YEARS OF INCREASING COOPERATION (1919-1928)

Contents

FOREWORD

By Carl G. Paulsen

This volume of the History of the Water Resources Branch of the United States Geological Survey by Robert Follansbee covers the period from July 1, 1919, to June 30, 1928. In conformity with the practice followed in the first volume of the "History," Mr. Follansbee has named this volume "Years of Increasing Cooperation."

The manuscript for this volume has been reviewed editorially by N. C. Grover and M. C. Boyer. The sections pertaining to the Colorado River Compact and gaging stations on the lower Colorado River have been revised by G. C. Stevens. The sections describing the "two-table" and "tag-line" methods of sounding were also revised by Stevens and reviewed by B. J. Peterson. The previous volume dealt with the activities of the Geological Survey in water resources investigations from the beginning to June 30, 1919, and was privately printed in 1939. Mr. Follansbee completed the manuscript of the present volume at about that time and continued the preparation of the manuscript for succeeding volumes during the remaining years of his service and after his retirement in June 1949. The completed manuscripts covering the History to June 30, 1947, were sent to the Washington office late in 1949. During his later years in the service the "History" was Mr. Follansbee's major interest. Those of us who knew him and were also acquainted with the progress of water resources investigations will appreciate the enormous amount of work by Mr. Follansbee in research, correspondence, interviews, and note-keeping which made possible the preparation of the manuscripts.

March 1953.

A HISTORY OF THE WATER RESOURCES BRANCH

OF THE

UNITED STATES GEOLOGICAL SURVEY

VOLUME 2. - YEARS OF INCREASING COOPERATION

JULY 1, 1919 TO JUNE 30, 1928

By Robert Follansbee

INTRODUCTION

This period of the Branch history covers the activities in the 9-year period July 1, 1919, to June 30, 1928 when Congress adopted the policy of 50-50 cooperation with the States, after which both Federal and State appropriations were substantially increased. The reaction from the heavy expenditures during the World War resulted in a general reduction in Federal expenditures for civil work during the period, and caused a decrease in the annual Federal appropriations for the Branch from a high of $180,000 for the years 1921 to 1923, to a low of $147,000 for 1928. The decreases in Federal appropriations were, however, coincident with increases in State cooperative funds from $126,000 in 1919 to $340,000 in 1928. Within the period, the total of Federal (Survey) and State funds available for water investigational work was increased 77 per cent from $274,000 ($148,000 Federal and $126,000 State) in 1919 to $487,000 ($147,000 Federal and $340,000 State) in 1928.

The increase in cooperative State funds was brought about largely as a result of the growing demand for power, caused by the rapid increase in industrial activities during and following the war. Obviously, stream-flow records were essential to the development of water power which was encouraged by the passage of the Federal Water Power Act in 1920. 1/ The intimate relation between stream flow and the development of power by steam in those sections of the country where such development depended upon the amount of water available for condensers was a less obvious but important reason for stream-flow records. The needs for additional supplies of water for municipalities were

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1/ p. 95.

increasing in the more densely populated regions and the demand for water for process uses in industries was becoming more pressing in the industrial sections. These situations created a growing demand for stream-flow records. The need for information relative to dependable yields from ground water reservoirs for municipal, industrial, and agricultural uses was also increasing. The proposal to construct the Boulder Canyon reservoir accentuated the need for definite knowledge relative to the sediment content of the Colorado River. The opposing trends in Federal and State appropriations progressively increased the ratio of State to Survey funds, and caused the States to press Congress for recognition of the policy of 50-50 cooperation.

Passage of the Federal Water Power Act not only caused an increasing demand for stream-flow records as a result of the requirements of the permits and licenses issued thereunder, but also made available to the Survey considerable funds for additional work. 2/ The growing demand for power increased the interest in stream flow among companies that were not subject to the Act, and such companies contributed services or material for stream gaging, or in some instances furnished essentially complete records which were checked by the Survey for publication. The greater utilization of water brought about more contributions by Federal agencies, particularly by the State Department for gaging international streams on the Canadian and Mexican borders. The result of these activities was an increase of 96 per cent in total available funds from about $294,000 in 1919, to $577,000 in 1928. In addition, considerable sums not included in these figures were expended by cooperative interests under Branch supervision. The number of gaging stations was increased from 1,251 to 1,830, and the technical personnel from 86 to 131. The expansion of the stream-gaging program included the measurement of more of the large rivers of the country, particularly the lower Colorado River, thereby disproportionately increasing the funds utilized. New equipment and methods were divised to meet the needs of the new types of stations that were constructed on large rivers. In the ground-water investigations it was possible to increase very materially the use of the quantitative methods developed previously, and to develop a new method by using types of desert plants as indicative of ground water and as measures of recharge.

The great increase in the cost of living and the many opportunities for employment outside the government service caused many engineers to resign from the Survey, particularly during the early years of the period. Referring to this situation as it affected the Survey, Director Smith reported to the Secretary of the Interior: 3/

> In too much of the current discussion of the small salaries paid by the Government and the emphasis put on the

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2/ p. 52..
3/ 41st Ann. Rept., p. 10, 1920.

> injustice and hardship suffered by the employees has tended to conceal a larger issue -- the great harm wrought to the public service -- for during this period that has been marked by a failure to adjust salaries to living expenses the Government work may have suffered as much as the Government workers. *** The net result is a loss in efficiency out of all proportion to the false economy represented by the Government pay scale.

The following excerpt from the News Letter illustrates the impossibility of acquiring riches in the Government service: 4/

> We have just learned of an engineer who started poor 20 years ago and retired with a comfortable fortune of $50,000. This money was acquired through industry, economy, conscientious efforts to give full value, indomitable perseverance, and the death of an uncle who left the engineer $49,999.50.

The reclassification of salaries in 1923, 5/ which resulted in considerable increases in them and the enactment of the retirement act in 1921, 6/ served as partial offsets to the attractiveness of private employment. There were, therefore, relatively few resignations during the later years of the period.

GENERAL ORGANIZATION

Nathan C. Grover continued as chief of the Branch throughout the period. The organization in effect July 1, 1919, consisted of the Division of Surface Waters under J. C. Hoyt, the Division of Ground Water under O. E. Meinzer, the Division of Quality of Water under A. A. Chambers, the Division of Enlarged and Stock-raising Homesteads under Grover, and the Division of Power Resources under A.H. Horton. The Divisions of Surface Water, Ground Water, and Power Resources continued unchanged during the period, as did that of Quality of Water, except that Chambers was succeeded by C. H. Kidwell in 1919, who was in turn succeeded by W. D. Collins in 1920. The Division of Enlarged and Stock-raising Homesteads, the work of which was closely affiliated with that of the Land Classification Branch, became the Division of Land Classification Investigations in 1924 when most of the field work of classifying the public lands was taken over by the Land Classification Branch. Thereafter, the Division continued general water-power and irrigation studies with a greatly reduced personnel. A special investigation under the general supervision of the Branch was the Superpower Survey carried on for two years or less under a special appropriation by Congress.

4/ Apr. 24, 1920.
5/ p. 10.
6/ p. 13.

In contrast with the preceding period during which relatively few changes in personnel were made, the present period had many changes. By reason of the increase in living costs immediately following the war, delay by Congress in providing for reclassification, and the increases in salaries in non-governmental employment, brought about by the increase in engineering construction and other activities, the future in Survey employment looked relatively uninviting, and many resignations, especially among the younger men, occurred during the early years of the period. These conditions were felt also in varying degrees among the older men.

The successive increases in funds, that resulted largely from increased cooperation, in part with additional States, and the discontinuance of cooperation by a few States caused many changes in field assignments. Prior to the present period, Survey funds had not been available for transporting household goods and personal effects, and the engineers and geologists who were transferred had to pay the expenses of such transportation from their personal funds. In 1919 the Survey regulations provided for transporting not-to-exceed 5,000 pounds of household goods and personal effects and 300 pounds of scientific and professional books at Survey expense, if the engineer or geologist was making a permanent change in headquarters "for the good of the service". The authority for these regulations evidently did not rest originally on a specific authorizing Congressional Act, as the "First Deficiency Act, fiscal year 1928," had as Sec. 6 the following:

> Sec. 6. Appropriations for the fiscal years 1926, 1927, 1928 and 1929 available for expenses of travel of civilian officers and employees of the executive departments and establishments shall be available also for expenses of travel performed by them on transfer from one official station to another when authorized by the head of the department or establishment concerned in the order directing such transfer: Provided, that such expenses shall not be allowed for any transfer effected for the convenience of any officer or employee.

