 1967); Jefferson, J.B. Wesselman; Jim Wells, C.C. Mason; Johnson, G.L. Thompson (open-file rept., 1968); Karnes, R.B. Anders (WSP 1539–G, 1962); Kendall, R.D. Reeves (WDB Rept. 60, 1967); Kerr, R.D. Reeves (open-file rept., 1968); Kimble, J.H. Patman; Kinney, R.R. Bennet and A.N. Sayre; Knox, E.R. Leggat; LaSalle, H.G. Harris; Lee, G.L. Thompson (WDB Rept. 20, 1966); Liberty, R.B. Anders (WDB Rept. 72, 1968); Live Oak, R.B. Anders; Maverick, E.T. Baker; McCullough, H.B. Harris;

Menard, R.C. Baker; Montgomery, B.P. Popkin; Morris, M.E. Broom; Newton, J.B. Wesselman (WDB Rept. 59, 1967); Nueces, G.H. Shafer (WDB Rept. 73, 1968); Orange, J.B. Wesselman; Pecos, C.A. Armstrong; Polk, G.R. Tarver (WDB Rept. 82, 1968); Reeves, W. Ogilbee; Refugio, C.C. Mason; Sabine, R.B. Anders (WDB Rept. 37, 1967); San Augustine, R.B. Anders; San Jacinto, W.M. Sandeen (WDB Rept. 80, 1968); San Patricio, G.H. Shafer (WDB Rept. 73, 1968); Titus, M.E. Broom; Tyler, G.R. Tarver (WDB Rept. 74, 1968); Upshur, M.E. Broom; Upton, D.E. White (WDB Rept. 78, 1968); Uvalde, R.D. Reeves (WSP 1584, 1964); Victoria, R. Marvin; Waller, C.A. Wilson (WDB Rept. 68, 1967); Webb, E.T. Baker; Wharton, E.T. Baker; Winkler, S. Garza (WSP 1582, 1962); and Wood, M.E. Broom (WDB Rept. 79, 1968).

Small-watershed investigations were conducted for the Soil Conservation Service on 11 flood-control and water-management projects in the Trinity, Brazos, Colorado, and Guadalupe River Basins and in an urban area on Waller Creek in Austin. One of the primary objectives of the investigations was to determine the effect of the structures on the sediment yield of the basin and to determine the sediment-trap efficiency of the structures. Numerous reports containing hydrologic data from and results of these studies were released to the open file or published by the Texas Water Development Board (WDB).

The Texas District contributed to the study of and reports on the Mississippi Embayment from its beginning in about 1958 until the project was completed 6 years later. The project chief for the Texas portion of the Embayment study, four counties in northeastern Texas, was Ernest T. Baker. (See Part IV, "Mississippi Embayment Project.")

Winslow supervised a series of reconnaissance ground-water investigations by major river basins following the implementation of the Texas Water Planning Act of 1957. This was a cooperative activity with the Texas Water Development Board in which the investigations were divided between the District and the Board, the results of which were published in numbered Bulletin reports of the Board. Study areas, project chiefs, and publications were: the Red, Sulphur, and Cypress River Basins, Baker (TWC Bull. 6306, 1963); the Brazos River Basin, Cronin (TWC Bull. 6310, 1963); the upper Rio Grande Basin, Davis (TWC Bull. 6502, 1965); the lower Rio Grande Basin, Baker (TWC Bull. 6502, 1965); and the Gulf Coast region, Wood (TWC Bull. 6305, 1965). Water Development Board employees made the studies for the Canadian, Sabine, Neches, Trinity, Colorado, and middle Rio Grande Basins.

Herberto B. Mendieta began a study in 1959 to determine the thermal structure and evaporation at Lake Colorado City under larger powerplant loads than were in existence during an earlier study. Another objective was to determine the effect of cool-water discharge from the newly constructed Champion Creek reservoir into the lower basin of Lake Colorado City.

Beginning in 1961 and continued through the end of this period were studies to determine the effects of urbanization on flood discharge and total runoff to delineate flood-hazard areas, and to provide water-quality data for runoff events which differ by season and magnitude. Studies conducted in Dallas, Dallas County, Houston, and Austin reflected differences in degree of urbanization, topography, geology, and to some extent, climate.

Also in 1961, Holland began re-determining drainage areas for all river basins in the State except the Red and Canadian River Basins, utilizing the latest topographic maps. The new drainage-area figures were published as Circulars 62–02, 62–03, 62–05, 63–01, 63–07, and 65–01 of the Texas Water Commission (now Texas Water Development Board).

Investigations of the chemical quality of the Brazos River Basin had been in progress since 1941 in cooperation with the Texas Water Development Board, the Brazos River Authority, the West Central Texas Municipal Water District, the Corps of Engineers, and others. In 1961, a comprehensive study began under the direction of Leon Hughes in cooperation with the Brazos River Authority to determine the nature and concentrations of mineral constituents in the surface waters of the basin; the geologic, hydrologic, and cultural factors that influence the chemical quality of the waters; and the suitability of the water for irrigation, domestic, and industrial use. Among the several reports published on the chemical quality of Brazos River water were those by Baker, Hughes, and Yost (open-file rept., 1962) and by Irelan and Mendieta (WSP 1779–K, 1964).

In 1961, a survey of the water-quality of lakes was started in the Brazos River Basin to delineate the stratification of salinity in these lakes and the movement of salinity by inflows, discharges, and seasonal changes. Stratification data for Possum Kingdom, Whitney, Hubbard Creek, Proctor, and Belton Reservoirs were obtained and reported by Donald K. Leifeste and Barney P. Popkin in 1968 (WDB Rept. 85). Under the direction of Jack Rawson, other water-quality parameters were added and the investigations extended to 41 Texas lakes by 1989.

In cooperation with the Texas Water Development Board, a reconnaissance of the chemical quality of water in Texas streams was started in 1961 under

Hughes' supervision. It was designed to expand the knowledge of stream quality throughout the State by periodic sampling at many sites. All available chemical-quality data were then summarized in a report for each major river basin. The Brazos River Basin, the first of these studies, was followed by the Sabine River Basin (Hughes and Leifeste, WSP 1809–H, 1965); the San Jacinto Basin (Hughes and Rawson, WDB Rept. 13, 1966); the Trinity Basin (Leifeste and Hughes, WDB Rept. 69, 1967); the Canadian Basin (Kunze and Lee, WDB Rept. 86, 1968); and the Sulphur River and Cypress Creek Basins (Leifeste, WDB Rept. 87, 1968).

A study, in cooperation with the Texas Water Commission, was made of the alluvial deposits of the Brazos River Valley between Whitney Dam and the Gulf of Mexico to determine the quantity and quality of the water available from the alluvium and to determine the relationship of the ground water to the stream water. The project, that began in 1962, was conducted by James G. Cronin and Clyde A. Wilson. Their report was published in 1967 (WDB Rept. 41).

In 1963, a study of the freshwater inflow into the Houston Ship Channel and Galveston Bay was begun by R. Smith and Kaminski for the Corps of Engineers. The results were published as an open-file report (1965).

Beginning in 1964, the Texas Highway Department funded studies of the magnitude and frequency of floods from drainage areas of less than 20 square miles. Schroeder, the project chief, prepared a report on the study (open-file rept., 1967).

A significant portion of the substantial Brazos River salt load originates within a four-county area of the upper Brazos River Basin. Hughes supervised a study that started in 1964 to determine the sources, quantity and movement of saltwater into the Brazos River within the area of origin. The results of the study were reported by Jack Rawson, Marvin W. Flugrath and Leon S. Hughes (open-file rept., 1968).

Goines reported on Brazos River Basin streamflow characteristics using computer-generated flow duration and flow frequencies prepared by the Survey at Headquarters (open-file rept., 1965).

A quantitative evaluation of the aquifers in the Houston District was made by Leonard A. Wood and Robert K. Gabrysch utilizing an electrical analog model of the ground-water system. The model was constructed by the Analog Model Unit in Phoenix, Ariz. The report on the study was published in 1965 (TWC Bull. 6508).

At BOR's request, Leggat explored the feasibility of artificially recharging the Hueco Bolson, the principal source of water for El Paso, and reported his findings in an administrative report. Leggat and Davis also used an electrical analog model constructed by the Analog Model Unit in Phoenix to evaluate the aquifer in the Hueco Bolson. The study was in cooperation with the city of El Paso and the Texas Water Commission. Results of the study were reported in 1966 (WDB Rept. 28).

In cooperation with the Texas Water Development Board, the effects of tides on the natural flow of the Brazos River upstream from its mouth near Freeport in March 1965 were investigated by Johnson, Rawson, and R. Smith (open-file rept., 1966).

An investigation was started in January 1966 to determine the quantity and source of loss of river flow in the Neuces River between 11 and 19 miles downstream from Lake Corpus Christi (Garza, WDB Rept. 75, 1968).

In early 1966, a water-quality survey of Big Mineral Arm of Lake Texoma and tributary streams was made in cooperation with the city of Sherman to determine the suitability of the water for a municipal supply. A report on the investigation, by Herberto B. Mendieta and Pat W. Skinner, was published in 1966 (WDB Rept. 35).

James G. Cronin integrated the results of many years of studies of the ground-water resources of the Ogallala Formation of the High Plains of Texas and New Mexico into one comprehensive report (HA–330, 1969).

Data were compiled and submitted to the Analog Model Unit in Phoenix, Ariz., for construction of an electrical analog model of the Texas-Louisiana Gulf Coast area. Basic models were then constructed for the Chicot and the Evangeline aquifers. Gabrysch was the project chief for the Texas portion.

The National Park Service (NPS) requested water-supply assistance at several national monuments and parks in the State. Since 1953, the Survey had made numerous hydrologic studies for the NPS in Big Bend National Park. Results of the investigations, by Roger C. Baker, Edward R. Leggat, and Jack Rawson, were released to the NPS as administrative or open-file reports and many, by Leggat during the 1960's, were unpublished. Investigations during this period of history ranged in scope from comprehensive inventories of wells and springs to attempts to locate local water supplies for ranger stations or tourist facilities in remote areas. Among the more ambitious studies were those undertaken to ensure long-term water supplies, such as the studies in the Panther Junction, Persimmon Gap, and Maverick areas.

In 1963, the NPS requested an evaluation of water supplies on Padre Island for the Padre Island National Seashore. Brian N. Myers made the study and reported his findings to the Park Service. In 1965, an investigation was made at NPS request of the ground-water resources of the Alibates Flint Quarries and the Texas Panhandle Pueblo Culture Monument near the Canadian River in Texas. Administrative reports were prepared for the Park Service by Myers.

### Special Activities

As SWB District Engineer and later as District Chief, Trigg Twichell represented the Survey on the DOI Southwest Field Committee, acted as liaison between the Geological Survey and other Department of the Interior bureaus on the Arkansas-White-Red Basins Interagency Committee (AWRBIAC), and served as DOI representative on the Hydrology and the Basic-Data Collection Committees of AWRBIAC during 1965. Twichell also served, after his Presidential appointment in 1955, as Chairman and Federal representative in compact negotiations between the States of Arkansas and Oklahoma and between Kansas and Oklahoma for the apportionment of Arkansas River water.

### Vignette

The start of the studies of water quality of lakes is remembered by the participants as transition of the "separate and disunited Branches" into a single but not-quite united Division. SWB cooperated in this study by lending QWB a motorboat but not their depth recorders—too expensive. So it was that a future Regional Hydrologist spent hours sounding with a lead weight finding the submerged river channels to locate key sampling points. This developed good character but also some terribly foul language.

## Utah

Based largely on material supplied *by* Ted Arnow with the assistance of Leon J. Jensen, Wallace N. Jibson, *and* Russell H. Langford

The Statewide WRD program in Utah was carried out by the independent Branches, GWB, QWB, and SWB, from 1957 until mid-1965, when it was changed to a Division activity. From 1957–65, however, the Branches coordinated their work through the Utah WRD Council made up of the heads of the three Branch offices in Salt Lake City. All Council meetings were attended by the Chief of the Administrative Services Section, most by the head of the project office in Logan, and some by chiefs of other field offices. W. Vaughn Iorns, who headed the special study of the Upper Colorado River Basin (see Part IV, "Upper Colorado River Project") also attended meetings of the Council when matters relative to his study were discussed. Each of the Branch offices and the Logan project office prepared individual programs and financial plans and dealt independently with cooperators.

From 1957 to 1959, the GHB also had an office in the old Post Office Building, Salt Lake City, staffed by Charles T. Snyder. Snyder, of the Denver-based Soil and Moisture Conservation program, did soil-moisture studies on land administered by the BLM.

### Organization and Personnel

#### *Administrative Services Section*

The Administrative Services Section was responsible to the WRD Council from 1957–65 and provided administrative services to all offices. It became part of the Division District in July 1965. The Section office was in Salt Lake City in the old Post Office Building (then the Federal Building) at 350 S. Main Street from 1957 to 1960, in the Empire Building at 231 E. 4th S. from 1961 to 1964, and in the new Federal Building at 125 S. State Street from 1964 to 1966. The Section chief was Reid S. Lawrence, and others in the Section during 1957–66 included Joseph L. Baiocchi, Ila B. Droz, Arline S. Greene, Viola A. Johnson, Clinton P. Ludvigson, and Georgia M. Swaldi.

#### *Ground Water Branch (1957–65)*

The District office was in Salt Lake City in the old Post Office Building from 1957 to 1960, in the Empire Building from 1961 to 1964, and in the Federal Building from 1964 to 1965.

Herbert A. Waite was the District Geologist from 1957 to 1960 when he transferred to Cairo, Egypt. Harry D. Goode was the Acting District Geologist until 1961 when Ted Arnow was reassigned from Puerto Rico. Other professional members of the staff in Salt Lake City during 1957–65 included Robert M. Cordova, Richard D. Feltis, Joseph S. Gates, James W. Hood, Olive A. Keller, Ira W. Marine, Marvin L. Millgate, Reed W. Mower, W. Baird Nelson, Donald Price, Gerald B. Robinson, Jr., Ralph E. Smith, and Seymour Subitzky. Nonprofessional staff members included D. Briane Adams, R. Glenn Butler, Karen Cook, Larry R. Herbert, Norman B. Holman, Barbara A. LaPray, Rose M. Powers, Doris A. Vandruff, and Larry L. Wollshleger. Nelson was killed in an automobile accident on June 15, 1959, while driving in central Utah on official duty. He was accompanied by a foreign participant from Turkey who suffered minor injuries in the accident.