It is apparent that some controlling statute made this provision, by Congress, necessary, and that it was further necessary to extend the provision back to cover the fiscal years 1926 and 1927 and to clear the appropriation for the 1928 fiscal year and those which may have already been passed for the fiscal year 1929. 7/

The field offices of the Branch became gradually and naturally the recognized local sources of information concerning Survey activities and reports. There were many such offices, about 20 in 1919 increased to about 50 in 1939 and more than 100 in 1944, in comparison with the field offices of other Branches of the Survey, which combined probably did not exceed a dozen; they were relatively stable in location and in the service of senior personnel. The clerks were encouraged and trained to serve the inquiring public by making it their

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7/ Letter from Washington Office to author.

business to know what all Branches of the Survey were doing in the region, the names and addresses of Survey employees who were working in the State or a near-by State, what Survey maps had been issued, how and where they could be obtained, and what Survey reports related to the region had been issued and how they could be obtained. Four offices of the Branch in the West were developed into offices of distribution where certain Survey publications were available just as they were in Washington, thus removing in part the handicap of the West in obtaining Survey reports. These offices which were in Denver, 8/ Salt Lake City, San Francisco and Los Angeles, maintained not only small stocks of Water Supply Papers for distribution, but also fairly complete reference libraries of Survey publications which were open to and were largely utilized by that part of the local public which was interested in any phase of the Survey's activities. Other field offices of the Branch, although not offices of distribution, endeavored to maintain for public reference sets of Survey publications that were as nearly complete as practicable. Thus the field offices of the Branch, by service to the public, had gradually come to have far broader Survey values than ordinarily pertain to local headquarters, and that certainly were not clearly foreseen when the first local Branch offices were established.

APPROPRIATIONS

The reaction to war-time expenditures, which had resulted in a cut in the 1919 appropriation, 9/ had no effect during the early years of this period. The Wilson administration appears to have relaxed somewhat in its efforts for economy during its last year and the gaging streams appropriations for 1920 and 1921 were increased to $175,000 and $180,000, respectively. The appropriations for 1922 and 1923 were continued in the amount of $180,000 for each year. However, Federal expenditures again became a matter of serious concern by 1923 and the appropriation for 1924 was reduced to $170,000. The creation of the Bureau of the Budget on June 10, 1921, 10/ gave the President greater opportunity to influence Congressional appropriations in their making than he had formerly had, and in accordance with his desire to cut down public expenditures, Congress reduced the annual appropriations for the Branch from $170,000 for 1925 to $165,000 for 1926, $151,000 for 1927, and $147,000 for 1928. Many organizations, notably, American Engineering Council, the American Society of Civil Engineers, the Southern Appalachian Power Conference, and the Association of State Geologists, recognized the increasing need for greater appropriations for the Branch and repeatedly passed resolutions endorsing such increases. One of the most serious attempts to attain this end was a bill providing for an inventory by the Survey of the water resources of the country at an estimated cost of $400,000 for

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8/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to 1919, p. 275.

9/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 320.

10/ 42 Stat. 20.

the first year and $500,000 for each of 19 succeeding years. Such a bill was introduced in Congress by Congressman Newton during the years 1926 and 1927, but was never reported out of committee. This non-action may have been due to the fact that during those years Congress had instructed the Army Engineers and Federal Power Commission to prepare estimates for conducting a similar but more comprehensive inventory. 11/

Another attempt was made near the end of the period after the Mississippi River flood of 1927. Congressman Temple, on Feb. 17, 1928 introduced a bill providing for topographic mapping and stream gaging in the lower Mississippi River Valley, "and in such other areas as have an immediate bearing on the solution of flood problems of the Mississippi River Basin." The bill carried an appropriation of $2,800,000 of which $500,000 was for stream gaging. This bill was not acted upon.

Three changes affecting the net amounts available under annual appropriations appeared during these years, two decreasing such amounts and one increasing them. (1) The reclassification of salaries 12/ increased the salary roll of the Branch by some $20,000 annually. The first year that this was in effect Congress made a supplemental appropriation to cover the increase, but thereafter failed to do so. (2) Another new though relatively small charge against the appropriation resulted from an order by the Director of the Bureau of the Budget that as an economy measure not less than 2 per cent of the amount expended for salaries of permanent employees be reserved for return to the Treasury, beginning with the fiscal year 1927. This required the withholding of about $2,700 for each of the years 1927 and 1928. (3) For many years a portion of the general administrative expenses of the Survey had been charged to the appropriation for each Branch, as Congress did not provide adequately for such expenses. Beginning with the fiscal year 1927, however, the Bureau of the Budget set up a specific item for these administrative expenditures, relieving the Branch funds of an annual charge ranging from $16,000 to $18,000. Thus these changes were largely compensating.

Until 1922 the Survey items were carried in the annual Sundry Civil bill. Beginning with the year 1923 the Sundry Civil bill was abolished, all items for each department were segregated into that department's bill, and thereafter the Survey items were carried in an Interior Department bill. The language of the Branch item continued unchanged (except as to amount) until the bill for the fiscal year 1926 was written, when a limit was placed upon the amount that could be expended for services in the District of Columbia. There had been a rather wide-spread feeling in Congress that many government bureaus were too greatly centralized in Washington, and the limit was set in an effort to prevent that condition.

11/ p.
12/ p. 10.

During the remainder of the period, this limitation was as follows:

1926	$71,730
1927	61,000
1928	73,000

As the Branch was highly decentralized, it was not at first seriously affected by the limitations on District of Columbia.

Beginning with the fiscal year 1927 the Geological Survey was specifically authorized to perform scientific and technical work for other Federal agencies by a transfer of funds from such agencies to the Survey for that purpose. This was accomplished by the following language in various Acts:

> Provided, That any sums transferred by any department or independent establishment of the Government to the Geological Survey for cooperative work in connection with the appropriation may be expended in the same manner as sums appropriated herein may be expended.

The successive reductions in the annual appropriations were very disheartening to the personnel of the Branch and were the subject of earnest discussions at each conference. The various States were increasing their cooperative funds and the Survey was falling farther and farther short of meeting such cooperative funds on a 50-50 basis. This situation was keenly realized not only by Director Smith and the Chief of the Branch, but especially so by the district engineers who were at all times in close contact with the cooperating State officials. Finally the district engineers decided upon a "last ditch" measure at the conference held Oct. 17-22, 1927, which took the form of a direct appeal to the Director that he recommend in the 1929 item (shortly to be considered by Congress) an increase sufficient to meet State cooperation on a 50-50 basis. Following long-established precedent, a committee was appointed to present the appeal, consisting of Lamb, Glenn L. Parker, and the author. Director Smith was not only sympathetic to the appeal, but was already prepared to recommend such increase. He read to them the following extract from the recommendations which he had written for his annual report: 13/

> The financing of cooperative effort, however, should be more equitably divided between the State and Federal Governments in the gaging of streams, where the reasons for a dollar-for-dollar arrangement are similar to those now recognized and generally adopted in the topographic mapping.

This was the first time his annual report had contained such a recommendation, and it is fair to assume that his action at that time was due,

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13/ U. S. Geol. Survey, Forty-eighth Ann. Rept., P.1.

in part at least, to the vigorous protests by cooperating State officials and engineering organizations against the small ratio of Survey to State funds in the cooperative programs. The success of the Director's recommendation and the efforts of the cooperating State officials will appear in the history of the next period. 14/

COOPERATION

Cooperation by State and Federal organizations and by permittees and licensees of the Federal Power Commission and the contributions of materials and services by private interests increased so much during the years 1919 to 1928 that the period has been entitled by the writer the "Years of Increasing Cooperation." Although there were much greater increases in cooperative funds of all kinds in the next period, the increases during this period came at a time when Survey appropriations were being decreased, and so served to maintain and increase the work of the Branch, and to support its trained personnel and sustain its spirit to overcome all difficulties through a period that otherwise was very depressing. Increasing cooperation became, therefore, the outstanding characteristic of the period and properly gave it its name.

From 1913 to 1919, the average cooperation from all sources had been about $160,000 annually. The growing interest in water power and other aspects of the water resources caused an increase in State and Federal (non-Survey) cooperative funds to a combined total which was more than double that of the previous period, as shown by the following tabulation:

1920	$191,665	1923	$253,175	1926	$340,275
1921	214,035	1924	324,610	1927	335,556
1922	248,754	1925	343,282	1928	427,907

These totals do not include some relatively small amounts paid by Federal agencies for minor cooperative investigations by the Ground Water Division. To these State and Federal cooperative funds should be added an average annual figure of about $135,000 contributed by permittees and licensees of the Federal Power Commission during the years 1922 to 1928 and an unknown, though very substantial amount represented by the records furnished in whole or in part by other private interests, in order to obtain a full measure of the cost of work done by or under the supervision of the Branch.

By the end of the period the total of the annual (non-Survey) cooperative funds was more than three times that of the Survey's appropriation.

A concise explanation of cooperative financing may serve to clarify the statements on the following pages with respect to the funds of various kinds utilized by the Branch or by other organizations in connection with the study of water resources. Congress recognized cooperation between

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14/ P.

the Survey and States or municipalities in the financing of water studies to which both parties contribute. There were, therefore, in this period Survey cooperative funds as well as State and municipal cooperative funds, and in the history of the next period it will appear that Congress set up a part of the gaging-streams item to be available only for cooperation with States and municipalities and also set a limit on the ratio of Survey to State or municipal participation in cooperative financing, thereby recognizing in the law that a part of each annual appropriation is a Survey cooperative fund. There appear statements, therefore, of Survey (Federal) and of State and municipal cooperative funds and expenditures that relate to such cooperative financing on a ratio basis.

Many Federal bureaus call upon the Survey to make specific investigations of the quantity, chemical quality or availability of surface or ground water in connection with specific problems or projects. In general, Survey funds have not been available in sufficient amounts for such additional work and the bureau requesting the investigation has paid all or a major part of the costs by transfer of funds or by reimbursement. Such funds, which may be referred to herein as Federal cooperative funds, should not be confused with the Survey cooperative funds that relate to cooperation with States and municipalities and that are also Federal funds. In connection with work performed for other Federal bureaus there is no principle of matching involved and the financing is arranged in each instance on the basis of availability of the funds in the Survey or in the bureau concerned.

Because water-power companies, irrigation companies or organizations, and other non-governmental agencies are interested in the collection of information with respect to water, such agencies have contributed to the accomplishment of the work, either by paying directly some of the costs such as gage readers' salaries, construction of gaging stations or certain features of them, or by contributing funds for expenditure by a non-Federal governmental unit such as a State or city. Such contributions may be loosely and incorrectly referred to as private cooperation. There is, however, no matching of funds or cooperation in that sense except in those instances where a State or municipality may add such contributed funds to its regularly appropriated funds. Assistance from such private sources is more properly referred to as "contributed" rather than as "cooperative".

Finally, the Federal Power Commission requires its permittees and licensees to perform such stream gaging as may be needed for a proper evaluation of the projects or for the assessment of charges. In order to be assured as to the reliability of the records, the Commission requires that this work shall be done by or under the supervision of the Survey. As a result, the permittees or licensees of the Commission may do the stream gaging under Survey supervision, paying all costs directly, or they may pay the Survey to do the work by advance of funds.

RECLASSIFICATION OF SALARIES

The inequalities in salaries paid for work in different units of the Federal service became so great during and immediately after the World War that Congress finally took cognizance of the situation. The inequalities had been increasing during the previous quarter of a century, with the gradual growth of lump-sum appropriations made for governmental activities organized during that period. Many of the older organizations had their salary rates set by statute, and while the rates were perhaps adequate when they were set many years previously, the increased cost of living had made them relatively too low in the succeeding years. Such salaries could only be changed by statute and generally such action had not been taken. On the other hand, activities that were begun later were generally supported by lump-sum appropriations under which the salaries were set by the administrative offices of the activity itself at higher rates than the long-standing statutory salaries, and they could be and were increased from time to time by the same administrative authorities. The Survey was fortunately in the latter class. War requirements had brought new organizations into existence and had practically doubled the number of civilian employees, which organizations with their relatively large lump-sum appropriations, were able to, and did, pay salaries that were still higher than those paid to the older organizations that were supported by lump-sum appropriations. Not only did these war-time activities pay the higher salaries of the period, but in an endeavor to keep down all expenses that were not directly connected with war activities Congress refused during the war to increase the salaries paid in the older organizations. There was a rather wide-spread attitude in Congress that the failure to receive increases should be looked upon as a sacrifice which the civilian employees should be glad to make as a contribution to the financing of the war. 15/ So high was the cost of living after the war that Congress was forced to continue the temporary expedient of voting salary bonuses which was started in 1917. 16/ In recognition of the higher rates paid by the war-time activities, the bonus did not apply in organizations created after July 1, 1916. For the fiscal year 1920 the bonus rate was increased from $120 to $240. This make-shift procedure shows clearly that the Government had adopted no definite policy with respect to employment and compensation. The rapid increase in the cost of living during and after the war and the great opportunity for outside employment immediately following the war caused many resignations, and finally focused the attention of Congress on the situation. As a result Congress passed an act, approved Mar. 1, 1919, creating a Joint Commission on Reclassification of Salaries, composed of members of both the Senate and the House, charged with the duty of reporting what readjustment of compensation should be made to provide uniform and adequate pay for the different

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15/ A personnel program for the federal Civil Service. H. D. 773, 71st. Cong. 3d Sess.

16/ Follansbee, Robt. Hist. of Water Res. Br., to June 30, 1919, p. 319.

classes of employment within the District of Columbia. The need for readjustment was greater in Washington than in the field, and, besides, by attacking the worst situation first Congress began its studies where the necessary facts on which to base legislation could be obtained more quickly and with less effort than in the scattered and varied field services. As an illustration of the increase in living costs in Washington the News Letter for June 23, 1919, presented diagrams showing that the cost of living had increased 78 percent between 1910 and 1918.

The Joint Commission sent questionnaires to the 100,000 employees in Washington, asking each employee to write his own description of his duties. The multiplicity of duties performed by various employees and the task of combining these duties into classes and grades is shown by the following statement in the Joint Commission's report to Congress: 17/

> The members of your Commission never fully appreciated the limitations of the human intellect until they undertook to agree on uniform and equitable pay for more than 1,700 different kinds of jobs.

The Commission did, however, succeed in reducing the 1,700 jobs to a rational classification and made an 884-page report to Congress in March 1920, recommending that the proposed classification be enacted into law effective July 1, 1920.

Evidently the "limitation of the human intellect" was recognized in Congress as the latter found it impracticable to review the 884-page report submitted 18/ and a number of attempts were made in Congress to simplify the original classifications. A number of bills classifying the civilian service were introduced during the next three years and out of these grew the classification act of 1923, 19/ which was approved Mar. 4, 1923, in the closing hours of the 67th Congress, just as the Geological Survey itself had been created in the closing hours of another Congress. 20/ The classification and rates of pay applied only to positions in Washington, but provision was made for a survey of the field services and a report thereon to Congress at its next regular session.

This report was made, and on Dec. 6, 1924, Congress passed an act making an additional appropriation for the fiscal year 1925 to enable the Departments and independent establishments to adjust the rates of pay in the field services as nearly as practicable in accordance with the classification act of 1923. As this adjustment had previously been made on July 1, 1924, it is evident that Congress had authorized the extension of reclassification to the field services and provided the funds needed for its accomplishment five months after the date set by the enabling act.

17/ H.D. 686, 66th Cong., 2nd Sess.

18/ Rept. Senate Comm. on Reclassification of Civil Service Employees, Feb. 3, 1922.

19/ 40 Stat. pt. 1, 1487.

20/ Follansbee, Robt., History of Water Resources Br. to June 30, 1919, p. 24.

The Bureau of the Budget in preparing estimates for the previous fiscal year, 1924, had proceeded on the basis that the reclassification would be extended to the field services.

The classification act was designed to equalize salaries rather than to raise them generally. As the equalization was generally upward, the net result was that the average salary was raised about 10 per cent, the newer organizations benefitting less than the older.

After the classification act had been in effect a few years, inequalities inevitably appeared, resulting in dissatisfaction on the part of a considerable number of government employees. To iron out these inequalities, Congress passed the Welch Act, approved May 28, 1928. 21/ That the reclassification of salaries had not formally been extended to the field service is shown by the fact that the Welch Act again contained the proviso that a survey of the field services should be made and a report submitted to Congress. This mandate was obeyed, but to this day (1939) Congress has not actually approved it. One reason for this delay is the matter of differential in cost of living in various parts of the country, which Congress has been reluctant to recognize by varying salaries for the same grades of work to offset this differential.

Before the reclassification acts became effective the only engineering grades were junior engineer, assistant engineer, and engineer. In 1916 the salary ranges for these grades were: $1,000 - $1,300, $1,380 - $2,000, and $2,400 - $3,000, respectively. Due to the increased cost of living caused by the war and its aftermath, the salaries for these grades were gradually increased until in 1923 they were: $1,600 - $1,800, $1,800 - $3,000, and $3,000 - upward.

Under the classification act of 1923 the rates for professional services were: junior engineer, $1,860 - $2,400; assistant engineer, $2,400 - $3,000; associate engineer, $3,000 - $3,600; engineer, $3,800 - $5,000; senior engineer, $5,200 - $6,000; and chief engineer $6,000 - $7,500. Inequalities still existed, and to correct these so far as possible, the Welch Act of 1928 was enacted which gave the following rates: junior engineer, $2,000 - $2,500; assistant engineer, $2,600 - $3,100; associate engineer, $3,200 - $3,700; engineer, $3,800 - $4,400; senior engineer, $4,600 - $5,200; principal engineer, $5,600 - $6,400; and a higher grade, designated in the act as Grade 7, $6,500 - $7,500.