Field headquarters and professional personnel during 1957–65 were: Cedar City (1957–65), George W. Sandberg; Delta (1962–63), Reed W. Mower; Fillmore (1960–61) Reed W. Mower; and Richfield (1956–65), Louis J. Bjorklund, Carl H. Carpenter, Raymond E. Jackson, Gerald B. Robinson, Jr., and Richard A. Young.

#### *Quality of Water Branch (1957–65)*

The District office was in Salt Lake City at Fort Douglas from 1957 to 1962, in the Empire Building from 1963 to 1964, and in the Federal Building from 1964 to 1965. The District laboratory, which also served a large area outside of Utah, was at Fort Douglas from 1957 to 1964 and in the Administration Building at 1745 W. 1700 S. during 1965.

John G. Connor was the District Chemist from 1957 to 1961 when he was replaced by Russell H. Langford, who transferred from Washington, D.C. Other professional members of the staff during 1957–65 included Roy E. Cabell, Arthur M. Diaz, Daniel C. Hahl, Alonzo H. Handy, III, Osamu Hattori, C. Albert Horr, Boyd F. Joyner, Cleo G. Mitchell, James C. Mundorff, Ralph F. Pascoe, Virgil H. Stone, and Kidd M. Waddell. Nonprofessional staff members included Lionel E. Anderson, Thomas E. Ault, John T. Finlayson, J. Paul Freeze, Patrick Hession, Charles E. Johnson, Glenn E. Johnson, Ilta M. Jonsson, Loretta B. Salazar (Conroy), and Ellen Schroeder.

QWB activities in the Upper Colorado River Basin in southwestern Wyoming and western Colorado and the Lower Colorado River Basin in northwestern Arizona, as well as certain activities in cooperation with the U.S. Air Force in Nevada, were carried out by the Salt Lake City District Office during 1957-65. In August 1961, concurrent with Langford's transfer to Salt Lake City, QWB activities in the remainder of Colorado (Missouri River, Arkansas River, and Rio Grande Basins) also were assigned to the Salt Lake City District. A field headquarters was established soon thereafter in Denver, Colo., to conduct the field work in eastern Colorado and to work closely with the Colorado GWB and SWB Districts in preparing interpretive reports on joint activities. In 1962, this field headquarters became a Subdistrict office of the Utah QWB District. Professional staff included C. Albert Horr, Robert Brennan, Richard K. Glanzman, Arthur W. Gosling, and John M. Klein.

#### *Surface Water Branch (1957–65)*

The District office was in Salt Lake City in the old Post Office Building from 1957–60, in the Empire Building from 1961–64, and in the Federal Building from 1964–65.

Milton T. Wilson was the District Engineer from 1957 to 1965. Professional members of his staff in Salt Lake City during 1957-65 included George L. Whitaker, Assistant District Engineer, Vernon K. Berwick, Elmer Butler, Harold W. Chase, Rulon C. Christensen, LaPhene Harris, Leon J. Jensen, E. Blaine Johnson, Leonard N. Jorgensen, John T. Limerinos, W. Don Peterson, J. Kenneth Reid, and Gerardus T. Riebeek. Other staff members included Marilynn Anderson, Lyle R. Booth, William C. Brand, Robert L. Carter, Michael J. Clinton, Rono D. Garff, V. Lambert Jensen, Lamonte S. Johnson, Viola A. Johnson, Reinhart T. Kowallis, Barbara A. LaPray, Sharol M. Lawrence, Jay V. Mower, Sharol A. Muller, Lane K. Nalder, Lloyd D. Nelson, Wilfred R. Oeltjen, Dwane M. Parker, George E. Pyper, Gerdena H. Richardson, Mary G. Rudy, Zona L. Simmons, Leah L. Stewart, and Dorothy H. Young.

Field headquarters and personnel during 1957–65 were: Green River (1957–65) staffed by technicians Glen J. Allen, Warren H. Dean, and Elmer C. Gerhart; and Hite (1957–58) staffed by technicians Elmer C. Gerhart and Lawrence E. Lopp.

A project office under the administrative supervision of the BAC was maintained at Logan for stream-gaging and related activities in the Bear River Basin in Idaho, Utah, and Wyoming in support of the Bear River Compact and the Bear River Commission. (See Part VIII, "Interstate Compacts"). Duties of the office staff included setting and monitoring stream-gaging standards for State and local hydrographers who were involved with the Compact, computing Compact allocations, and checking compliance with the Compact. Albert B. Harris was Engineer-in-Charge in 1957, succeeded by Wallace N. Jibson in 1958; both were assisted by Glenn C. Anderson. Other personnel included Evelyn S. Fullmer, Richard B. Garrett, and Budd S. Robison.

Field headquarters staffed by technicians were maintained in Mexican Hat (1957–62), Fred E. Singleton; Moab (1957–60), Jack W. Pehrson; Monticello (1965–66), Dennis E. Wilberg; Panguitch (1961–62), Jack W. Pehrson; and Richfield (1963–65), Jack W. Pehrson. The field headquarters in St. George (1957-65) was staffed by engineer Wilson McConkie. The Subdistrict office in Vernal (1957–65) was headed by Dayl J. Webb, Engineer-in-Charge, assisted by engineers Robert E. Norris and Gerardus T. Riebeek and technicians Pauline A. Adams, Donald M. Batty, George L. Deans, Ivan W. Freestone, and John M. Mollinet.

Until 1961, SWB operations in Nevada were under the supervision of the Salt Lake City District office and were conducted from the Carson City Subdistrict headquarters and from the Elko field headquarters. (See also in Part X, "Nevada.")

#### *Water Resources Division Council (1957–65)*

The Utah WRD Council functioned effectively, and its members worked well together to plan and conduct data-collection activities and investigative projects. Examples of this close relationship include: (1) preparing a summary report on the water resources of Utah (see Part IV, "Water Resources of States"), [also published as Utah Geological and Mineralogical Survey Bulletin 73 (1964)] and of a long-range plan for water-resources investigations in Utah (Arnow, Langford, and Wilson, Utah Dept. of Natural Resources Coop. Investigations Rept. No. 1, 1964); (2) developing a plan, including cooperative-program funding, with the Topographic Division represented by Joe Lang, District Engineer, that resulted in publishing a special detailed topographic and bathymetric map of Great Salt Lake (USGS Map, 1:125,000 scale, 1974); (3) carrying out a detailed investigation of the hydrology of Salt Lake County from 1963 to 1970 which resulted in 10 published reports (see following section on "Interpretive Studies"), that is believed to be the first comprehensive Divisionwide study of its kind planned, developed, and conducted by a WRD Council in the Nation.

#### *Water Resources Division (1965–66)*

All Branch activities were combined into a Division-level District in July 1965, with Milton T. Wilson designated as the District Chief. He retired in December 1965; in January 1966, Ted Arnow was named as District Chief; and in June 1966, Russell H. Langford transferred to the National Headquarters in Washington, D.C. The District office was in the Federal Building in Salt Lake City, and the District laboratory was in the Administration Building. Allen G. Hely, hydrologist, and Nick H. Panas, technician, joined the Salt Lake City staff after the 1965 reorganization.

Field headquarters after the reorganization were in Cedar City, Green River, Monticello, Richfield, and St. George. The project office remained in Logan, and the Subdistrict office remained in Vernal.

### Funding and Cooperation

Funds for the WRD programs in Utah during 1957–66 were obtained from the Federal-State cooperative program (Coop), the Federal program (Fed), and other Federal agencies (OFA). In addition, small amounts were paid by the Utah Power and Light Company, a licensee of the FPC, for streamflow data. The total funds available to the District increased steadily throughout the period, as shown in table 1. Table 2 shows the total funds for each year by Branch (1958–64) or discipline (1965–66) activities.

Utah District funds by source, fiscal years 1958, 1962–66
[In thousands of dollars]

| Fund source | 1958 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|
| Coop | 304.3 | 395.0 | 408.4 | 557.5 | 620.5 | 622.8 |
| Fed | 94.7 | 79.8 | 64.3 | 68.8 | 68.2 | 71.2 |
| OFA | 34.3 | 26.6 | 48.0 | 63.9 | 65.5 | 68.2 |
| FPC | .7 | .7 | 1.0 | 1.0 | 1.3 | 1.0 |
| Total | 434.0 | 502.1 | 521.7 | 691.2 | 755.5 | 763.2 |

Source: Actual expenditures from program documents; except that entries for 1958 are for only part of the fiscal year. Figures are not available for FY 1959-FY 1961

Utah District funds, fiscal years 1958, 1962–66 by Branch (FY 1958, FY 1962–64) or by discipline (FY 1965 and FY 1966)
[In thousands of dollars]

| Branch | 1958 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|
| GW | 122.0 | 171.6 | 146.2 | 233.2 | 258.4 | 197.7 |
| QW | 59.8 | 65.2 | 75.6 | 93.4 | 106.3 | 135.9 |
| SW | 252.2 | 265.3 | 299.9 | 364.6 | 390.8 | 429.6 |
| Total | 434.0 | 502.1 | 521.7 | 691.2 | 755.5 | 763.2 |

The Federal program provided support to all three Branches for the collection of basic hydrologic data, primarily water-quality (including fluvial sediment) and streamflow data in the Upper Colorado River Basin in support of river compacts. In addition, small amounts of Federal funds helped to continue a study of Great Salt Lake during FY 1963, supported a study of the saline ground-water resources of Utah during FY 1964, and supported the evaluation of water-quality networks. Federal funds also provided periodic support for the preparation of the Utah part of a flood-frequency report for Part 10, the Great Basin.

#### *Cooperating Agencies*

The Federal-State cooperative program constituted by far the greatest part of the total program, and the Utah State Engineer (Department of Natural Resources, Division of Water Rights) was the most important cooperator throughout the entire period. The work with the State Engineer during FY 1958 was 93 percent of the Federal-State cooperative program and 65 percent of the total program. These percentages gradually decreased as other cooperators entered the program; but in FY 1966 the work with the State Engineer still was 66 percent of the Federal-State program and 53 percent of the total program. The program with the State Engineer covered all phases of hydrologic work, including Statewide collection of basic hydrologic records and interpretive investigations.

Other cooperators in ground-water investigations were the Utah Water and Power Board (Department of Natural Resources, Division of Water Resources), which in FY 1964 began supporting a continuing study of ground-water conditions in Utah; and the Utah Geological and Mineralogical (later Mineral) Survey, which in FY 1966 provided support for a study of springs in Utah.

Cooperators in quality-of-water investigations included the Metropolitan Water District of Salt Lake City that supported the analysis of water samples; the State Fish and Game Department that in FY 1961–63 supported a study of the relation of water quality to fish culture; the University of Utah that in FY 1959–62 supported a study of the dissolved-mineral contribution to Great Salt Lake; and the Utah Geological and Mineralogical Survey that supported a study of the quality of water in western Utah in FY 1964–66, a reconnaissance of water quality in the Sevier River Basin in FY 1964, a continuing study of the chemical hydrology of Great Salt Lake starting in FY 1964, and a study of the springs of Utah starting in FY 1965.

Cooperators in surface-water investigations included Grand County, Cedar City, and St. George, all in FY 1958; the Utah Water and Power Board during FY 1958 and continuously after FY 1964; Salt Lake County continuously after FY 1962; the Bear River Commission continuously after FY 1963; and Utah State University during FY 1963. The State Road Commission supported a study of the magnitude and frequency of floods during the entire period.

#### *Other Federal Agencies*

Thirteen other Federal agencies funded short investigations or continuing phases of the program in Utah with the BOR providing most of the OFA funds for the collection of water-quality (chemical and sediment) and streamflow data. The AEC, the National Park Service, the Air Force, and the Army also funded the collection of chemical-quality data. Collecting and analyzing sediment data were also funded by the Soil Conservation Service.

Ground-water investigations at specific installations were funded by the National Park Service and the Federal Aviation Administration.

In addition to BOR funding, the U.S. Army Corps of Engineers, the Forest Service, the Soil Conservation Service, the Fish and Wildlife Service, the Public Health Service, the Bureau of Indian Affairs, and the Department of Health, Education, and Welfare also funded the collection of streamflow data.

### Summary of Program

The program essentially was that of collecting, processing, and publishing basic hydrologic records and conducting studies that resulted in interpretive reports. Most of these studies were investigations of specific areas or sites where new hydrologic data were collected, but others involved the analysis of hydrologic data previously collected.

Information for this section is from program documents, from "Water Resources Investigations in Utah, 1962 and 1968", and "Bibliography of U.S. Geological Survey water-resources reports for Utah" (1987).

#### *Hydrologic Records*

Ground-Water Records.—At observation wells, 1,162 water-level measurements were made in 1958 and 3,976 in 1966; 475 discharge measurements were made in 1958 and 1,529 in 1966; 140 chemical-quality samples were taken in 1958 and 345 in 1966; and 227 temperature observations were made in 1958 and 664 in 1966. At springs, 21 discharge measurements were made in 1958 and 245 in 1966; no chemical-quality samples were taken in 1958, and 85 samples were taken in 1966; and no temperature observations were made in 1958 and 195 were made in 1966. In the statewide observation-well network in 1962, 44 wells were measured continuously, 380 semiannually, and selected wells in project areas were measured periodically.

Surface-Water Records.—It was reported in 1962 that 195 gaging stations were operated by the District, of which 79 were classified as primary (long-term hydrologic), 35 were secondary (short-term hydrologic), and 81 were operated for mater-management purposes. There were also 125 crest-stage gages maintained to record peak stages of floods, statewide. Of considerable interest to government agencies, industry, and the public was the continuous record of the water level of Great Salt Lake that began more than 100 years ago.

Water-Quality Records.—It was reported in 1962 that temperature, chemical-quality samples, and suspended-sediment data were obtained at 14 stream and lake sites in Utah. In 1968, soon after this period of history ended, 29 stream and lake sites were in the program and the water-quality program included chemical-quality sampling at 18 sites, biological-quality at one site, pesticide content at two sites, suspended-sediment load at 19 sites, and temperature observations at all 29 sites. Also in 1968, there were 89 ground-water wells in the program where temperatures were periodically observed and samples were obtained for chemical analyses. The District also continued to periodically sample the Great Salt Lake for dissolved-solids content of the water.