After the passage of the Welch Act inequalities still existed in certain grades and to remove these the Brookhart Act was enacted in 1930. By its terms the rates for professional services were: junior engineer, $2,000 - $2,600; assistant engineer, $2,600 - $3,200; associate engineer, $3,200 - $3,800; engineer, $3,800 - $4,600; senior engineer, $4,600 - $5,400.

21/ 45 Stat. 776.

RETIREMENT ACT

A solution of the problem of the aged employees was equally as important to an efficient civil service, as was an equalization of salaries for substantially similar duties and responsibilities. The studies of the Joint Commission on Reclassification of Salaries showed the great need for a system of retirement. There was in effect a most expensive civil pension system whereby employees were retained in office after they had passed their usefulness. To quote the Commission: [22]

> Thousands of superannuates encumber the payrolls and reduce the morale of the departments. Some are brought to their desks in wheeled chairs, and in one case an employee frankly told your commissioner that he had no duties because he was blind. Of course, no administrative officer has been found heartless enough to dismiss these faithful servants from the positions they occupy.

The Commission went on to state that the salaries of these superannuates amounted to much more than a generous retirement system would cost, to say nothing of the decreased efficiency resulting from their presence. It recommended the immediate enactment of an actuarially sound retirement law.

The problem of the aged employees was one of long standing, particularly in the older bureaus, and about 1912 an organization of employees urged Congress to pass a retirement act. Congress was so unsympathetic to the idea that in retaliation a member introduced a bill which would limit all civil service employment to a seven-year tenure, unless qualified by reexamination. A threat of the passage of that bill cooled the ardor of the employee advocates of retirement and nothing came of their efforts. However, one or more bills were introduced afterwards but these likewise failed of passage.

When the Joint Commission on Reclassification of Salaries made its report in 1920 the problem had become so acute and was so closely related to efficiency in the civil service that Congress, on May 22, 1920, within two months of the Commission's report, passed a retirement act whereby employees paid into a retirement fund $2\frac{1}{2}$ percent of their salaries [23] and were retired at 70 years of age. The government agreed to pay the additional amount necessary to retire all civil employees on a sliding pension scale having a top limit of $720 annually.

The retirement act was amended on July 3, 1926, to increase the employee contribution to $3\frac{1}{2}$ percent and the maximum pension to $1,000. It was later found that in many instances employees within a short time of their retirement, resigned and withdrew their contribution to the

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22/ H. D. 686, 66th Cong. 2nd Sess.

23/ 41 Stat. 614

retirement fund with the interest at 4 percent which it had drawn. The purpose of this action was to purchase an annuity larger than the Government pension. If this procedure were followed generally the pension fund would be depleted so seriously that greatly increased Federal appropriations would be required. To remedy this situation the retirement act was again amended on May 29, 1930. By this amended act 24/ the pension consisted of two parts - one, a maximum of $900 per annum which the Government paid at the rate of $30 per year for each year of service up to 30 years, and the other, the amount of the annuity purchasable by the amount standing to each employee's account under the provision outlined. If the combined pension was less than $1,200 annually, the Government increased it to that amount, which was considered the minimum pension for those who were retired at 70 years of age after 30 years of service.

The first member of the Branch to be retired was E. C. Murphy whose retirement was effective Oct. 16, 1926.

DIVISION OF SURFACE WATER

Washington Office

At the beginning of the period, G. C. Stevens was in charge of the Computing Section and was ex-officio district engineer of the Middle Atlantic States. Requests for special data that required much of Steven's time for preparing answers gradually became so numerous that on July 1, 1921, A. H. Horton, in charge of the Division of Power Resources, took over also the district-engineership of the Middle Atlantic States district.

The many requests for special data left Stevens little or no time for preparing records for publication in the annual reports, and on Jan. 1, 1924, the Computing Section was divided into the Section of Investigations under Stevens, the Section of Reports under B. J. Peterson who had been Stevens' principal assistant, and the Section of Instrument Design under C. H. Au. Mr. Au had been employed on a full-time basis since Oct. 1, 1920 in the Survey's Division of Scientific and Technical Equipment, which later became the Section of Field Equipment. He was transferred to the Branch on Mar. 1, 1921.

The Section of Reports continued the review and preparation of records for publication in the annual reports, and engineers from several districts were detailed to Washington during each winter to assist. In addition, B. L. Bigwood was assigned to the section from December 1919 to February 1924; O. D. Mussey, October 1923 to March 1926; D. S. Wallace, February 1923 to June 1923 and June 1926 to June 1927; J. W. Mangan, March 1926 to May 1927; and W. C. Wiggins, December 1923 to March 1925. Marion Walters, who had been in the section since the early days of the Water Resources Branch, resigned July 1, 1920.

24/ 46 Pt. I, Stat. 468.

Au's work in the Section of Instrument Design, which was guided largely by the needs of the field engineers as expressed by the district engineers at the various periodic conferences and by continuing correspondence, was supervised directly by J. C. Hoyt who was always striving to raise the standards of facilities for field work.

Willis E. Hall continued as chief clerk until his death, Mar. 13, 1925. He was succeeded by Miss Marian J. Dickman who was "acting" until she was appointed Branch chief clerk on Apr. 1, 1926.

Field

During this period there were many changes both in district engineer personnel and in district boundaries. G. K. Larrison resigned in June 1919 at the close of the previous period, C. C. Covert in 1922, Warren E. Hall, R. C. Rice, and E. L. Williams in 1923, and C. H. Pierce in 1925. F. F. Henshaw was transferred to the Federal Power Commission in 1928. Covert, Hall, and Henshaw were "old timers," having been connected with the Survey since the days of the Hydrographic Branch.

The successive increases in funds, due largely to cooperative appropriations for stream gaging by additional States and the discontinuance of cooperation by a few States that had previously made such appropriations, caused many changes in districts and district boundaries. Just at the close of the previous period, the Pennsylvania district was created, but was discontinued in 1921. The South Atlantic States district was divided into the North Carolina (1921) and Tennessee (1920) districts. Illinois became a separate district in 1919, Iowa in 1920, and Arizona in 1921. The New Jersey, Ohio, and Missouri districts were created in 1921. Virginia became a subdivision of the Middle Atlantic States district in 1925 and was made a district in 1926. The Iowa and Kansas districts were closed in 1927 because of discontinuance of cooperation.

State Cooperation

State cooperative funds were increased from $126,312 in 1919 to $320,558 in 1928. Apparently a principal cause of the increase was the interest in water-power development aroused by the expanding needs of industry for power following the war. An awakened interest by a number of States in the value of their water resources was another important cause. As a result, cooperation was started with ten additional States, most of which made substantial appropriations for stream-gaging. On the other hand, lack of interest resulted in the discontinuance of cooperation by seven States, each of which had previously contributed only a few hundred dollars annually.

The following table shows, by sections of the country, the amount of State cooperation in the first and last years of the period, - the percentages of the total in the eastern and southern, central and western

sections (including Hawaii). Note that all sections of the country increased their cooperative funds, the greatest increase in amount being in the west, though in the percentage of the total there was a decrease in the western section.

State cooperative funds in 1920 and 1928

Sect.	1920 Amt.	Perc. of Total	1928 Amt.	Incr. in Amt.	Perc. Incr.	Perc. of Total
East. & Southern	$25,080 1/	17	$90,863	$65,783	252	28
Central	12,860	9	49,836	36,976	290	16
Western	105,940	74	179,859	73,919	70	56
Total	$143,880 1/	100	$320,558	176,678		100

1/ Exclusive of Pennsylvania cooperation which lasted only two years.

These amounts represent cooperation with the Surface Water Division only.

The increase in the Central section came largely from cooperation by Ohio, which started in 1921 and yielded $30,117 in 1928. Without this cooperation there would have been only a slight increase in State cooperative funds in that section, indicating that except for Ohio the central states had not then increased substantially in water-consciousness. In general, it may be stated that water power was the dominant factor in cooperation in the eastern and southern states, and irrigation in the western states, although water power was important there also. In the central states the factors were water power, flood prevention, drainage, and navigation.

At the end of the period, 31 states were cooperating in surface-water investigations.

In 11 of the States, the cooperating agencies were changed,- in five as a result of general reorganizations of the State governments to reduce the number of departments, and in six by the creation of new agencies or by transfers to existing agencies for various reasons.

The annual expenditures from State cooperative funds were:

1920	$169,660	1923	$207,562	1926	$291,902
1921	174,855	1924	273,169	1927	283,045
1922	214,568	1925	306,429	1928	320,558

In addition to the cooperation indicated by these figures several States and municipalities contributed complete records, increasing from 40 in 1920 to 75 in 1928.

The details of cooperation with each State follow.

Maine.- Cooperation was continued with the Water Power Commission of Maine until it was abolished in 1923 as the result of a "pocket veto" by the Governor who disapproved the Commission's opposition to State development of water power. The Governor realized, however, the necessity for continuing stream gaging and provided funds for that purpose from his contingent fund until the next session of the legislature. At the 1925 session the legislature empowered the Public Utilities Commission to cooperate with the Survey in the water-resources investigations and thereafter provided funds for that purpose.

The annual expenditures of State cooperative funds were:

1920	$4,290	1923	$4,233	1926	$5,107
1921	4,435	1924	5,107	1927	5,215
1922	4,330	1925	5,278	1928	6,114

The flood of May 1923, the severest of record on the Penobscot River, increased the interest in the State's streams, and possibly the apprehension with respect to the practicability of their control, and resulted in somewhat greater appropriations beginning with the fiscal year 1924. Similarly, the widespread 1927 floods were followed by a larger appropriation for the next year.

The Survey allotments were:

1920	$ 850	1923	$1,000
1921	1,000	1924	1,000
1922	1,000	1925	600

The allotments for the New England district were not segregated by States after 1925.

New Hampshire.- The Commission on Water Conservation and Water Power of New Hampshire, with which cooperation had been started in 1917, was a temporary body created to study the possibilities of developing water power and water storage. Its work was completed in 1920, and when the 1921 legislature made an appropriation of $3,000 25/

25/ Chap. 189

for continuing cooperation with the Survey during the biennium, the Public Service Commission was designated as the cooperating agency of the State. In its report for 1922, the Commission stated: 26/

26/ Vol. 12, p. 17

> Beyond question this work is of great public benefit and in order that it may be continued we recommend that a similar appropriation (for the next biennium) be made.

That report contained a summary of all stream-flow records to date. State cooperation continued during the period, and the following expenditures were made from the amounts allotted by the State:

1920	$1,560	1923	$1,306	1926	$1,682
1921	1,400	1924	1,808	1927	1,395
1922	1,450	1925	1,161	1928	2,410

Water power was the chief interest in the State's streams until the New England flood of November 1927 aroused the people to the flood menace and the problems related to flood control. An increase in the State appropriation followed in 1928.

The Survey allotments were:

1920	$1,000	1922	$1,500	1924	$1,500
1921	1,500	1923	1,500	1925	1,500

The allotments for the New England district were not segregated by States after 1925.

Vermont.- Vermont's interest in water power, which had been aroused in 1913 when cooperation was begun, continued during the early years of the period. Never very strong, this interest gradually subsided and beginning with the fiscal year 1924 the State ceased its appropriation for cooperative stream gaging. The severe floods during the fall of 1927, however, showed the menace of the uncontrolled streams and the Governor called a special session of the legislature which appropriated a considerable amount for rehabilitation work. Of this appropriation $16,000, together with another $16,000 contributed by the utilities of the State, was allotted to the State flood-control committee for the preparation of a report on flood control. That committee made an allotment for cooperation with the Survey. The chairman of the flood-control committee was also the chairman of the Public Service Commission, and this Commission became the cooperating State agency. During the remainder of the fiscal year 1928 the Survey's work was limited essentially to the collection of field data for the computation of the 1927 flood discharges, and the preparation of a report on that flood, published as Water-Supply Paper 636c.

The State cooperative expenditures and Survey allotments during the period of cooperation were:

Year	State	Survey
1920	$1,060	$ 900
1921	1,270	1,000
1922	1,130	1,000
1923	1,200	1,000
1924		1,000
1925		500
1928	2,596	

The allotments for the New England district were not segregated by States after 1925.

Massachusetts.- Cooperation with Massachusetts was continued through the Department of Public Works and in the fiscal year 1928 cooperation was also effected through another State agency, the

Metropolitan District Water Supply Commission, which, about 1926, began the construction of works to divert water from the Connecticut River to the metropolitan area. As opposition to the proposed diversion developed in the State of Connecticut, the Commission decided that records of flow should be obtained at four points where there were no gaging stations. The Commission asked for Survey cooperation and made an allotment for that purpose.

The annual expenditures from State cooperative funds were:

Year	Dept. Public Works	Year	Dept. Public Works	Met. Dist.	Total
1920	$2,450	1925	$3,197		$3,197
1921	2,970	1926	3,899		3,899
1922	3,200	1927	3,801		3,801
1923	2,877	1928	4,323	$1,000	5,323
1924	3,060				

The increase beginning in 1926 was due chiefly to need for rebuilding recorder stations.

The Survey allotments were:

1920	$2,125	1923	$2,500
1921	2,500	1924	2,500
1922	2,500	1925	2,500

The allotments for the New England district were not segregated by States after 1925.

Connecticut.- In 1919 the State Board of Health of Connecticut was engaged in a special study of pollution and had established several gaging stations equipped with pressure-type gages. The records obtained were not satisfactory and the sanitary engineer in charge of that work asked C. H. Pierce for advice. This led to cooperation with the Survey that lasted from the fall of 1919 to June 30, 1921, when the special study was completed. Four of the stations established by the Board of Health were maintained under the cooperative agreement, and two others were established, making a total of six State cooperative stations in operation during those years. The expenditures from State funds were $1,005 in 1920, and $365 in 1921.

Questions related to water supplies available for municipal use led the General Assembly in 1925[27] to authorize the State Geological

[27] Special Act of 1925, Chap. 240.

and Natural History Survey to report to the next session of the Assembly on the water resources of the State. R. H. Suttie, a member of the engineering faculty of Yale University, who had been a member of the New England district's personnel in 1918-19, was selected to prepare the report which contained, among other matter, a compilation of all precipitation and run-off records for Connecticut. It was

presented to the Governor for transmission to the 1927 session of the General Assembly with the recommendation that a cooperative arrangement be made with the United States Geological Survey for the purpose of collecting systematic stream-flow records over a period of years. 28/

28/ State Geol. & Nat. Hist. Survey Bull. 44, p. 14.

At this time the Massachusetts Metropolitan District was preparing to divert water out of the Connecticut River Basin; the State of Connecticut feared the effects of such diversions and realized the necessity for complete information regarding the discharges of State streams. 29/ Accordingly, the General Assembly made an appropriation

29/ Letter from Prof. R. H. Suttie.

for cooperation with the Survey, and as there was no State department specifically charged with supervision of the State's waters, the Governor became the cooperating official. State expenditures during 1928 were $1,359. The Survey allotment for the New England district was not segregated by States.

New York.- In New York, cooperation with both the State engineer and the Conservation Commission continued through 1921. In 1921 the Governor recommended that, in the interest of efficiency and economy, all engineering work of the State be performed by the State engineer's office, and the legislature enacted laws transferring to that office various organizations that had engineering functions, including the Division of Waters in the Conservation Commission, effective July 1, 1921. 30/ Thereafter the State engineer became the only cooperating

30/ Rept. State engineer for year ending June 30, 1921, p. 27.

State official. In the last year before the change the total State cooperative expenditures were $16,340, and during the next three years the annual expenditures were reduced to a low point of $10,755, indicating, perhaps, that economy then outweighed the State's interest in its water resources. During the following years, however, interest in water power became relatively stronger and the cooperative expenditures were gradually increased to $15,680 in 1927. During that year the State government was reorganized along the lines of the Federal government and some 70 or more bureaus were merged into 18 departments. The office of State engineer was abolished, and the duties of that office were transferred to the Department of Public Works.

The annual State cooperative expenditures during the period were:

Year	State engineer	Conservation Commission	Department of Public Works	Total
1920	$ 2,500	$ 9,995		$12,495
1921	3,995	12,345		16,340
1922	13,330 1/			13,330
1923	10,755 1/			10,755
1924	11,085 1/			11,085
1925	15,492 1/			15,492
1926	15,576 1/			15,576
1927	17,680 1/			17,680
1928			$17,566	17,566

1/ Including small amounts of municipal cooperative funds.

The Survey allotments were:

1920	$4,975	1923	$5,500	1926	$4,500
1921	6,000	1924	5,500	1927	4,225
1922	5,500	1925	4,500	1928	3,400

New Jersey.- The study of the water supply of New Jersey made in 1894 by C. C. Vermuele, the State geologist, although based largely on precipitation records, had furnished what was long regarded as adequate information, and the people of the State, believing that there was sufficient water for municipal and industrial uses, were not water-minded. However, by 1906, the growth in population and industry had brought about conditions that led to a realization of the necessity for protecting the surface waters from contamination and the 1906 legislature created a commission to investigate the practicability and probable cost to the State of acquiring title to its potable waters. As a result of that Commission's report, 31/ the State Water-Supply

31/ Report of Commission to General Assembly, 1907.