The hydrologic records for Utah that were collected during the period of this history were included in 56 separate reports, largely Water-Supply Papers, the numbers and titles of which are contained in "Publications of the Geological Survey, 1879–1961" and in "Publications of the Geological Survey, 1962–1970."

#### *Interpretive Studies*

The interpretive studies that were conducted, all or in part, during 1957–66 are listed by topic or area of study and resulting publication number with authors and date. Separate data reports, open-file reports, and administrative reports that resulted from these studies are not listed nor are studies that resulted only in open-file or administrative reports. Many of the data reports were released separately in a series entitled USGS Utah Basic (or Hydrologic) Data Reports (or Releases). The data reports and the open-file reports are listed separately in the "Bibliography of U.S. Geological Survey water-resources reports for Utah".

Abbreviations used in the following section are "C" for USGS Circular; "CIR" for Utah Department of Natural Resources Cooperative-Investigations Report; "GG" for Utah Geological Society Guidebook to the Geology of Utah; "IB" for Utah Department of Natural Resources Information Bulletin; "PP" for USGS Professional Paper; "TP" for Utah Department of Natural Resources Technical Publication; "WC" for Utah Department of Natural Resources Water Circular; WRB for Utah Geological and Mineral Survey Water-Resources Bulletin; and WSP for USGS Water-Supply Paper.

Among the interpretive studies that were conducted all or in part during the 1957 to 1966 period of this history were those of the hydrogeology of Navajo Lake by M.T. Wilson and H.E. Thomas (PP 417–C, 1964); geology and hydrology of the Weber Delta district by J.H. Feth and R.J. Brown (PP 450–B, 1962) and by J.H. Feth and others (PP 518, 1966); geology and ground water in the Jordan Valley by I.W. Marine (PP 424–D, 1961), by I.W. Marine and Donald Price (WRB 7, 1964), and by Ted Arnow (WC 1, 1965); ground water in northern Utah Valley by R.M. Cordova and Seymour Subitzky (TP 11, 1965); ground water in the area east of Great Salt Lake by R.E. Smith and J.S. Gates (WRB 2, 1963); geology and ground water in the central Sevier River Valley by R.A. Young (IB 3, 1960) and by R.A. Young and C.H. Carpenter (IB 5, 1961, PP 424 B, 1961, and WSP 1787, 1965).

There were also studies of the magnitude and frequency of floods by V.K. Berwick (C 457, 1962), by J.L. Patterson and W.P. Somers (WSP 1683, 1966), and by Elmer Butler, J.K. Reid, and V.K. Berwick, (WSP 1684, 1966); ground-water resources of Bryce Canyon National Park area by I.W. Marine (WSP 1475–M, 1963); water production from oil wells of the Uinta Basin by R.D. Feltis and H.D. Goode (PP 424–C, 1961); and by H.D. Goode and R.D. Feltis (WRB 1, 1962); water supply at Capitol Reef National Monument by I.W. Marine, (WSP 1475–G, 1962).

The physical and chemical hydrology of Great Salt Lake was investigated by A.M. Diaz (PP 450–E, 1962), by D.C. Hahl, R.H. Langford, and C.G. Mitchell (WRB 3, 1964), by D.C. Hahl, M.T. Wilson, and R.H. Langford (PP 525–C, 1965), by A.H. Handy and D.C. Hahl (GG 20, 1966), by A.H. Handy (PP 575–B, 1967), by D.C. Hahl (WRB 10, 1968), and by D.C. Hahl and A. H. Handy (WRB 12, 1969).

Studies were made of the ground water or of the geology and ground water of: Pavant Valley by R.W. Mower (PP 424–C and IB 7, 1961 and WSP 1794, 1965); Tooele Valley and part of the Oquirrh Mountains by J.S. Gates (PP 450–D, 1962, WSP 1619–K, 1963, and TP 12, 1965) and by J.S. Gates and O.A. Keller (WC 2, 1970); the upper Sevier River Basin by R.D. Feltis and G.B. Robinson, Jr. (IB 12, 1963) and by C.H. Carpenter, G.B. Robinson, Jr., and L.J. Bjorklund (WSP 1836, 1967); the Sevier Desert by R.E. Mower, (IB 10, 1963) and by R.W. Mower and R.D. Feltis (WSP 1854, 1968); near Zion National Park by J.S. Gates (GG 19, 1965); in basins of southwestern Utah by G.W. Sandberg (TP 13 and WSP 1822, 1966); and in the Sevier River Basin between Yuba Dam and Leamington Canyon by L.J. Bjorklund and G.B. Robinson, Jr. (WSP 1848, 1968).

Additionally, studies were made of ground water in the San Pitch River Basin by G.B. Robinson, Jr., (WSP 1896) (1971); in northern Juab Valley by L.J. Bjorklund (TP 17, 1968); and in southern Utah and Goshen Valley by R.M. Cordova and R.W. Mower (IB 18, 1967) and by R.M. Cordova (TP 28, 1970); from the bedrock underlying the Colorado Plateau by R.D.

Feltis (TP 15, 1966, and PP 650–B, 1968); and in Cedar Valley by R.D. Feltis (TP 16, 1967).

A hydrogeologic reconnaissance near Price was made by R.M. Cordova (WRB 4, 1964); the discharge of Clear Lake Springs was reported by R.W. Mower (WSP 1839–E, 1967); and a reconnaissance of the chemical quality of water in western Utah was made by K.M. Waddell (WRB 9, 1967) and in the Sevier Lake Basin by D.C. Hahl and J.C. Mundorff (TP 19, 1968).

Ground-water conditions in Utah were reported from 1964 onward by Ted Arnow and others (CIR 2, 1964 and CIR 3, 1965), by J.W. Hood and others (CIR 4, 1966), and by A.H. Handy, R.W. Mower, and G.W. Sandberg (PP 650–D, 1969).

The water resources of Salt Lake County were reported on by Ted Arnow and R.E. Mattick (PP 600–B, 1968), by R.E. Mattick (PP 600–D, 1968), by R.W. Mower (PP 600-D, 1968 and PP 650-C, 1969); by A.A.R. Zohdy and D.B. Jackson (PP 650-C, 1969); by R.W. Mower, (PP 700–B, 1970); by R.E. Mattick, (PP 700–C, 1970); by Ted Arnow, Richard Van Horn, and Reed LaPray (PP 700–D, 1970); and by A.G. Hely, R.W. Mower, and C.A. Harr (TP 31 and 34, 1971).

Extensions of streamflow records was reported by J.K. Reid, L.E. Carroon, and G.E. Pyper (TP 20, 1969), and reports on springs of Utah were prepared by J.C. Mundorff (WRB 13, 1970 and WRB 16, 1971).

Results of hydrologic reconnaissances were reported of the Snake Valley area by J.W. Hood and F.E. Rush (TP 14, 1966); of Skull Valley by J.W. Hood and K.M. Waddell (TP 18, 1968); and of Rush Valley by J.W. Hood, Donald Price, and K.M. Waddell (TP 23, 1969).

In summary, interpretive studies in the Utah District from May 1957 to May 1966 resulted in the preparation of 77 reports, of which 39 were published in the Federal series, 36 in the series of cooperating agencies, and 2 in other publications. An additional 31 reports (mostly containing basic hydrologic data) were released to the open file. A few additional reports were released to specific Federal cooperating agencies. The Utah District program produced hydrologic information that was included in 164 separate published reports.

### Vignette

A Near-Death Experience on the Green River
as told to Leon J. Jensen *by* George L. Deans

On an extremely cold day in the early 1960's, Ivan Freestone and I of the Vernal office arrived at the Green River gaging station near Manila, Utah, to make a discharge measurement. As the river was covered with ice, depth soundings and velocity observations would have to be made through holes chopped through the ice, but first, we would have to determine the thickness of the ice. Being cautious, we decided that I, at about 140 pounds in contrast to Ivan's 200 pounds, should be the first to go out onto the ice to test its strength. When I was about a third of the distance across the river, I checked the ice thickness and found it was quite thin, but sufficiently strong to hold me—alone. I told Ivan to stay where he was, the ice would not hold him. But Ivan misunderstood and thought that I had given him the go-ahead to proceed.

Ivan began to cross the ice and as he came close, the ice broke. I went completely under but Ivan hung on to the edge of the ice. While Ivan was trying propel himself onto stronger ice, I surfaced, grabbed one of his long legs and pulled myself up his body, hand over hand, until I was able to reach firmer ice. Ivan was then able to pull himself onto solid ice.

We returned to the car and changed into dry clothing, always carried for such an emergency. Ivan then said that we should now make the discharge measurement. My response was that I had just gone through a near-death experience and was not about to repeat the performance. I had other plans for the rest of my life and was not going to take another chance on losing it in an icy, watery grave. We left the river without the measurement.

En route back to Vernal, we stopped at Green Lakes where I called the District Engineer in Salt Lake City and told him that I was resigning from the Survey; the work was just too dangerous.

## Vermont

*By* O. Milton Hackett, reviewed *by* Arthur L. Hodges, Jr.

As in earlier years, WRD activities in Vermont from 1957–65 continued under the jurisdiction of the Branches. There was no resident office. Work was carried out by and directed from the Boston District (surface water), the New York District (ground water) at Albany, and the New York-New England District (quality of water) also at Albany. Total funding for the program in FY 1958 was $43,000, nearly all for the collection and processing of streamflow records, and with only token amounts for a small observation-well program and the collection of samples for water-quality analyses. Sources of funds were the Federal-State program—both sides—53 percent of total (cooperating State agency, the Vermont Water Conservation Board), the other Federal agencies program 26 percent (from the U.S. Army Corps of Engineers), the Federal program, 12 percent, and the FPC, 9 percent. Throughout the 1957–66 period the basic program remained at about the same level, with support from the Vermont Department of Highways for a study of the peak-flow characteristics of streams, beginning in FY 1963, bumping up the total funding for that and succeeding years to about $70,000 annually.

In 1965, the Division-level Central New England District was established at Boston under Charles E. Knox, District Chief, and all WRD activities in Vermont were placed under his direction. As most past activity had involved streamflow measurement under his direction, little was changed. Coincidentally, at about this time, support from the Water Resources Board (WRB) enabled the District to begin a reconnaissance of the ground-water resources of Vermont. Arthur L. Hodges, Jr., was assigned to conduct this study from a new field headquarters located in the offices of the Vermont Department of Water Resources (DWR) at Montpelier.

In succeeding years, the results of Hodges' work were released by the DWR in a series of ground-water "favorability" maps covering the several river basins of the State. The first of these, released in 1966, was "Ground-water favorability map of the Batten Kill, Wallomsac River and Hoosic River basins." By the end of 1968, such maps had been released for 11 of the Vermont river basins.

Support for the ground-water study raised total funding for the Vermont program to $103,200 for FY 1966. The Federal-State program accounted for 80 percent, the OFA program for 11 percent, the Federal program for 6.5 percent, and the FPC (drawing from the Green Mountain Power and New England Power Companies) 2.5 percent. The WRB was the principal cooperating State agency, with the Department of Highways a substantial contributor also.

According to the District Annual Program, as of August 15, 1966, continuous streamflow records were collected at 48 stations and periodic records of peak discharge at 40. Contents of five reservoirs were monitored. Precipitation was measured periodically at 11 sites and water content of snow at 19. Ground-water levels were measured periodically and samples for water quality collected at 20 sites. Underway were the study of the peak-flow characteristics of streams and the statewide reconnaissance of ground-water resources.

The close of the report period found the Vermont program continuing much as before, but showing some promise for an enlarged scope in the coming years.

## Virginia

*By* J. Wyatt Gambrell, reviewed *by* Granville A. Billingsley, Joseph S. Cragwall, Jr., *and* Allen Sinnott

The period began on a traumatic note. The statewide cooperative program with the Virginia Department of Conservation and Development (formerly the Virginia Conservation Commission and later the Department of Conservation and Economic Development) which had begun in 1925 as a modest stream-gaging station network and had grown to include ground-water and water-quality programs, came to an end on June 30, 1957. This resulted from a provision in the Department's biennial appropriation prohibiting the payment of funds to any Federal agency for water-resources investigations.

The restriction was the result of a feeling within the State government that the program should be operated by the State. The point was made that in cooperative programs with most other Federal agencies, Federal support was in the form of grants to State agencies and that the work was accomplished under State direction by State employees.

### Readjustment

Since the operations of the GWB and the QWB were financed almost entirely by the cooperative program, it was necessary to close those District offices. Allen Sinnott, GWB District Geologist, had transferred to New Jersey in February 1957. Frances H. Dowell, secretary, remained on the rolls until June 30. Merle E. Schroeder, QWB District Chemist, had been transferred to Fayetteville, Ark., in December 1956. Stanley F. Kapustka succeeded him and had the responsibility of closing the laboratory before transferring to Baton Rouge, La. Responsibility for the few continuing elements of the water-quality program (three sediment-discharge stations supported by Federal program funds and water-quality analyses for the Department of Defense) were assumed by the Raleigh, N.C., QWB District.

The situation was different with respect to the SWB in that a substantial part of the program was funded by other Federal agencies (principally the U.S. Army Corps of Engineers and the TVA), small cooperative programs with local governments, permittees and licensees of the FPC, and Federal program funds. In consequence, it was decided to try to continue to operate the SWB District office at a reduced level. Donald S. Wallace, SWB District Engineer, with the full support of the Washington, D.C., office, was successful in obtaining additional funding from the Corps and the

TVA and in increasing the cooperative programs with the local governments. Funding of approximately $105,000 was available in the fiscal year beginning July 1, 1957.

Wallace continued as District Engineer until his appointment as SWB Area Chief, ACA. He transferred to Arlington in April 1958. Carlton W. Lingham, who had been in the Virginia District for several years, acted in the interim until J. Wyatt Gambrell, who transferred from Chattanooga, Tenn., assumed the lead position in August 1958. Lingham was then designated Assistant District Engineer. The office remained in the Natural Resources Building on the grounds of the University of Virginia throughout the period.