Commission was created in 1907, and was charged with general supervision of all the sources of potable and public water supply in order that they might be economically and prudently developed for the use of the people of the State. 32/ After the creation of the Commission,

32/ Chap. 252, P.L. 1907, p. 633.

a small fee for additional diversions was charged to provide funds for the administration of the law.

In 1915 the State Water-Supply Commission was consolidated with other State organizations in the Department of Conservation and Development. 33/

33/ Chap. 241, P.L. 1915, p. 426.

In 1917, H. T. Critchlow was appointed engineer in charge of the Division of Waters in the Department. He had had experience in

stream gaging, both in Panama and in the Survey, 34/ and realized the

34/ p.

necessity for measuring the streams. In 1919, he reopened two of the stations discontinued by the Survey in 1906 and established two new ones, together with about 20 stations at which gage heights only were obtained. In order to obtain funds for any expansion of this work it was necessary for Critchlow to educate his superiors, and the simplest way was to show them just what was involved in the maintenance of gaging stations. He therefore took his "bosses" to the stations and not only explained the process of stream gaging, but made current-meter measurements in their presence.35/ His efforts were apparently

35/ Statement to author.

successful as the next session of the legislature appropriated funds for stream gaging. The legislature was willing to make this appropriation since the money did not come from the general funds, but from the fees collected by the Commission and segregated for its use. Critchlow then asked the Survey's permission to reopen the old Survey stations. Instead, however, cooperation was arranged and a district was established in New Jersey.

Cooperation continued during the remainder of the period and the State cooperative expenditures and Survey allotments were:

Year	State	Survey
1922	$11,550 1/	$1,500
1923	11,100	3,000
1924	9,354	3,000
1925	11,089	2,900
1926	11,797	3,000
1927	11,249	2,325
1928	11,674	2,500

1/ Includes $365 municipal cooperation.

Pennsylvania.- Cooperation was in effect in Pennsylvania during only about two years of this period. The State Water Supply Commission had carried on its own stream-gaging program since 1906.36/ Doubts

36/ Follansbee, Robt., Hist. of Water Resources Br. to June 30, 1919, p. 266.

as to the accuracy of certain of the records had arisen in the Commission and during the winter of 1918-19 it requested Covert who was maintaining a number of gaging stations in New York on streams flowing into Pennsylvania, to review the Pennsylvania records. He referred the request to the Washington office and B. J. Peterson went to Harrisburg in April 1919 to inspect records and methods. As a result, cooperation was arranged whereby Peterson was detailed to

the Commission to apply Survey standards in the computation of the records. He did not, however, supervise the field work. This detail lasted until the latter part of November. By that time the Commission wished to apply Survey methods and standards to the field also, and arranged for the Survey to detail an engineer to the Commission who would be paid by the State, would supervise both field and office work, and, in effect, be the district engineer. O. W. Hartwell was so detailed in November 1919. About 16 months later, in March 1921, the Chief Hydraulic Engineer advised the Commission that the Survey could increase its allotment for the next fiscal year from the $200 then being allotted to not less than $1,000 provided the Commission would cooperate in the usual manner whereby the Survey would appoint the employees in the U. S. Civil Service so far as practicable, and have direct supervision over them. The Commission was unwilling to make such an arrangement, particularly as its own contribution to the stream-gaging program was about $20,000 annually, and Hartwell's detail was terminated in June 1921. During the two-year period of cooperation the expenditures from State cooperative funds were $25,780 during 1920, and $19,420 during 1921.

Maryland.- In 1924 the State Board of Health of Maryland began a study of pollution in the upper part of the Potomac River Basin and as this required the establishment and operation of several additional gaging stations, the State geologist arranged cooperation with the Survey and financed the State's obligations, in part, by contributions from several private organizations interested in the study, which supplied him with the following amounts, used chiefly for paying gage observers:

1925	$ 84	1927	$433
1926	169	1928	130

A small amount of cooperation with cities was also in effect.

Virginia.- The depression in agriculture following the World War was severely felt in Virginia which is chiefly an agricultural State, and the need for additional sources of revenue from industry was acute. The success of the efforts of neighboring States in attracting new industries by means of their water-power resources suggested a similar effort in Virginia. Accordingly, in March 1924 the legislature, under the leadership of J. R. Horsley, Speaker of the House, created the Water Power and Development Commission for investigating the water power, industrial, and agricultural interests and resources of the State. 37/ To the Virginia Geological Survey was assigned the

37/ Chap. 359 (H.B. 290)

duty of making a survey of the water-power resources. In this survey, which was the only part of the investigation with which this History is concerned, the State Geological Survey was authorized to cooperate with the Federal government whenever satisfactory arrangements could be made.

About $4,000 was available to the State Survey for the purpose and Albert W. Giles, acting State geologist, came to Washington in the

fall of 1924 to discuss with A. H. Horton the possibilities of cooperation. A conference was held later in Norfolk with J. R. Horsley, then director of the Water Power and Development Commission, at which cooperation was arranged. As the headquarters of the State Geological Survey, the State cooperating agency, were at the University of Virginia in Charlottesville, and as this was a reasonably central point from which to conduct State-wide field work, A. H. Horton established a sub-office in the Brooks Museum Building on the campus on February 21, 1925, with J. J. Dirzulaitis, his principal assistant, in local charge.

During the next year the State geologist, Dr. Wilbur A. Nelson, set out to educate the people of the State as to the value of their water resources, and one means employed was a question and answer column which he conducted in the Sunday issue of the Richmond Times-Dispatch. From one to three questions and answers on the State's water resources were furnished by Dirzulaitis and published each week.

The following year Governor Byrd proposed a general reorganization of the State government, and accordingly the legislature, in March 1926, consolidated several organizations, including the Water Power and Development Commission and the State Geological Survey into the State Commission on Conservation and Development. Among the duties of the new Commission was that defined in Section 528:

> It shall be the duty of said commission to make or cause to be made a careful investigation of the streams and navigable rivers within and bordering upon the State, of the methods, means and cost of improving the same; of preventing their pollution; of conserving the water supply thereof; of using the same for the production of power, and how and in what ways the said streams and rivers may be made of most value to the State and to the people thereof.

So successful was Nelson's campaign of education that the legislature appropriated $30,000 for the next biennium for carrying out the duties described in this section. With the large increase in State funds Virginia was made a separate district on March 1, 1926, with Dirzulaitis as district engineer. The State cooperative funds spent during this period were:

1925	$ 4,138	1927	$14,099
1926	10,340	1928	16,824

During 1925 and 1926 the Survey allotment was included in that for the Middle Atlantic States, but for 1927 it was $2,325 and for 1928, $2,500.

North Carolina.- At about the beginning of this period, Thorndyke Saville became hydraulic engineer of the North Carolina Geological and Economic Survey, whose director was Col. Joseph Hyde Pratt. At this time water power was an important factor in the State's development and Saville, who was an enthusiastic believer in North Carolina's water-power possibilities, called upon Warren E. Hall, then district engineer in the South Atlantic States district,

for all available records of North Carolina streams. When Saville discovered that these records were all old, as little or no work had been done in the State since the Survey discontinued activities there in 1909, he wished to resume the work and, on behalf of the State, offered cooperation provided the Survey would establish a district office in North Carolina. As no other State in the district was cooperating in any considerable amount, it was decided to move the district office to North Carolina from Atlanta where it had been since work was first started in 1894. The change was made in January 1921 when the new district office was opened at Asheville, in the heart of the power region of the State, which the local Chamber of Commerce and other promoters called "The Land of the Sky."

Not only was interest in water power increasing, but with the rapid industrial development, many industrial plants and small cities were seriously polluting the streams of the States. The streams are subject to wide extremes in flow, having high floods and very low minimum discharges, and many cities were, therefore, seeking additional sources of supply either from larger streams or by constructing storage reservoirs on the streams from which they were already taking their supplies. Thus, as North Carolina became progressively more water-minded, the legislature gradually increased the funds of the State survey. In 1925 the State government was reorganized and the duties of the Geological and Economic Survey were taken over by the newly-created Department of Conservation and Development. Saville continued as chief hydraulic engineer of the new organization, and as the State's cooperating official.

Expenditures of State and municipal cooperative funds were:

	State	Municipal	Total
1920	$ 415		$ 415
1921	2,315		2,315
1922	4,140		4,140
1923	4,492		4,492
1924	5,920		5,920
1925	9,694		9,694
1926	6,296	$1,742	8,038
1927	6,793	723	7,516
1928	11,168		11,168

The decrease in State funds for the years 1926 and 1927 was due to a State program of economy. The increase during 1928 was due to a municipal cooperative program for which the funds were combined with those of the State. As a result of the Florida "boom" the population of that State increased rapidly during the "twenties" and the relatively cool "Land of the Sky" in North Carolina attracted increasing numbers of summer residents. The increase in population for even a few months in the year, demonstrated the need for additional supplies of water for some cities, involving either development of new sources or the construction of reservoirs on developed sources of supply. Since, in either situation, additional gaging stations were needed, the municipal cooperative program was arranged.

Prior to 1924 the Survey allotments for the South Atlantic States district were not segregated by States, but thereafter Survey funds were specified for North Carolina and the following allotments were made:

1924	$4,000	1927	$3,375
1925	3,600	1928	2,800
1926	3,600		

Georgia and Alabama.- The State geologist of Georgia continued to pay a few gage observers' salaries until 1923, when he lost interest as there was no Survey office in Atlanta.

The annual amounts were:

1920	$ 535	1922	$270
1921	1,300	1923	240

The State geologist of Alabama, likewise, continued to pay gage observers' salaries until 1923, as follows:

1920	$175	1924	$60
1921	110	1925	60
1922	110	1926	60
1923	72		

West Virginia.- Cooperation with the State geologist of West Virginia, which had ceased in 1915 because of lack of State funds, was resumed in 1919 when Dr. I. C. White, State geologist, notified the Survey that the legislature had appropriated $500 for cooperation with the Survey in 1920, and the same amount in 1921. Cooperation thus renewed was continued during the period. A small amount of city cooperation was also in effect. The actual expenditures from these cooperative sources (chiefly State) were:

1920	$355	1923	$486	1926	$499
1921	590	1924	525	1927	400
1922	425	1925	550	1928	229

Kentucky.- Cooperation with the State geologist of Kentucky was continued through 1924, and he paid the following amounts to gage observers:

1920	$250	1923	$425
1921	270	1924	330
1922	650		

Tennessee.- The cooperation with the State geologist of Tennessee, Dr. Wilbur A. Nelson, which was started in 1918,[38] was

[38] Follansbee, Robert, History of Water Resources Branch to June 30, 1919, p. 326

continued during the period. Nelson's great interest in the stream-gaging program, and his success in obtaining contributions of private

funds to start the work, together with his statement that he would do everything possible to obtain a substantial appropriation by the next legislature, or from other sources if necessary, induced the Survey to establish a district in Tennessee in January 1920. The office was opened at Nashville with W. R. King who had been reinstated in the Survey on November 29, 1919, as the district engineer.

The comprehensive survey of the Tennessee River that was being made by the Army Engineers 39/ increased the State's interest in water

39/ p. 50.

power and Nelson took advantage of the situation to urge State appropriations. The Southern Appalachian Power Conference, of which he was one of the organizers in 1922, promoted still further interest in water power. As a result, the State increased very materially the appropriations for stream gaging during the latter part of the period.

The following State cooperative expenditures and Survey allotments were made:

Year	State	Survey
1920	$ 490	$1,890
1921	1,305	2,500
1922	3,090	3,000
1923	3,152	3,000
1924	4,684	3,000
1925	3,881	2,900
1926	10,189	3,000
1927	13,724	2,800
1928	12,747	2,500

The large increase for 1926 and subsequent years was due to Nelson's success in convincing the legislature of the value of the work and of the need for its expansion.

Ohio.- The real beginning of cooperative stream gaging in Ohio came about chiefly through the efforts of Prof. C. E. Sherman of the civil engineering department of the State University. He had been connected with a barge canal survey made by the Army Engineers in 1894, and from that experience realized the need for topographic maps in Ohio. In 1901 he obtained an appropriation for the Ohio Cooperative Topographic Survey, of which he was appointed director. This appropriation for topographic mapping was used in cooperation with the Topographic Branch of the United States Geological Survey. Successive appropriations of $25,000 annually were obtained until the map of the State was completed in 1916. When the mapping program was nearing completion in 1913, Prof. Sherman turned his attention to a study of the State's water resources and increased the estimate for the State appropriation from $25,000 to $27,500, of which $2,500 was to be used for hydrographic surveys. This was the year of the great Miami flood. The legislative committee to which the estimate was referred did not

appear to know the meaning of the word hydrographic, and fearing that it was a new kind of joker, struck out the $2,500 increase.40/ The next

40/ Statement of Prof. Sherman to the author.

year Sherman made a report to the Department of Public Works in another unsuccessful attempt to get an appropriation for stream gaging. He continued his efforts, however, and in 1921 finally obtained an appropriation of $12,000 for the next biennium. The legislature was accustomed to the item in the appropriation bill for the Ohio Cooperative Topographic Survey to continue cooperation with the Geological Survey, and rather than educate the legislature to accept a new item, the stream-gaging estimate was carried under the old heading with the familiar wording so that the appropriation appeared as follows:

Ohio Cooperative Topographic Survey

For cooperation with the United States in survey, examination, report, and publication upon the waters of Ohio for all purposes, $12,000. To be paid upon vouchers approved by the Governor who is hereby authorized to enter into agreement with the United States authorities for cooperation in the work; and if the Governor finds it necessary he may delegate the work to a competent person and pay him a reasonable compensation from this appropriation.

As under previous appropriations for cooperative topographic mapping, to Sherman was delegated the duty of representing the State under this act.

It is of interest to note that legislators who had apparently not known what "hydrographic surveys" were, understood, appreciated and were willing to spend State money for "survey, examination, report, and publication upon the waters of Ohio." The importance of using common words is strikingly demonstrated by this incident.

Before the session of the next legislature, Sherman, with characteristic energy, started a campaign to make the citizens of Ohio water-minded. In this he was greatly aided by General Edward Orton, dean of the college of engineering, and, at the time, president of the Columbus Chamber of Commerce. The Chamber of Commerce appointed a permanent water resources committee of 16 members, consisting chiefly of engineers of the several State and Federal departments in Columbus. A pamphlet treating of the need in Ohio for stream-flow records, prepared by Professor Sherman, was published by the Chamber of Commerce in the public interest and 5000 copies circulated throughout the State, especially through similar business organizations. The plea for an enlarged program was based on the greatly increased utilization of the streams in connection with the needs and activities of the growing population. Manufacturing plants were using greater quantities of water than formerly and the feasibility of many steam-power plants depended on the availability of sufficient supplies for the condensers during low-water seasons. Many cities that were using

ground-water sources for the municipal supplies were growing so fast that they were looking to new and more productive sources in the streams. The need for controlling floods was also apparent. In closing the argument for an enlarged stream-gaging program, the pamphlet stated:

> It seems strange that while we have made careful studies of our coal, gas, oil, and other mineral resources, we have done next to nothing with our surface waters which promise in future to become one of the most important resources we have.

A program of 120 gaging stations, of which 80 should be equipped with recorders at the rate of 10 yearly for 8 years, was advocated and an appropriation of $66,000 for the next biennium was recommended. Citizens were advised not only to urge this program upon the members of the General Assembly, but also to urge their Congressmen to make larger Federal appropriations. So successful was the campaign of education that the State appropriated $50,000 for the fiscal years 1924 and 1925 and continued to provide that amount during the remainder of the period.

The annual expenditures from State cooperative funds and Survey allotments were:

Year	State	Survey	Year	State	Survey
1922	$6,000	$3,000	1926	$24,684	$3,500
1923	6,000	3,000	1927	25,316	3,275
1924	24,866	3,000	1928	30,117	2,800
1925	25,134	2,900			

Illinois.- Cooperation with the Division of Waterways of Illinois was continued throughout the period. That division was a part of the Department of Public Works and Buildings until June 30, 1925. By an amendment of the Administrative Code which became effective on July 1, 1925, the Division of Waterways was transferred to the newly-created Department of Purchases and Construction, and the powers broadened to include the control and management of the Illinois and Michigan Canal, previously operated under a separate commission.41/ A small amount of municipal cooperation was also in effect.

41/ Letter from J. H. Morgan to the author.

Regarding the purpose of the stream-gaging program and the value of the records, the Division of Waterways reported:42/

42/ Third Ann. Rept., p. 19, 1920.

> Streams in the southern part of the state frequently overflow their banks, inundating large tracts of fertile land and inflicting heavy damage on the crops. Surveys and tentative plans for improving several of these streams have already been made. * * * In planning these improvements it is essential to know the frequency, duration and magnitude of the floods, as

well as the ordinary and low flows. These data are obtained by the gaging stations on the most important streams in that section. The same is true of streams in the northern part of the state.

The records of flow of streams are of great value. The division has many calls for them and its engineers are frequently called upon to produce them in settlement of disputes. They also preclude construction that will prevent disposal of flood waters resulting in overflow and damage.