Other personnel assigned to Charlottesville during the period included David D. Dickstein (who transferred to Pennsylvania in 1963), Edward H. Nuckles, Raymond O. Abrams (who moved to Washington Headquarters in 1958), Eugene H. Ogilvie (until his death in 1964), Melvin S. Berry (until 1966), Phil M. Shackelford (1958 on), Warner C. Wood, who was District Clerk, Ilar E. Bowman (until 1962), Clairiece G. Humphrey (1963 on), Earley M. Miller (1964 on), Donald H. Rapp (1965 on), Roger N. Pollard (1965 on), and A. Wayne Clingenpeal (1965 on).

The Marion Subdistrict office, located in the Municipal Building or in an annex to it on Main Street, continued to operate the streamflow network in southwest Virginia (New River, Tennessee River, and upper James River Basins) throughout the period. Wilson G. Bonham was Engineer-in-Charge until his transfer to Delaware in October 1957. He was succeeded by Samuel Grady Anderson, who continued in that capacity for the remainder of the period. Walter E. Hendrick, Jr., Howard D. Williams, and Jean M. Stone were assigned there during this period.

### Water Resources Division Council

The Virginia WRD Council, made up of the heads of the local District offices, had an Administrative Services Section as an operational arm to carry out the accounting and other "housekeeping" functions of the three local District offices. In anticipation of the drastic curtailment in programs, the Section was disbanded at the beginning of the period. Vernon E. Ragland, who was its head, transferred to the Topographic Division in Washington, D.C. Warner C. Wood transferred to the SWB as District Clerk.

The Council continued to function throughout the period. Wallace and then Gambrell were the SWB members. Sinnott continued as the GWB representative and Granville A. Billingsley, the QWB District Chemist at Raleigh, N.C., represented that Branch. Meetings were held as needed to prepare work plans and other programming documents.

### Gaging Station Program

In the final year of the statewide cooperative program, 178 daily streamflow stations (including 12 springs) were in the network. The Survey continued to operate 95 of these and the Virginia Division of Water Resources, using State employees who had previously worked in the cooperative program under the supervision of the District Engineer, assumed responsibility for the operation of 56 stations. The others, including all of the spring stations, were discontinued. (Note: Following his retirement as SWB Area Chief, ACA, Wallace returned to Charlottesville in 1960 to head the State office.)

The most significant change in the network during the period was the addition of several water-management stations. Seven of these were in the Big Sandy River Basin where they were needed by the Huntington, W. Va., District of the Corps of Engineers in connection with the operation of its water-control projects in that basin. All were reinforced concrete gage houses and wells, six were equipped with measuring cableways, and one had an artificial control for the accurate measurement of low flows. The cost (except for two which were included in Corps' construction contracts) is reflected in the increase in OFA funds beginning in FY 1964. To meet the stream-gaging requirements of FPC projects, one station was established on North Anna River and one established and one relocated in the Roanoke River Basin. Increases in funding beginning in FY 1964 reflect these changes.

A few stations were discontinued as needs of the cooperators changed and at the end of the period (FY 1966) 96 stations were in operation. Of these, 43 were classified as primary, 15 as secondary, and 38 as water management.

### Flood-Plain Mapping Project

For several years a small cooperative program with the city of Alexandria had provided support for the operation of streamflow stations on Cameron Run and Four-Mile Run. In 1959, the city, faced with the problem of regulating development in the Cameron Run Basin, asked for assistance in defining the flood plain. Since part of the basin is in Fairfax County, the county government joined in the request. In response, a project was designed to compute flood profiles for floods having recurrence intervals of 25, 50, and 100 years, and to delineate, on large-scale (1 inch = 100 feet) topographic maps, the areas inundated. Since urbanization increases the magnitude of flood peaks, the effects of ultimate development were considered. This was a pilot project offering an opportunity to study the effects of urbanization on runoff and to develop and test methods of computing peak discharge and flood profiles. This fact justified the Division's participation and the expenditure of Federal funds.

Both the city and county participated in financing the work in the Cameron Run Basin. Fairfax County, recognizing the value of the maps as planning and regulating tools, quickly asked that similar work be undertaken on all of the other streams in the county. At that time much of the county was still rural with negligible encroachment onto the flood plains, so there was an opportunity to study the effects of increasing urbanization.

To accomplish the work, a Subdistrict office was established in northern Virginia. Daniel G. Anderson was Engineer-in-Charge, transferring from the Research Section, SWB, in September 1959. He was assisted by Louis G. Conn (until 1965), who had moved from the Tennessee District in August. The transfer of James F. Bailey from North Carolina in April 1960 completed the initial staffing. The office temporarily occupied space in the ACA headquarters in Arlington before moving to an office building in Fairfax early in 1960.

Others who worked on the project during the period were Frederick G. Gugel (1962 on), John W. Lanier (1965 on), and Frederick Paul Kapinos (1966 on).

The large-scale topographic maps, used as the base for delineating the flood-prone areas, were prepared by the Topographic Division. This was the first time that the Topographic Division had mapped at this scale, and numerous unforeseen problems (including cost overruns) had to be overcome.

The methodology developed and used in determining the effect of urbanization and computing peak flows and flood profiles is described in WSP 2001–C (1970), "Effects of urbanizing on floods in northern Virginia," by D.G. Anderson. The final maps were furnished to the cooperators and released to the public as open-file reports.

### Highway Programs

A small cooperative program with the Virginia Department of Highways had begun in 1952. The restriction on "repay" cooperation that terminated the statewide cooperative program of water-resources investigations in 1957 applied only to the appropriation for the Department of Conservation and Development, so the program with the Department of Highways was not affected. This was a typical "highway program" providing for the operation of a network of crest-stage gages and the preparation of reports on the frequency and hydraulic characteristics of floods at specific bridge sites.

In 1964 the program was expanded greatly with federally allotted research funds (100 percent repay by the cooperator). A network of gages equipped with flood-hydrograph and rainfall recorders was established on small streams (under 50 square miles). Installations were ultimately made at approximately 85 sites. The data were used to develop flood-frequency relationships for small streams.

Earley M. Miller, who had transferred to Many, La., in 1957 when the District program had been severely curtailed, moved back to the District to head the highway program in August 1964. Donald H. Rapp, who joined the staff in 1965, assisted him.

### Resumption of Cooperation

In 1957, the decision to maintain a District office in Virginia was made with the hope that some day the political climate would change and a comprehensive statewide cooperative program of water-resources investigations could be resumed. In 1965, this hope began to materialize.

Dorothy S. McDiarmid, a member of the Virginia House of Delegates from Fairfax County, became interested in water-resources investigations and in the fact that the State was not availing itself of the Division's expertise or of the Federal funds that would be available as part of a cooperative program. McDiarmid wrote the Governor, the Director of the Department of Conservation and Economic Development, and others with influence in the State government expressing these thoughts. Her efforts did not appear to be producing results because the restriction on "repay" cooperation, which had appeared in every appropriation act since 1958, was in the Governor's budget bill for the biennium beginning July 1, 1966. However, it was deleted in Committee from the appropriation act. The writer was never able to find out what behind-the-scenes maneuvers resulted in the deletion.

The State felt that high priority should be given to water-quality investigations and that the laboratory at Charlottesville should be reactivated. Accordingly, a study of the water-quality and streamflow characteristics of the James River Basin was undertaken as one of the segments of the new cooperative effort. Jolly D. Thomas would transfer from Maryland and would be assisted by a chemist employed by the State.

At the time the program was terminated in 1957, data collection had been completed on several ground-water projects, but the reports had not been written. These reports, which formed the second segment of the new program, were on the ground-water resources of Accomack and Northampton Counties, by Allen Sinnott and Chase G. Tibbitts, Jr. (Virginia Div. Mineral Resources, Mineral Resources Rept. 9, 1968); geology and ground-water resources of the Middle Peninsula, by D.J. Cederstrom (open-file rept., 1969); ground-water resources of the Northern Neck Peninsula, by Allen Sinnott (open-file rept., 1969); and results of aquifer tests in sands of the Potomac Group in the Franklin area, southeastern Virginia (1949–1950), by Allen Sinnott (open-file rept., 1968).

As a third segment, a study to determine the deficiencies in ground-water data and to design a remedial program was undertaken.

While the removal of the restriction on cooperation removed the legal barrier, no additional funds were specifically appropriated. Therefore, it was necessary for the State to divert money from the general appropriation for water-resources investigations and only a small amount, $30,000, could be made available. The Survey agreed to match a small part, $10,000, of the State's direct expenditures for data collection, so a total of $80,000 became available.

### Cooperation and Funding

Cooperative programs with the Virginia Department of Conservation and Economic Development, Virginia Department of Highways, the city of Alexandria, and the county of Fairfax have been discussed earlier. Additional funding was provided during the period through agreements with the county of Chesterfield and thecities of Charlottesville, Newport News, Norfolk, Roanoke, and Staunton.

As mentioned above, the Corps of Engineers and the Tennessee Valley Authority were major sources of funds. From 1964 through the end of the period, funds from the Corps were increased significantly to cover the cost of constructing gaging station facilities in the Big Sandy River Basin. Other Federal agencies which provided financial support during all or part of the period were the Defense General Supply Center (Richmond Q.M. Depot), Department of Agriculture, Public Health Service, and (for water analyses) the Departments of the Air Force and Army.

The city of Radford, an FPC licensee, required streamflow data throughout the period and provided funding. Other licensees (or permittees) of the FPC were Virginia Electric and Power Company and the Appalachian Power Company.

Funds available are shown in the following table:

Virginia District funds, fiscal years 1958, 1960–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 19.0 | - | 102.4 | 104.1 | 111.4 | 107.3 | 124.3 | 164.0 | 164.3 |
| OFA | 38.8 | - | 48.1 | 52.6 | 77.2 | 59.9 | 112.1 | 87.7 | 110.9 |
| Fed | 60.5 | - | 40.1 | 50.6 | 43.6 | 47.3 | 43.9 | 35.0 | 43.7 |
| FPC | 5.4 | - | 5.6 | 5.6 | 5.6 | 20.1 | 18.2 | 6.9 | 7.9 |
| Total | 123.7 | - | 196.2 | 212.9 | 237.8 | 234.6 | 298.5 | 293.6 | 326.8 |

Note: Amounts shown are from the Consolidated Work Plans and are actual expenditures except those for 1958 and 1966, which are estimates of funds available at the beginning of the fiscal year. Data for 1959 are no longer available.

### Reorganization and Move to Richmond

Because the SWB was the only Branch with an operational program in the State, the question of reorganization along Division lines had been academic. Now, however, with the resumption of cooperation with the Department of Conservation and Economic Development and with the expectation that a comprehensive program of investigations would ensue, it seemed appropriate to reorganize. Wyatt Gambrell was designated District Chief, WRD, effective July 17, 1966. In November 1966, the new District office was moved to Richmond, leaving a Subdistrict office in Charlottesville with Lingham in charge.

### Summary

The period was one of transition for the Virginia District. It began as a "bare-bones" holding operation and ended on an optimistic note with hope for the future. The intervening years were hard, particularly from the standpoint of financing. Without the help in absorbing overhead costs provided by such projects as the northern Virginia flood-plain mapping project, the expanded highway program, and the Corps construction program, we might not have made it!

## Washington

Condensed from material supplied *by* Frank T. Hidaka assisted *by* Leslie B. Laird, Donald Richardson, Eleanor M. Smith, Fred M. Veatch, Kenneth L. Walters, *and* typists from the Tacoma District

WRD programs in Washington were administered and operated by the Branches, two of which were headquartered in Tacoma, and one in Portland, Oreg., until August 1964, when the District began operating on a Division basis.

## Organization and Personnel

### *Surface Water Branch (1957–64)*

The SWB programs in the State were administered and supervised from the District office located in Tacoma. The Tacoma office was responsible for surface-water operations west of the Cascade Mountains and for gaging-station site selection and construction in the entire State. East of the Cascades, the Spokane Subdistrict office was responsible for gaging-station operation, maintenance, and initial computation of streamflow records.

The District office was located at 207 Federal Building in Tacoma until 1964, when the office was moved to 1305 Tacoma Avenue South. The move to the new office coincided with the conversion of the District to Division-level operations.

Fred M. Veatch served as District Engineer, a position he held from 1940 until his retirement in 1964. His principal assistant was J. Robert Throckmorton. William C. Griffin served as Office Engineer until 1958, when he transferred to Branch Headquarters in Washington, D.C. He was succeeded by William H. Krabler. Other key staff members were G. Lawrence Bodhaine, District and Pacific Northwest flood specialist until 1963 when he transferred to Denver; Donald M. Thomas, supervisor of snow surveys, among other duties, until he transferred to Trenton, N.J., in 1960; Arthur A. Seldal, Thomas' successor; Perry G. Sherman, supervisor of gaging-station construction and major maintenance and generally responsible for the operation of the warehouse, or the "Base," where supplies and equipment were stored and gaging-stations structures were prefabricated; Leslie V. Jacobs, operated the Base until he died in 1960; and James A. Malesky, Jacobs' successor.

Eleanor M. Smith served as Administrative Assistant during the entire period and was assisted principally by F. Leota Baker and Edith H. Land. With the formation of the Washington WRD Council in 1958, Smith became responsible for administrative services to the Branch Districts and to the office of the General Hydrology Branch in Tacoma.

Other professional members of the Tacoma staff included Byron N. Aldridge, John H. Bartells, James C. Blodgett, Henry C. Broom, John E. Cummans, Frank T. Hidaka, Stuart H. Hoffard, Robert J. Longfield, Donald O. Moore, Elmer G. Pearson, Donald Richardson, John Savini, Milton C. Swecker, and John R. Williams.

Among the technicians, engineering aids, construction personnel, and clerical personnel who contributed significantly to District operations during this period were Catherine M. Ackerman, Bonnye H. Ballard, Charles J. Bartholet, Helen Baydo, Teresa A. Borra, W. Miles Darden, Walker V. Frederick, Gustav A. Haven, Oliver C. Hettick, Thomas G. Higgins, George W. Hill, Marian A. Hollander, Earle A. Johnston, Warren M. McCall, Alfred W. McCann, Tamara McKenney, Gail M. McQuillan, Agnes P. Ranlett, Daniel J. Roberts, Joyce H. Ross, Sverre S. Rostgaard, David A. Seabrook, Arthur A. Seldal, Ralph H. Shoemaker, Tekla Stevens, Douglas E. Thompson, and Deanna L. Walth.

Earl G. Bailey, responsible for compiling and preparing for publication the streamflow records through 1960, had offices in the Perkins Building in Tacoma. He and his project were under the administrative supervision of the BAC, PCA. Henry C. Broom and Patricia L. Anderson served as his assistants. In 1961, upon completion of the compilation, Bailey and Anderson were reassigned to the District office in Tacoma. Broom, who had transferred to Boise, Idaho, in 1958, returned to Tacoma in 1961.

The Spokane Subdistrict, headquartered at N. 1106 Washington Street, was headed by Mearle M. Miller, Engineer-in-Charge, until 1960 when he transferred to the California District. He was succeeded by Walter C. Scott, formerly of the Delaware River Master's office in Pennsylvania. Personnel assigned to the office for all or part of the period included David H. Appel, Eva L. Bews, Charles W. Boning, John C. Brannan, Kenneth J. Craig, Henry I. Colson, Joseph E. Drobny, Charles R. French, Ronald L. Hanson, Jerry B. Hicks, Larry L. Hubbard, John J. Janssen, David L. LaFrance, Maurice B. Miles, Edmund G. Nassar, Mary J. Pounder, Clifford F. Schneider, Earl L. Smith, David W. Weiss, and Frieda Young.

### *Ground Water Branch (1957–64)*

The GWB District headquarters was at 2128 South 38th Street and later at 3020 South 39th Street in Tacoma with Arthur A. Garrett serving as District Geologist until 1964. Bruce L. Foxworthy was his principal assistant until 1959 when he became District Geologist in Portland, Oreg. Kenneth L. Walters, who transferred from Kansas in 1957, served as the principal assistant for the remainder of the period. The professional staff included Henry W. Anderson, Jr., James W. Bingham, Denzel R. Cline, Maurice W. Grolier, Donald H. Hart, Marion H. Helmer, Lowell D. Jones, Grant E. Kimmel, James E. Luzier, Charles E. Price, and James M. Weigle. Other personnel who made important contributions during the period were Glen D. Holmberg and Edwin C. Kennison. Margaret A. Hellyer served as clerk-typist during the entire period.

In 1961, a field unit with Matthew I. Rorabaugh in charge was established in the Perkins Building in Tacoma. The unit, which reported to the BAC, PCA, was funded by the Bonneville Power Administration to investigate the relationship of ground water to streamflow of the Columbia River.

#### *Quality of Water Branch (1957–64)*

The QWB operations in Washington were under the administrative and technical supervision of the District office located in Portland, Oreg. (See also in Part X, "Oregon.")

#### *General Hydrology Branch (1957–66)*

The GHB maintained an office in the Perkins Building in Tacoma until 1964, when it was moved to 1305 Tacoma Avenue South. The office was headquarters for glacier research, Mark F. Meier in charge (see Part IV, "Snow and ice studies"), and for various interagency studies in connection with the management and development of the Columbia River, Wilbur D. Simons in charge. Although never a part of District operations, the GHB office shared with the District certain functions, such as administrative services, and there was a limited exchange of personnel. John Savini assisted both Meier and Simons until 1960, when he was reassigned to the SWB District in Tacoma. In 1964, the GHB office became a field unit of the Office of the Area Hydrologist, PCA.

#### *Water Resources Division (1964–1966)*

Washington became a Division-level District in August 1964. Leslie B. Laird, who was District Chemist, Portland, Oreg., was appointed as the first District Chief. J. Robert Throckmorton was the Assistant District Chief for operations until he retired in 1966. Earl G. Bailey was then appointed as Throckmorton's successor. Arthur A. Garrett served as Assistant District Chief for projects and Walter R. Scott transferred from Spokane in 1965 to take over the position of Assistant District Chief for plans and programs. John F. Santos, Albert D. Van Denburg, Patrick A. Glancy, Jerry D. Stoner, Norman F. Liebbrand, and Michael F. ReMillard were transferred from Portland, Oreg., previous headquarters for QWB work in Washington, to Tacoma. Supervision of the functions and personnel of the Pasco field office was reassigned from Portland to Tacoma at this time.

After the establishment of the Washington WRD District, Joseph P. Beverage, John J. Burt, Willard W. Clique, William A. Dawson, Marvin O. Fretwell, Lynn E. Hoffman, Dee Molenaar, James R. Mount, David A. Myers, and Eugene O. Welch were hired or transferred into the District.

The Spokane Subdistrict office continued to function as it had under SWB operations with no change in responsibilities; however, Savini replaced Scott as Engineer-in-Charge.

### Funding and Cooperation

The District programs were funded from the Federal (Fed) program, the cooperative (Coop) program, other Federal agencies (OFA), and FPC licensees. Minor Federal-program funding supported data collection at several sites of Federal interest in the State. Cooperative programs provided the major source of funds at 63 percent in 1958 and 72 percent in 1966 of the total District funding. This period was one of great growth in the program. As shown in the following table, funding from all sources increased about 170 percent from $467,900 in 1958 to $1,269,800 in 1966.

Washington District funds fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Fed | 46.6 | | | | | | | 48.3 | 86.2 |
| Coop | 296.8 | 341.2 | 475.3 | 465.2 | 559.2 | 615.1 | 877.0 | 822.4 | 924.7 |
| OFA | 93.8 | | | | | | | 132.9 | 148.4 |
| FPC | 30.7 | 40.4 | 50.0 | 51.5 | 59.7 | 81.2 | 64.1 | 89.8 | 110.5 |
| Total | 467.9 | | | | | | | 1,093.4 | 1,269.8 |

Note: Funds shown for 1958, 1965, and 1966 were obtained from District files, and should be accurate. Fed and OFA funding amounts were not available for FY 1959–FY 1964.

#### *Cooperating Agencies*

The principal cooperator during the period 1957 to 1966 was the State Department of Conservation, which supported the statewide network of stream-gaging stations, ground-water observation wells, and studies of ground-water occurrence and problems in selected counties. Toward the end of the period, the program was expanded to include water-quality and suspended-sediment data collection and investigations. Funding was also increased for areal appraisal and interpretive studies, which were needed to provide answers for the State's water-management and development problems.

The State Departments of Fisheries and Game provided cooperative funds to maintain a network of small-stream gaging stations in western Washington and to make low-flow measurements of many streams each year. A statewide network of crest-stage gages was supported by the State Department of Highways. The State Pollution Control Commission helped finance the collection of water-quality and suspended-sediment data.

Cities that supported the collection of streamflow data included Seattle, Tacoma, Spokane, Aberdeen, Bremerton, and Olympia. The Municipality of Metropolitan Seattle, a regional agency, provided funds for water-quality studies and data collection in the Duwamish estuary and Puget Sound.

Cooperative funds were provided by many small towns through the stream-gaging trust fund administered by the State Department of Conservation.

#### *Other Federal Agencies*

Federal agencies that provided funds for the collection of data for their operating, planning, or other needs included the U.S. Army Corps of Engineers, the BOR, the Bonneville Power Administration, and the Department of State for the International Joint Commission. The National Park Service funded ground-water studies at many sites in parks, and the AEC funded the study of the movement of radionuclides in the Columbia River (see Part IV, "Columbia River Radionuclide Studies"). The Department of the Army and Air Force also contributed funds during this period.

#### *Federal Power Commission Licensees*

The cities of Seattle and Tacoma, Public Utility Districts in Chelan, Cowlitz, Douglas, Grant, Pend Oreille, and Snohomish Counties, and other agencies including the Crown Zellerbach Corporation, Pacific Power and Light Company, Puget Sound Power and Light Company, and Washington Public Power Supply as licensees of the FPC funded the collection of streamflow data at their powerplants.

### Summary of Program

In 1958, surface-water activities made up 76 percent of the total water-resources programs of the Division in the State, ground-water programs accounted for 22 percent, while quality-of-water work was only 2 percent. However, by 1966, quality-of-water programs had increased to 35 percent of the total program, surface-water work had decreased to 55 percent, and ground-water activities made up the remaining 10 percent. Collecting and publishing basic water data made up 75 percent of the work in 1958 but had decreased to 55 percent by 1966 when a greater emphasis was being placed on areal appraisals and interpretive studies.

#### *Streamflow Records*

In 1958, the District operated 283 continuous-record stream-gaging stations. In 1966, the number had increased to 384, consisting of 114 primary, 79 secondary, and 171 water-management stations. Periodic measurements of low flow were made at 118 sites and measurement of peak discharge at crest-stage gages at 200 sites.

#### *Ground-Water Records*

In 1966, continuous or daily water-level measurements were made in 13 wells, and periodic measurements were made in 130 wells. Water-level measurements were also made in many wells as a part of special ground-water investigations.

Annual reporting of ground-water levels in the State was started in 1964 in cooperation with the State Department of Conservation. Each report contained a summary of the variations in ground-water levels, as well as the records of water level.

#### *Quality-of-Water Records*

In 1958, chemical-quality records were collected at only four sites and no suspended-sediment data were collected. However, continuous water-temperature data were collected at 32 sites, and periodic temperature measurements were made at all the stream-gaging stations. By 1966, the water-quality data-collection program had been greatly expanded with chemical-quality data being collected daily at 11 sites and periodically at 23 sites. Water-temperature data were collected on a continuous basis at 43 sites.

Water samples collected from 200 wells were analyzed for chemical quality in 1965 to monitor changes in water quality of specific aquifers and to document the water quality for ongoing areal ground-water investigations.

Sampling of shallow, domestic ground-water wells in Lewis County was started in 1964 to determine whether any changes in methane gas content of the ground water was occurring from the storage of natural gas in a large, natural dome more than 2,000 feet below land surface.

#### *Other Data Activities*

Washington was one of a few Districts that operated a large-scale snow-survey program. Its program involved measuring snow depth and water content at 54 locations in the Cascade Mountains. Early in the period, the snow-survey sites were reached by snowshoes or skis, but by the end of the period, all travel to the courses was by helicopter.

The use of small helicopters for mountain-flying operations was risky due to the ever-changing weather conditions. The District's safety record was good, however, with only one helicopter accident that occurred in the Skagit River Basin in March 1960. A helicopter, carrying Ronald L. Hanson, Fred Dupuis (WAE), and the pilot lost power on takeoff during a snowstorm and crashed in deep snow on a streambank. Fortunately all occupants suffered only minor cuts and scratches and the equipment was undamaged. After a cold night, they were rescued by another helicopter.

Data from the snow surveys were used during the spring snowmelt period to help forecast stream runoff for the operation and management of storage reservoirs for electric-power generation and flood control. A summary of the snow-survey data collected through 1960 was published in Washington State Water-Supply Bulletin (WSB) No. 13 (1961).

Precipitation data obtained by District staff from 17 sites in high-altitude areas of the western slope of the Cascade Mountains were published by the National Weather Service.

Drainage-area data for western Washington were compiled by Donald Richardson (open-file rept., 1962). Drainage-area data for eastern Washington were compiled by J. Rodney Williams (open-file rept., 1965).

"Municipal, industrial, and irrigation water use in Washington, 1965" by L.B. Laird and K.L. Walters, containing more data for Washington than was published in the nationwide report on water use (Circ. 556, 1965), was open-filed in 1967.

#### *Special Studies*

During this 1957 to 1966 period of history, the traditional water-resources investigations by the District were expanded to cover sediment transport, water quality, total water resources, and specific water problems. Many of the principal studies during the period are summarized below.

Special streamflow studies were mainly those of the magnitude and frequency of floods. As a part of a nationwide effort, reports were prepared describing methods by which flood frequency and magnitude could be estimated for any site on any stream. Data for the State of Washington were contained in Water-Supply Papers 1687, 1688, and 1689 (all 1964).

Donald Richardson's analysis of streamflow data from logged and unlogged watersheds in the upper Green River Basin indicated no significant effect of logging on volume and rate of runoff (open-file rept., 1965).

The effect of wind and barometric pressure on measurements of reservoir storage at Roosevelt Lake on the Columbia River were analyzed by E.G. Nassar (open-file rept., 1965).

W.R. Scott reported on the characteristics of streamflow in the Colville River Basin (open-file rept., 1969).

Savini and Bodhaine analyzed current-meter velocity observations from discharge measurements at seven Columbia River gaging stations to evaluate methods then in use (WSP 1869–F, 1971).

Among the special ground-water studies were those of Thurston County by E.F. Wallace and Dee Molnaar (WSB 10, 1961); west-central Lewis County by J.M. Weigle and B.L. Foxworthy (WSB 17, 1962); Ahtanum Valley in Yakima County by B.L. Foxworthy (WSP 1598, 1962); the Pullman area of Whitman County by B.L. Foxworthy and R.L. Washburn (WSP 1655, 1963); Walla Walla River Basin by R.C. Newcomb (WSB 21, 1965); Island County by H.W. Anderson, Jr. (WSB 25, 1968); north-central Spokane and southeastern Stevens Counties by D.R. Cline (WSB 27,1969); and southwestern King County by J.E. Luzier (WSB 28, 1969).

A number of ground-water studies were undertaken at the request of the National Park Service, Bureau of Indian Affairs, and the Department of Defense to determine the potential for developing ground water for domestic use. Among these were studies at the border stations at Laurier and Ferry, by K.L. Walters (Cir. 422, 1960) and at Mount Rainier National Park, by J.E. Luzier (open-file rept., 1964). Other studies for these agencies and for which the results were not formally published included those at Inchelium, Colville Indian Reservation, by M.J. Grolier (1961); at Whitman National Monument, Walla Walla, by J.W. Bingham (1962); and at the Navy installation at Zelatched Point, Jefferson County, by K.L. Walters (1965).

Ground-water studies made in eastern Washington, largely related to irrigation, included those of artificial recharge of basalt aquifers in Walla Walla area, by A.A. Garrett (PP 450–C, 1962); in the Pullman area, by B.L. Foxworthy and R.L. Washburn (WSP 1655, 1963); and of ground-water withdrawal in the Odessa area of Adams, Grant, and Lincoln Counties, by A.A. Garrett (WSB 31, 1968).

Seepage from Chester Morse Lake and Masonry Pool in King County was evaluated by F.T. Hidaka and A.A. Garrett (WSP 1839–J, 1967).

The chemical and physical quality of ground water in Washington was reported by A.D. Van Denburgh and J.F. Santos (WSB 24, 1965). L.B. Laird reported on the chemical quality of the surface waters of the Snake River Basin (PP 417–D, 1964) and J.F. Santos reported on the quality of the surface waters of the Lower Columbia River Basin (WSP 1784, 1965). The quantity and the source of sediment transported in the Walla Walla River Basin of Washington and Oregon was investigated by B.E. Mapes (WSP 1868, 1969); in the Palouse River Basin of Washington and Idaho during July 1961 to June 1965 by P.R. Boucher (WSP 1899–C, 1970); and in the Chehalis River Basin during October 1961 to September 1965 by P.A. Glancy (WSP 1798–H, 1971).

A comprehensive study of the radionuclide movement in the Columbia River as solutes, or associated with sediments, was conducted in cooperation with the AEC (see Part IV, "Columbia River Radionuclide Studies").

An investigation was started in 1962 to define the effect of industrial and municipal wastes on the water quality of the Duwamish estuary from its mouth to Renton, and on the waters of Puget Sound. Data included not only the regular water-quality parameters but also coliform bacteria, plant nutrient, phytoplankton, and saltwater intrusion. This program included one of the first installations of continuous automatic water-quality recorders. Data recorded by the four units installed on the Duwamish River included dissolved oxygen, specific conductance, pH, and chloride. This study also included sampling of water quality and bottom materials 1 to 3 times per week in Puget Sound offshore of Seattle from a surplus 40-foot Coast Guard boat obtained by the Survey for this purpose. Samples were collected from depths up to 300 feet in all kinds of adverse weather conditions, making this duty one to be avoided by most employees. Results of the investigation were reported in several reports including one by J.R. Williams on the movement and dispersion of fluorescent dye in the Estuary (open-file rept., 1964) and the one by W.L. Haushild and E.A. Prych on modeling the coliform-bacteria concentrations and pH in the salt-wedge reach of the estuary (open-file rept. 76–415). A summary of the studies made during 1963–67 was reported by J.F. Santos and J.D. Stoner (WSP 1873–C, 1972).

The results of another estuarine study that began in 1963 in the Upper Grays Harbor were reported by J.P. Beverage and M.N. Swecker (WSP 1873–B, 1969).

A summary of the water resources of Washington by F.T. Hidaka was included in the U.S. Senate Committee on Interior and Insular Affairs Report, "Mineral and water resources of Washington." (See Part IV, "Water Resources of States.")

During this period of history, more than 10 Federal and State agencies, under Survey leadership, began preparing a report on the water resources of Puget Sound and adjacent waters for the Pacific Northwest River Basins Commission (Pacific Northwest River Basin Commissions, 1971).

Other studies that described both surface water and ground water and their quality included those of the Flett Creek Basin during 1959–61 by F.M. Veatch, G.E. Kimmel, and E.A. Johnston (open-file rept., 1966) and of King County by Donald Richardson, J.W. Bingham, and R.J. Madison, with a section on sediment in the streams by R.C. Williams (WSP 1852, 1968).

## West Virginia

*By* Gerald Meyer assisted *by* Lunsford B. Holland, Porter E. Ward, *and* George W. Whetstone

During most of this 1957–66 period of history, WRD programs in West Virginia were conducted independently by the Surface and Ground Water Branches, with water-quality support provided by visiting Quality of Water Branch personnel. It was in April 1966 that the Branches were merged into a Division-level District.

Geographic impediments to interdisciplinary cooperation far exceeded any possible organizational or discipline barriers. District offices were situated in the cities in which their principal State cooperating agencies were located: the SWB District headquarters in Charleston and the GWB District headquarters in Morgantown—200 sinuous, pre-Interstate miles and 6 hours of alert mountain driving apart; or, for the more adventuresome, 1.5 hours and unpredictably longer via bucking, low-flying, three-flights-a-week Lake Central DC–3.

Staff complements and program funds increased only modestly throughout the period, despite rising demands for water information associated with the growing numbers and complexity of water problems and water issues confronting States of the Appalachian region. The total program in West Virginia was always somewhat small. Nevertheless, past and ongoing basic-data programs and areal investigations provided a firm foundation for the broadened information system instituted during the period to address newly arising water-data needs. In the absence of significant staff increases, much of the new work was extracted from the hides of the existing work force.

A joint interbranch investigation of Kanawha County, started in 1957 and funded by the regular cooperative program and Kanawha County Court, was the first formal multidisciplinary hydrologic study in West Virginia. A new series of publications was initiated to report on integrated investigations of surface, ground, and chemical characteristics of the State's water.

Organizational and management structure was modified during the period in order to accommodate changing requirements. In the early years, deliberate cooperative efforts among District staffs through a State WRD Council chaired annually from among the District supervisors improved communications, technical collaboration, and overall efficiency. Near the end of the period, in 1966, formal integration of water programs and personnel into a WRD District headed by a "line" District Chief was effected.

These progressive changes in programs, funding, personnel, and organization during the period 1957–66 are described more fully in the following sections.

## Organization and Personnel

### *Surface Water Branch*

West Virginia is nicknamed "The Mother of Rivers," in reference to the large number of major eastern streams whose headwaters lie in the highland region of the State. Surface water is the State's primary water source for massive demands of chemical and power plants, for river transportation via extensive systems of locks and dams, and for public water supplies of the several largest cities. These economically vital usages of the State's water, coupled with proneness of the Appalachian region to problems of flooding, dictated a surface-water program larger than ground-water or quality of water activities.

SWB District headquarters was at Charleston in the U.S. Court House until 1961, and then in the New Federal Building and U.S. Court House. A Subdistrict office was maintained in Elkins to conduct operations in the eastern and northern regions of the State. The full complement in 1957 included eight engineers, three technicians, and a clerk-stenographer; in 1966 it consisted of eight engineers, six technicians, and two clerk-stenographers.

Warwick L. Doll, District Engineer from 1957 until his death in 1962, was succeeded by William C. Griffin. In April 1966 Griffin was appointed WRD District Chief for West Virginia. Other Charleston headquarters personnel and periods of service during 1957–66 were: engineers Eric D. Bressee, 1957–66; Walter S. Bush, 1957-60; James H. Clippard, Jr., 1960–61; Eugene A. Friel, 1957-66; Prentis M. Frye, 1965–66; Frank O. Morris, 1966; Gerald S. Runner, 1964–66; Robert H. Simmons, 1957–64; and Arthur A. Vickers, 1957–58; technicians and aides Frances L. Gilliland, 1957–66; Calvin E. Phillips, 1959-63; Orville B. Rose, 1964–66; and Albert Tyre, 1964-66; clerk-typists and stenographers Christine C. Brittain, 1963; Annie L.F. Cunningham, 1961–62; Cora K. Jones, 1957–65; Eunice Mae Jones, 1959-60; Nancy L. Kinser, 1966; and Lillian C. Peters, 1964–66.

Lunsford B. Holland, Engineer-in-Charge of the Elkins Subdistrict throughout the period of this history, directed field operations in the eastern panhandle, Valley and Ridge region, and parts of northern West Virginia. Holland's flood expertise was utilized widely within the District and in other Districts by temporary assignment. His staff consisted of two engineers and two technicians at the beginning of the period, and one engineer and three technicians at its end. They were engineers Charles J. Crickard, 1957–62, and Robert B. Scott, 1957–66; technicians and aides Fred R. Green, 1957–66; Alvin R. Jack, 1966; Ronald M. Simmons, (WAE), 1966; and Julia L. Varner, 1957–63.

### *Ground Water Branch*

Ground water was an important source of municipal and rural domestic water supply throughout West Virginia. Chemical-plant and municipal wells constructed in permeable alluvial deposits adjacent to the Ohio River pumped enormous quantities of ground water derived by induced infiltration through the riverbed.

GWB District headquarters were at Morgantown throughout this period, in quarters of its principal State cooperator, the West Virginia Geological and Economic Survey (G&ES). The geologic setting at West Virginia University was conducive to the hydrogeological nature of the Branch investigations. A Subdistrict office was maintained in Charleston at times for investigations in the southern part of the State. The full complement in 1957 consisted of three geologists, with the addition of a clerk-stenographer late in the year; in 1966, it consisted of four geologists, one geophysicist, and one clerk-stenographer.

Charles W. Carlston was District Geologist in 1957. He was succeeded by Gerald Meyer, who served from 1958 to 1964 and then Porter Ward, from 1965 to 1966. Other staff members in Morgantown were geologists Paul P. Bieber, 1957–58; John T. Gallaher, 1966; James E. Luzier, 1962; Tully M. Robison, 1961–63; Richard A. Wilkins, 1960; and Benton M. Wilmoth, Jr., 1963–66; aides Stanley B. Cohen (WAE), 1960; Greg E. Eddy, 1963; E. F. Speiden, Jr., (WAE), 1960; and John J. Watkins, (WAE), 1958–59; and clerk-stenographer Anna D. Trowbridge, 1957–66.

Assigned to the Charlston Subdistrict office were geologists Benton M. Wilmoth, Jr., 1957–62, and Phillip W. Johnson, 1966; and geophysicist Thomas E. Williams, 1966.

### *Quality of Water Branch*

Stream and ground-water quality and contamination control were issues of increasingly strong concern in West Virginia during the period 1957–66, and the number of water-quality investigations grew throughout the period. QWB personnel who participated in field investigations and monitoring activities included George W. Whetstone, District Chemist, Columbus, Ohio, Roger J. Archer of the Columbus laboratory, and John W. Wark, sediment specialist from Rockville, Md. Whetstone was also a member of the West Virginia WRD Council and an active participant in cooperative and Federal program planning and implementation in the State.

QWB personnel from the Columbus laboratory and Rockville, Md., field office maintained the water-quality networks in West Virginia. QWB personnel also took part in field studies including the river-basin studies funded mostly under the Federal-State cooperative program, and, in collaboration with SWB and GWB District personnel, the acid-mine drainage investigations funded by other Federal agencies.

## Funding and Cooperation

As shown in the following table, total funding increased greatly over the period. The largest increase occurred in work for other Federal agencies, attributed mainly to new funding in the last 2 years of this period by the U.S. Army Corps of Engineers, the PHS, the Department of HEW, and the Bureau of Mines.

West Virginia District funds, fiscal years 1958–65
[In thousands of dollars]

| Fund source | 1958 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 |
|---|---|---|---|---|---|---|---|
| Coop | 98.9 | 76.6 | 101.6 | 100.9 | 101.8 | 111.8 | 122.9 |
| OFA | 45.9 | 79.6 | 59.4 | 48.8 | 56.9 | 75.0 | 116.9 |
| Fed | 22.4 | 22.0 | 30.1 | 28.3 | 35.6 | 32.4 | 32.6 |
| FPC | 1.6 | 1.7 | 1.8 | 1.8 | 1.8 | 2.0 | 2.0 |
| Total | 168.8 | 179.9 | 192.9 | 179.8 | 196.1 | 221.2 | 274.4 |

Source: The figures in the table above are from the annual consolidated work plan of the West Virginia District. These internal program documents were not available, however, for all years of this period of history.

During 1957–66, the State Division of Water Resources was the primary State cooperating agency for the surface-water program, with additional substantial cooperative (Coop) support provided by the State Public Service Commission. The State Highway Department supported the collection of flood data from the operation of a network of crest-stage gages to aid design of highway drainage structures. Several counties contributed funds for streamflow data.

The West Virginia Geological and Economic Survey was the principal State cooperating agency for ground-water studies, which included a number of county ground-water investigations and river-basin areal ground-water appraisals.

The Ohio River Sanitation Commission (ORSANCO), in a cooperative program with the Columbus, Ohio, QWB Laboratory, supported five daily water-quality stations in the State.

Among other Federal agencies (OFA), the U.S. Army Corps of Engineers sponsored gaging-station operations in several river basins to aid its water planning and engineering purposes. The U.S. Army Corps also supported, with the PHS, a ground-water reconnaissance study of the Kanawha River Basin. Funds from the HEW and the Bureau of Mines funded acid-mine drainage investigations. The Forest Service, Soil Conservation Service, and several other Federal agencies sponsored various streamflow and surface-water-quality studies during the period. Two FPC permittees and licensees underwrote stream-gaging operations relating to power generation. Moderate Federal (Fed) program funds helped support gaging-station operations.

## Summary of Programs and Publications

### *Water Records*

Streamflow Records.—In 1962, 91 continuous-record streamflow stations were operated, 38 of which were classified as primary; 12, secondary; and 41, water-management stations.

Ground-Water Records.—Also in 1962, continuous and periodic records of water-level fluctuations in 20 observation wells, most of them in principal aquifers throughout the State, were maintained. The records documented in general terms the changes in ground-water storage throughout the State. Some of the records were utilized in ground-water project studies conducted during the period.

Water-Quality Records.—The water-quality network expanded during the period. In 1962 the District and QWB personnel collected chemical-quality data at only three sites. By 1968, the only year near the close of this period for which such information is available, chemical-quality data were being collected at 3 sites, temperature data at 16 sites, and suspended sediment data at 11 sites.

Chemical sampling accompanied most ground-water county and areal investigations, and as of 1965, large numbers of complete and partial analyses of water from principal aquifers of the State were on file, many of which were recorded and utilized in the various descriptive and analytic publications.

#### *Special Studies*

The floods of March 1963 from West Virginia to Alabama were documented by Harry H. Barnes, Jr. (open-file rept., 1963).

Among the principal ground-water investigations during the period were those of the counties of Harrison, by R.L. Nace and P.P. Bieber (G&ES Bull. 14, 1958); Monongalia, by C.W. Carlston (G&ES Bull. 15, 1958); Berkeley and Jefferson, by Bieber (G&ES Bull. 21, 1961); Ohio, by T.M. Robison (G&ES Bull. 27, 1964); and Mason and Putnam, by B.M. Wilmoth, Jr. (G&ES Bull. 36, 1965).

The GWB program also yielded a number of journal papers and abstracts, examples being: "An examination of the relationship of geology to flooding and landslides," by V.T. Stringfield and R.C. Smith (G&ES, Invest. 13); "Description of the chemistry of fresh ground water in West Virginia," by Gerald Meyer (West Virginia Acad. Sci. Proc., 1960); "Hydrogeology of waste disposal ponds," by Gerald Meyer (Water Pollution Control Federal Jour., 1960); and "Particle size and permeability of Kanawha River valley alluvium" and "River-bed recharge to alluvium of the lower Kanawha River valley," both by B.M. Wilmoth, Jr., (West Virginia Acad. Sci. Proc., 1960 and 1963).

Discharge of fluvial sediment in the Salem Fork Basin was described by R.F. Flint (WSP 1798–K, 1972).

Water-resources investigations conducted jointly by the Branch Districts resulted in reports summarizing the water resources of Kanawha County, by W.L. Doll, B.M. Wilmoth, and G.W. Whetstone (G&ES Bull. 20, 1960) and of the State, by W.L. Doll, Gerald Meyer, and R.J. Archer (West Virginia Dept. Nat. Resources, Div. Water Resources, 1963).

West Virginia water information of the period was included in a number of regional water-resources publications including a water atlas of the Appalachian region by W.J. Schneider and others (HA–198, 1965) and an assessment of coal-mine drainage and its impacts on stream quality in the Appalachian region by J.E. Biesecker and J.R. George (Cir. 526, 1965).

## Wisconsin

*By* C.L.R. Holt, Jr. assisted *by* retirees William J. Drescher, Jack H. Green, Rachel Hagen, *and* Kenneth B. Young, *and* District Chief Vernon W. Norman *and* his wife, Pat, who computerized the text

The WRD programs in Wisconsin were developed, administered, and executed by the Branches until July 1966 when Wisconsin became a Division-level District. During the 1957 to 1966 period of this history, the Wisconsin WRD Council, consisting of the Branch District supervisors, provided a unifying approach to data collection and to the development of interdisciplinary studies of water resources. By the early 1960's, projects were being keyed to Council and cooperators' long-range plans and oriented toward solving water problems. Through the aegis of the Council, the Branch offices collaborated in planning and programming, in liaison with the cooperating agencies, in submitting to cooperators consolidated annual progress reports and proposed programs.

### Organization and Personnel

#### *Surface Water Branch*

The SWB District office was in Madison at 666 State Office Building, near offices of the Public Service Commission of Wisconsin, a principal cooperator, until December 1963, when the office was moved to 5001 University Avenue. Francis T. Schaefer was District Engineer until August 1960, when he became SWB Area Chief, ACA. He was succeeded by Kenneth B. Young, reassigned from the WRD Planning Section in Washington, D.C. Robert H. Brigham, Assistant District Engineer until 1959 when he accepted an assignment to Lashkar Gah, Afghanistan, was replaced by Theron R. Dosch, who transferred from Menlo Park, Calif. Frederick C. Dreher headed the SWB data unit.

Other key staff members included Duane H. Conger and Donald W. Erickson, who did the floods work. Lawrence A. Martens (1960–62), Roman T. Mycyk (1963–64), Herbert G. Stangland (1963–67), Kevin L. Carey (1966), and James M. Bergman (1966) contributed their engineering expertise during briefer periods. Engineering technicians Keith S. Brigham, Donald C. Hurtgen, and Burns L. Kaupanger were mainstays of the surface-water data program. Secretarial services were supplied by Geraldine E. Dreher until 1958, when she was succeeded by Nancy Stoycheff Marquardt.

### *Ground Water Branch*

The GWB District office was in the Science Hall of the University of Wisconsin, near offices of the principal cooperator, the Wisconsin Geological and Natural History Survey. William J. Drescher, District Engineer until 1957 when he was designated GWB Area Chief, MCA, was also headquartered there. C.L.R. Holt, Jr., was appointed District Geologist in 1958 and served in that position until he was named District Chief in July 1966.

Edmund F. LeRoux, Thomas G. Newport, William K. Summers, and Denzel R. Cline were key members of the staff during the early years of this period. In 1958, Newport was transferred to Benghazi, Libya, Doyle B. Knowles transferred in from Alabama and Charles F. Berkstresser, Jr., arrived from California. In 1960, LeRoux was assigned to GWB headquarters in Washington, D.C. Berkstresser returned to California and was replaced by Robert W. Devaul from Chile in 1962. Also in 1962, Knowles resigned, returned to Alabama to work for the Alabama Geological Survey and was replaced by Edwin P. Weeks, who arrived from Wyoming in 1963. Weeks also headed the interdisciplinary study of the Little Plover River. Louis J. Hamilton also arrived in 1963 to conduct a river basin study.

Roy E. Audini conducted the observation-well and springs-studies programs assisted, beginning in 1960, by Robert M. Erickson. Loretta E. Lepeska was the secretary to Holt and Drescher until 1959 when Joal N. Fenn joined the District as Holt's secretary. Lepeska continued through 1966 as secretary to Drescher. Fenn remained as Holt's secretary through 1965 when Rachel A. Lansing assumed the position. Noreen Garfoot Esser was clerk-typist until 1965.

In 1960, a field headquarters was established in Wauwatosa to handle increasing work in southeastern Wisconsin. Roy W. Ryling transferred from Arkansas to head this office, resigned, and was replaced by Rickard D. Hutchinson in 1962 when the office was moved to Waukesha in space supplied by the Southeastern Wisconsin Regional Planning Commission. Jack H. Green transferred to Waukesa from Sacramento, Calif., in 1963 to head the office and to help with the expanding program.

### *Quality of Water Branch*

The QWB District office at Columbus, Ohio, provided laboratory analyses of water quality and sediment, program guidance, and special water-quality studies in Wisconsin.

### *Other Organizational Arrangements*

As there was no WRD ground-water program in Illinois during this period of history, the Wisconsin GWB District conducted water-supply and other studies at the Argonne National Laboratory near Chicago for the AEC, and the Wisconsin District Geologist represented the GWB on the Illinois WRD Council.

## Funding and Cooperation

About 70 percent of the total funds for the District's programs for FY 1958–FY 1966 were from the cooperative (Coop) program; about 17 percent from the Survey's Federal (Fed) program; about 11 percent from other Federal agencies (OFA); and about 2 percent from licensees of the FPC. The Federal program supported a few gaging stations, compiling surface-water records, evaluating the quality-of-water network, research on rating characteristics of hydro-power plants, monitoring tritium, and preparing a report on the 1965 Mississippi River flood. In FY 1962, Federal funds supported a study of the water resources of the Beloit-Janesville area to aid in planning emergency supply and municipal and industrial development. Streamflow data collected at gaging stations on the Chippewa, Red Cedar, Wolf, Wisconsin, and Flambeau Rivers was funded by hydroelectric power companies licensed by the FPC.

As shown in the following table, total funds increased from $178,900 in FY 1958 to $362,500 in FY 1966.

Wisconsin District funds, fiscal years 1958–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 136.5 | 149.2 | 177.5 | 180.8 | 203.2 | 220.4 | 263.7 | 279.5 | 301.2 |
| OFA | 7.6 | - | - | - | - | - | - | - | 34.1 |
| Fed | 29.9 | - | - | - | - | - | - | - | 19.4 |
| FPC | 4.9 | 6.2 | 5.9 | 5.2 | 5.8 | 5.9 | 6.9 | 6.9 | 7.8 |
| Total | 178.9 | - | - | - | - | - | - | - | 362.5 |

Source: Reliable District program documents, FY's 1958 and 1966. Less reliable Headquarters compilations from unknown sources for other fiscal years.

### *Cooperating Agencies*

The Wisconsin Geological and Natural History Survey (G&NHS), University of Wisconsin, was the primary State cooperator throughout the period for statewide information on ground water, river-basin assessment of water resources, county hydrologic and geologic studies, and of areas of municipal and industrial development, and for research into ground- and surface-water relationships. The Public Service Commission of Wisconsin was the major cooperator for statewide streamflow and lake data.

The Highway Commission of Wisconsin supported a statewide program to acquire flood information from small drainage areas and hydraulic and hydrologic analyses at specific bridge sites. The Wisconsin Conservation Department, Committee on Water Pollution, supported the collection of streamflow and sediment data and the evaluation of effectiveness of watershed-improvement practices, and contributed to the study of interrelationships of ground water and surface water. The Conservation Department also supported the study of effects of irrigation on streamflow, a statewide sediment reconnaissance, and contributed to the continuing programs to collect streamflow and ground-water level data.

The Madison Metropolitan Sewage District funded the gaging of Badfish Creek that carried treated effluent to a lake.

The Southeast Wisconsin Regional Planning Commission (SEWRPC) supported a water-resources study of the southeast Wisconsin-Fox River Basin and gaging stations on several small streams in its area of responsibility.

In 1966, the Wisconsin Department of Resources Development contributed to the streamflow-data program.

#### *Other Federal Agencies*

The Corps of Engineers Districts of Rock Island, St. Paul, and Chicago funded a number of gaging stations on major rivers for flood control and management purposes. The Fish and Wildlife Service funded the collection of streamflow data in the Horicon Refuge area. The Soil Conservation Service funded the collection of streamflow data needed to evaluate several watershed-protection projects.

### Summary of Program

Collecting, interpreting, and publishing water data continued to be a strong and level component of the District programs. Studies of the hydrology of water problems and water-data needs around the State, plus the use of network concepts, aided the data-collection processes to meet expanded data needs and objectives. Increasing applications of automated monitoring equipment and computer technology improved the timeliness of data collection, processing, and publication.

During this period, interpretive investigations were expanded from studies that concentrated attention on needs of the present to those that develop readiness for needs of the future. Topical, areal, and site studies were undertaken to provide water facts for use by planners and managers. County resource-evaluation studies were continued to supply planning information for urban and rural areas. Flood- and low-flow frequency studies utilized statistical analysis of streamflow records for design and water-management needs. Research included hydrologic processes and ground-water/surface-water relationships.

In preparing long-range plans for water-resources studies in Wisconsin, Holt had proposed investigating and reporting on the water resources of the State by river basins. Basin priority was based on current water problems and on anticipated information needs. His proposal was accepted by the G&NHS, and studies began in FY 1963 of the lower and middle portions of the Wisconsin River Basin, followed by the Fox-Wolf River Basin. Immediately after the close of this period of history, the program was expanded to include all river basins in the State—a major commitment of funds and personnel.

#### *Water Records*

Streamflow Records.—In 1965, the streamflow-data program included 91 continuous-record stations, consisting of 56 stations for long-term hydrologic (primary) needs, 17 stations for short-term areal (secondary) needs, and 18 stations for water-management needs. Also included were 180 low-flow partial-record stations and 115 flood-flow crest-stage stations.

Ground-Water Records.—In 1965, the water-level data program included 25 continuous-record observation wells and 169 partial-record (periodic) observation wells. Water-level records were also obtained from several wells proven to respond to far-distant earthquakes. Chemical-quality data were collected at 13 observation wells and 7 springs.

Water-Quality Records.—In 1965, periodic measurements of sediment discharge were made at 45 streamflow stations and of temperature at 32 stations. Chemical quality, temperature, and sediment data were collected daily from one federally supported station.

A modest program of chemical-quality sampling of water from 13 observation wells was underway in 1965. At least 100 ground-water samples were collected in project areas for chemical analysis, and the data were open-filed.

Other Data Activities.—In 1965, water-level measurements were made daily at 10 lakes and reservoirs, and reservoir contents were determined monthly for 32 reservoirs.

Streamflow duration tables were updated every 2 years for the Public Service Commission to aid the Commission in determining allowable diversions from streams.

Observation-well data were processed in the Madison office and entered on hydrographs. Reports based on these data included that on water levels in observation wells through 1957 by R.E. Audini, C.F. Berkstresser, Jr., and D.B. Knowles (G&NHS Info. Cir. 3, 1959) and trends in ground-water levels through 1966, by R.W. Devaul (G&NHS Cir. 9, 1967). Ground-water pumpage and water-level changes in the Milwaukee-Waukesha area were reported by J.H. Green and R.D. Hutchinson (WSP 1809–1, 1965).

"Water-quality records in Wisconsin and Michigan" was open-filed in 1964.

#### *Special Studies*

Among the principal studies that were conducted all or in part within the period 1957–66 was that of the hydrology of the Little Plover River Basin, Portage County, by E.P. Weeks, D.W. Ericson, and C.L.R. Holt, Jr. (WSP 1811, 1965). The Little Plover project, a study in sand-plains hydrology by Weeks, Holt, and G.F. Hanson, University of Wisconsin, was documented as a movie in 1963.

Studies of the water resources of counties during this period included those of the geology and ground-water resources of Fond Du Lac County, by T.G. Newport (WSP 1604, 1962); the geology and ground-water resources of Rock County, by E.F. LeRoux (WSP 1619–X, 1963); the ground-water resources of Waupaca County, by C.F. Berkstresser, Jr., (WSP 1669–W, 1964); the geology and ground-water resources of Waushara County, by W.K. Summers (WSP 1809–B, 1965); the geology and ground-water resources of Dane County, by D.R. Cline (WSP 1799-U, 1965); the geology and water resources of Winnebago County, by P.G. Olcott (WSP 1814, 1966); and of Racine and Kenosha Counties, by R.D. Hutchinson (WSP 1878, 1970).

Water-resources investigations were also made of areas of the State, other than counties, including those of the hydrology of upper Black Earth Creek Basin, by D.R. Cline, with a section on surface water, by M.W. Busby (WSP 1669–C, 1963); ground water in Cherokee Marsh area, Dane County, by C.L.R. Holt, Jr. (open-file rept., 1963); ground-water conditions in the Green Bay area, 1950–60, by D.B. Knowles (WSP 1669–J, 1964); the Green Bay area, by D.B. Knowles, F.C. Dreher, and G.W. Whetstone (WSP 1499–G, 1964); the hydrology of zinc-lead mines in southwestern Wisconsin, by C.L.R. Holt, Jr. (open-file rept., 1966); and the Troy Valley of southeastern Wisconsin by J.H. Green (PP 600–C, 1968).

Topical studies included those by E.D. Weeks of field methods for determining vertical permeability and aquifer anisotropy (PP 501–D, 1964) and the use of water-level recession curves to determine the hydraulic properties of glacial outwash in Portage County (PP 501–B, 1964).

K.L. Carey made studies of the configuration and roughness of the underside of river ice of the St. Croix River (PP 550–B, 1966 and PP 575–C, 1967).

D.W. Ericson reported on the magnitude and frequency of floods in Wisconsin (open-file rept., 1961) and K.B. Young reported on the flow characteristics of Wisconsin streams (open-file rept., 1963). Young also reported on the effect of treated effluent diversion on Yahara River flow (open-file rept., 1965).

An example of the special studies made for the State Highway Commission was that of the flood-flow characteristics at a proposed bridge site on the Wisconsin River near DeKorra, by D.W. Ericson (open-file rept., 1961).

C.R. Collier reported on sediment characteristics of small streams in southern Wisconsin, 1954–59 (WSP 1669–B, 1963).

R.W. Ryling reported his preliminary study of the distribution of saline water in the bedrock aquifers of eastern Wisconsin (G&NHS Circ. 9, 1961).

A summation of the State's water resources, water problems and information needs was reported in "The water resources of Wisconsin," by C.L.R. Holt, Jr., K.B. Young, and W.H. Cartwright in Wisconsin Blue Book, State of Wisconsin (1964).

## Wyoming

Based on material provided *by* Bruce H. Ringen *and* reviewed *by* Ellis D. Gordon, Thomas F. Hanly, Marlin E. Lowry, James G. Rankl, *and* James F. Wilson, Jr.

The WRD programs in Wyoming were conducted by the Surface Water, Quality of Water, and Ground Water Branches throughout the period, each headquartered in different, widely spaced cities until late 1961 when Wyoming became a SWB District with headquarters in Cheyenne, where the GWB District had been headquartered for several years. With two of the three operating Branches in Cheyenne, the Wyoming WRD Council was activated and an Administrative Services Section was established in 1961. The Administration Services Section was staffed by Francis C. McLeran during its first year, then by Helen M. Lee for the remainder of this period of history.

## Organization and Personnel

### *Surface Water Branch*

In 1957, SWB operations in Wyoming were directed from Casper, a Subdistrict office of the Colorado District, and then, beginning in 1962, from Cheyenne, headquarters of the newly created Wyoming SWB District. With the establishment of the Wyoming SWB District, the Casper Subdistrict operations came under the supervision of the District Engineer in Cheyenne.

The Casper Subdistrict office was at 150 South Jackson Street. George L. Haynes was Engineer-in-Charge, until he transferred to Santa Fe, N. Mex., in 1962. He was assisted by Jack R. Carter, who was in charge of the "highway program," a cooperative endeavor with the Wyoming Highway Department to obtain flood data relevant to the design of road-stream crossings, and Kenneth B. Rennick, office engineer. Rennick succeeded Haynes as Engineer-in-Charge. Others on the Casper staff who served there more than a year included Lawrence D. Becker, Cora E. Brusaw, Thad W. Custis, Harold E. Hodges, Robert W. Jesse, Tommy J. Lehman, Stuart A. Lounsbury, Eric L. Meyer, Phillip B. McCollam, Donald J. Pangburn, Jess O. Ragsdale, James G. Rankl, Maxine A. Rose, Patrick D. Sperry, and Jerry T. Welch. Gerald W. Armentrout had joined the Casper staff by 1966.

A field office of the Casper Subdistrict was in Kemmerer until 1958 and was manned by Ragsdale.

The Wyoming SWB District was established in late 1961 with Leon A. Wiard, formerly of the Santa Fe, N. Mex., District, as District Engineer. Cheyenne was chosen as the headquarters of the new District with offices at 2123 Carey Avenue where the offices of the GWB District were located. In 1964, the offices were moved to 219 E. 8th Avenue, along with those of GWB. Wiard alternated with Ellis D. Gordon, District Geologist, GWB, to chair the Wyoming WRD Council.

Those who moved from Casper to Cheyenne were Carter, in 1962, and Rankl in 1963. Other members of the Cheyenne District staff at various times from 1962 to 1966 included Gordon S. Craig, Grover H. Durham, Janet M. Johnson, Gary E. Largent, Gary D. Robinson, and Marvin D. Stevens. Dannie L. Collins, Thomas N. Keefer, Milo D. Cress, and Donald Illingworth joined the Cheyenne staff in 1966.

In 1963, a Subdistrict office was established in Cheyenne with James G. Rickher in charge. By the end of this period of history Terry J. Perkins, Kenneth L. Wahl, Terry L. Collins, Russell G. Houser, and Stanley M. Howard were also on the Cheyenne Subdistrict staff.

Becker moved from Casper in 1964 to establish a Subdistrict office in Riverton. He was assisted at various times by Sandy DiGiovanni, and by Lehman and O'Connell, previously of Casper, and by Dennis E. Whitehead, Gary D. Robinson, and Marvin D. Stevens. In 1965, McCollum, also previously of Casper, established a field headquarters in Lovell. He was assisted by James L. Lynch and Donald D. Englert.

### *Quality of Water Branch*

Headquarters for water-quality work in Wyoming during the entire period of this history was at 1214 Bighorn Avenue, Worland, with Thomas F. Hanly in charge. In 1957, the Worland office was a Subdistrict office of the Lincoln, Nebr., QWB District. During 1957 and 1958, Worland's area of operations was largely the Missouri River Basin in Wyoming and Montana but also included part of the Columbia River Basin, where the Worland staff assisted the Portland, Oreg., QWB District, and part of the Colorado River Basin, where assistance was provided to the Salt Lake City, Utah, QWB District.

On January 1, 1959, the Worland office became headquarters for the newly established QWB District responsible for water-quality work in Wyoming and Montana. Hanly, now District Engineer, continued to be responsible for field work, records computation, and the Worland sediment laboratory.

Among those who were on the Worland staff for more than a year during this 1957 to 1966 period of history were David E. Barge, Marguerite E. Barnett, David L. Bertsch, Philip R. Boucher, Donna W. Brownell, Timmy R. Cummings, Don C. Dial, Harold R. Fabricius, Arvo R. Gustafson, William L. Haushild, Richard Koogle, Hugh W. Lowham, Irvin L. McKim, William E. Miller, Raymond L. Muench, Leonard M. Nelson, Robert W. Paris, Ronald C. Reichenbaugh, Samuel J. Rucker, John R. Tillstra, Dennis E. Whitehead, and Richard G. Wunder.

A field headquarters was maintained in Riverton with Robert C. Williams in charge until 1961 when he was succeeded by Charles F. Obert. Others on the Riverton staff at times during this period included Clyde L. Cook, Jack D. Dewey, and James L. Lynch.

### *Ground Water Branch*

In 1957, Horace M. Babcock was District Engineer for GWB operations in Wyoming until he transferred to Branch headquarters later that year. Ellis D. Gordon succeeded Babcock in January 1958 as District Geologist and served for the remainder of the period. District headquarters were initially in Cheyenne at

2002 Capitol Avenue, moved to 2123 Carey Avenue in 1962, and were at 219 E. 8th Avenue from 1964 on.

Others on the Cheyenne staff during this period included Marvin A. Crist, Ruth V. Foresman, Warren G. Hodson, Marlin E. Lowry, Lawrence J. McGreevy, John R. Rapp, Charles J. Robinove, Edwin P. Weeks, George E. Welder, and Harold A. Whitcomb. John H. Domeyer and Theodore J. Vore joined the staff in 1966.

Field headquarters were maintained for the duration of projects at Buffalo by Richard A. McCullough (1960–62), Green River by John R. Rapp (1961–62), and Sheridan by Marlin E. Lowry (1961–62).

## Funding and Cooperation

Most of the funds for the District's programs were from the cooperative (Coop) program and other Federal agencies (OFA). The Survey's Federal (Fed) program funds supported the operation of several gaging and sampling stations and observation wells where the collection of hydrologic records was in the Federal interest.

The following table shows the approximate funding by source for District activities in Wyoming throughout the period except for FY 1959–FY 1962, for which years funding information is not available.

Wyoming District funds, fiscal years 1958, 1963–66
[In thousands of dollars]

| Fund source | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
|---|---|---|---|---|---|---|---|---|---|
| Coop | 146.2 | - | - | - | - | 227.2 | 251.1 | 319.6 | 354.8 |
| OFA | 163.5 | - | - | - | - | 151.6 | 173.0 | 205.7 | 227.1 |
| Fed | 46.4 | - | - | - | - | 26.6 | 25.1 | 35.7 | 21.9 |
| Total | 356.1 | - | - | - | - | 405.4 | 449.2 | 571.0 | 603.8 |

Source: District program documents.

### *Cooperating Agencies*

The Wyoming State Engineer was the principal cooperator during the period for statewide water-resources activities, including the operation of networks for collecting basic ground-water and streamflow data, including the quality of the water, and for making special hydrologic studies.

The State Highway Department, beginning in 1954, cooperated in the Statewide network of crest-stage gages, in flood-frequency studies, and in the preparation of reports on flood-flow characteristics at specific stream sites.

The Wyoming Natural Resources Board supported the collection of records of streamflow, chemical quality, and sediment discharge at selected sites in the State and a special sediment study on Rock Creek. Early in the period, the Board cooperated in several local ground-water investigations.

The city of Cheyenne funded a continuing study of the changes in water-table elevations in the city's well fields and, late in this period, supported the operation of a gaging station.

During the closing years of this period, the State Department of Agriculture cooperated in a statewide study of the chemical quality of the surface waters of Wyoming and in a local ground-water study.

### *Other Federal Agencies*

The BOR funded a number of gaging and chemical and sediment sampling sites and ground-water studies to gain information necessary to plan and implement the Missouri River Basin Development Program.

The Omaha District of the U.S. Army Corps of Engineers funded a number of gaging stations in the Bighorn, Powder, and Green River Basins.

The National Park Service funded ground-water studies in Grand Teton and Yellowstone National Parks and at Devils Tower National Monument.

## Summary of Program

Collecting basic streamflow and water-quality data and processing and publishing water records continued as the primary activities of the SWB and QWB Districts in Wyoming. Groundwork was laid for shifting the emphasis from traditional measurement of water and sediment runoff to investigations related to water-management needs and environmental impacts. County and areal studies were the main thrusts of the GWB District.

In 1957, studies were underway or had been completed to obtain information on the availability of ground water in 4 of the 23 counties, which made up only about 10 percent of the State. It was apparent that the need for such appraisals was sooner than county studies permitted. Studies of principal geologic basins and adjoining mountains were then begun and, by the end of this period, there was published information or studies in progress for 50 percent of the State.

Program growth was in cooperative projects, such as that with the Wyoming Highway Department in studies of floods from small watersheds and those with the Wyoming State Engineer.

### *Water Records*

Data activities are summarized here for 1962, a typical year, as reported in "Water Resources Investigations in Wyoming, 1962."

Streamflow Records.—A total of 212 continuous-record stations were being operated in September 1962, including 82 classified as primary (long-term hydrologic), 39 as secondary (short-term hydrologic), and 43 as serving water-management needs. Most of the stations were equipped with a combination of analog recorders and the new digital recorders. Most were driven by floats in a stilling well, but a few mercury manometer or "bubble gages" were being introduced. A large number of crest-stage stations were operated for the "highway program." Throughout the period, the District gave priority attention to measuring and documenting notable floods. The District made many indirect measurements at gaging stations and crest-stage sites, the results of which were reported with regular streamflow records.

Ground-Water Records.—The District reported 240 wells in the observation network in 1962, 83 of which were measured monthly and 157 were measured semiannually. Collection of information relevant to principal aquifers in specific locations and in support of active or planned ground-water investigations continued throughout the period. This information was generally open-filed and used as appropriate in subsequent maps and reports.

Water-Quality Records.—The District collected suspended-sediment data on a daily basis at 13 sites, less frequently but regularly at 3 sites, and infrequently at 3 sites during 1962. Stream chemical-quality data were collected daily at 11 sites, less frequently but periodically at 5 sites, and infrequently at 3 sites. Chemical quality was analyzed for wells and springs in connection with ground-water investigations.

### *Special Studies*

Among the special studies that were conducted, all or in part, within FY 1957–66 were the hydrologic studies in the vicinity of Glendo, by Welder and Weeks (WSP 1791, 1965) and in the Wheatland Flats area, by Weeks (WSP 1783, 1964). Ground-water investigations were made in National Parks and Monuments, including an analysis of the ground-water movement within Yellowstone and Grand Teton National Parks, by McCullough, Weeks, McGreevy, and Gordon (Circ. 494, 1964, and WSP 1475–F, 1966).

Investigations also included those of the geology and ground-water resources of Niobrara County, by Whitcomb (WSP 1788, 1965), of northern and central Johnson County, by Whitcomb, Cummings, and McCullough (WSP 1806, 1966), of Sheridan County, by Lowry and Cummings (WSP 1807, 1966); and of Laramie County, by Lowry and Crist (WSP 1834, 1967).

The scope of ground-water studies was shifted to larger areas and reconnaissances were then made of the ground-water resources of the Great Divide and Washakie Basins and some adjacent areas in southwestern Wyoming, by Welder and McGreevy (HA–219, 1966); of the Wind River Basin area, by Whitcomb and Lowry (HA–270, 1968); and of the Green River Basin in southwestern Wyoming, by Welder (HA–290, 1968).

A study of the magnitude and frequency of floods in Wyoming was made by Carter and Green (Circ. 478, 1963).

An administrative report on ground-water levels in the vicinity of Cheyenne by McGreevy, Lowry, and Gordon was submitted to the city of Cheyenne.

Other studies made or underway by the Wyoming District during this period included those of sedimentation and chemical quality of surface water in the Big Horn River Basin, regional ground-water flow in the Tensleep Sandstone in the Bighorn Basin, mining hydrology of trona deposits in the Green River Basin, chemical-quality reconnaissance of surface water in the Medicine Bow River Basin, statewide collection of geologic, geophysical, and hydrologic data, and a compilation of flood data east of the Continental Divide in the State.

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The U.S. Geological Survey, a bureau within the Department of the Interior and the Nation's largest earth-science agency, was established in 1879 following several federally sponsored, independent, natural-resource surveys of the West and Midwest. National interest in developing arid and semiarid lands resulted in the establishment in 1888 of the Irrigation Survey, the forerunner of the Water Resources Division, to study the availability of water for irrigation, sites for reservoirs, and artesian areas of the arid and semiarid lands of the United States. The Irrigation Survey was terminated in 1890, but streamflow measurements continued in a modest way until 1894, when Congress authorized the Geological Survey to gage streams and determine the water supply of the United States, including the investigation of ground water and artesian wells in arid and semiarid regions.