Annual expenditures from State cooperative funds and Survey allotments were:

Year	State	Survey
1920	$3,620	$1,500
1921	4,000	1,700
1922	3,820	1,500
1923	3,862	1,500
1924	3,815	1,500
1925	4,299	1,500
1926	4,223	1,500
1927	4,852	1,400
1928	4,658	1,200

Wisconsin.- Cooperation with the State Railroad Commission of Wisconsin was continued, and the following State cooperative expenditures and Survey allotments were made:

Year	State	Survey	Year	State	Survey
1920	$6,245	$3,375	1925	$6,161	$3,250
1921	4,725	3,500	1926	6,154	3,500 1/
1922	6,045	3,500	1927	6,845	3,275 1/
1923	6,146	3,500	1928	6,440	2,800 1/
1924	6,252	3,500			

1/ Includes a small unspecified amount for Minnesota.

The cooperating agency felt that most of the stations needed had already been established and that the combined State and Federal allotments were sufficient to maintain and operate them. The slight increase in State expenditures during 1927 and 1928 was doubtless brought about by the reductions in Survey allotments, in an endeavor to provide sufficient funds to avoid a serious curtailment in the stream-gaging program.

Minnesota.- The 1919 session of the legislature of Minnesota reorganized the State government. In the reorganization, the State Drainage Commission with which the Survey had cooperated prior to 1917 was abolished and its duties transferred to the newly-created Department of Drainage and Waters. Unusual floods on the Minnesota, Red Lake, and Roseau Rivers in 1919 called attention to the need for

flood control, and the Department of Drainage and Waters made an emergency allotment for a study of control possibilities, which included the establishment and maintenance of a number of gaging stations.43/

43/ Letter from C. L. Batchelder to the author.

Cooperation which was thus resumed was continued throughout the period. Expenditures from State cooperative funds and Survey allotments were:

Year	State	Survey
1920	$610	$300
1921	465	300
1922	810	300
1923	420	300
1924	483	300
1925	555	250
1926	293	
1927	379	
1928	296	

After 1925 the allotments for the Wisconsin-Minnesota district were not segregated by States.

Iowa.- When W. G. Hoyt arranged cooperation with the State Highway Commission of Iowa in 1918,44/ there was apparently little interest

44/ Follansbee, Robert, History of Water Resources Branch to June 30, 1919, p. 329

in the State's water resources, except on the part of the State geologist, who was cooperating with the Survey in the maintenance of gaging stations on a few principal streams for general statistical purposes. Iowa is chiefly an agricultural State with sufficient water for farm, domestic, and municipal needs, and with small water-power possibilities. Its floods are generally of the cloudburst type, which cause relatively little damage except to highways, and it was only the records of these flash floods that interested the Highway Commission.

A sub-office under the Madison district office was established at Ames in March 1919 in charge of E. D. Burchard who was transferred from the New York district. In July 1920 Iowa was made a separate district. Cooperation with the Commission continued through the fiscal year 1925. Iowa was not accustomed to the large expenditures needed for carrying out a State-wide highway program and at that time there was an insistent demand that the Highway Commission economize in its expenditures. As one means toward that end the Commission decided that other State agencies should support the stream-gaging program and ceased to contribute to it. An attempt was made to obtain a State appropriation but the Budget Director was not convinced of the need for such action and failed to include an item for that purpose in the budget. Dean Anson Marston, however, was interested in continuing the work and during 1926 and 1927 obtained small amounts from the State College Experiment Station.

Expenditures from State cooperative funds were:

Year	Highway Commission	Eng. Exp. Sta.	State Geologist	Total
1920	$2,340		$655	$2,995
1921	2,415		705	3,120
1922	2,300		725	3,025
1923		(segregation not available)		3,229
1924	2,459		750	3,209
1925	2,386		500	2,886
1926		1,558	504	2,063
1927		(segregation not available)		1,493

The Survey allotments were:

1920	$1,700	1923	$2,000	1926	$2,000
1921	2,000	1924	2,000	1927	1,375
1922	2,000	1925	2,000		

Missouri.- Drainage and flood-control work had been carried on in Missouri for several years and engineers had felt the lack of stream-gaging records. In addition, the interest in water power brought about by the war impressed on the attention of engineers the great need for stream-flow records. In 1920, the engineers of the State advised Dr. H. A. Buehler, the State geologist, that they would support him in an effort to start a State-wide stream-gaging program. Buehler's attitude is shown in the introduction to the report on the Water Resources of Missouri 45/ published in 1927:

45/ Beckman, H. C., Water Resources of Missouri, 1857-1926, Missouri Bureau of Geology and Mines, Vol. XX Second Series, p. 9, 1927

> With the ever increasing demand for electric power there is no more important problem pertaining to the development of the natural resources of our State than the possible utilization of the waters of the major streams of the Ozark region * * *. In order to postulate hydro-electric installation the amount of water available must be known, therefore stream-flow data must be had.
>
> Recurring destructive floods especially in North Missouri have destroyed crops to the value of millions of dollars. In large part this is useless waste that can be eliminated by proper channel and levee improvements. With (stream-flow) figures at hand, flood-control becomes a matter of mathematical computation and not essentially guess work.

Through Buehler's efforts the 1921 session of the legislature enacted Senate Bill 372 which provided that:

> The Board of Managers of the Bureau of Geology and Mines is hereby directed to make a survey of the water resources of the State, including the determination of water power, flood prevention, area of watersheds, underground water supply, chemical composition of waters, and to show locations where water power can be generated, and the amount and character of lands that would be inundated by the erection of dams to secure water power. To do this gaging stations shall be established and such surveying and other field work shall be done as may be deemed necessary * * *. The work, as far as possible, shall be done in cooperation with the United States Geological Survey and other Government and State Bureaus.

This authorization was accompanied by a substantial appropriation.

Soon after the enactment of the law, Buehler completed cooperative arrangements with the Survey which resulted in June 1921 in the establishment of a district office at the Missouri School of Mines and Metallurgy at Rolla, where the State geologist had his headquarters. E. L. Williams was district engineer.

The annual State cooperative expenditures and Survey allotments during the remainder of the period were:

	State	Survey
1922	$9,810	$4,000
1923	8,879	4,000
1924	8,775	4,000
1925	9,472	3,600
1926	9,927	3,600
1927	9,882	3,375
1928	8,325	2,800

Arkansas.- The 1923 session of the Arkansas Legislature required of the State Geological Survey, among other duties,46/

46/ Par. 3, Sec. 2, Act 573 of 1923.

> An investigation of the available water powers of the streams of the State, and of the problems of flood control and land drainage, so that information will be available to citizens of the State that will enable them to develop the hydro-electric possibilities and reclaim the rich agricultural lands along these waterways.

Sufficient funds for starting a stream-gaging program were not provided and little was done. However, the construction of a number of water-power plants increased the interest in the State's streams, and that interest was further quickened by the floods in them during the winter of 1927 which aided materially in making the flood in the Mississippi River the greatest of record. The legislature then in session made an appropriation to the State Geological Survey to enable it to carry out the act of 1923 as a result of this interest.

Dr. George C. Branner, State geologist, entered into cooperation with the Survey in September 1927 and the resulting stream gaging was placed in charge of W. S. Frame under H. C. Beckman, district engineer at Rolla, Mo. The State contributed $2,713 during 1928, and the Survey $500.

North Dakota.- Cooperation with the State engineer of North Dakota was continued through the fiscal year 1925 and then discontinued. The expenditures from State cooperative funds were:

1920	$575	1923	$650
1921	270	1924	1,617
1922	565	1925	500

The Survey allotted $300 annually during those years.

South Dakota.- The lone station maintained in cooperation with the State engineer of South Dakota 47/ was discontinued in the late

47/ Follansbee, Robert, History of Water Resources Branch to June 30, 1919, p. 330

fall of 1920. The State engineer expended $180 during the fiscal year 1920, and $45 during 1921.

Kansas.- Cooperation with the Kansas Water Commission was continued through 1927. Although the suit to enjoin the collection of the sand-tax 48/ was decided in favor of the State, the State auditor

48/ Follansbee, Robert, History of Water Resources Branch to June 30, 1919, p. 331

ruled that the resulting revenues should go into the general funds of the State, and that the Water Commission should apply to the legislature for appropriations the same as other State departments. This procedure was followed. 49/

49/ Letter from R. C. Rice to the author.

During the 1925 session of the legislature, a fight over the appropriation bill developed, and the chairman of the Ways and Means Committee of the Senate eliminated the item for stream gaging. Some years previously he had known of the questionable quality of the records collected by another organization, due to inadequate supervision, and assumed that the Survey's work was similar in character. As there was then no widespread demand for stream gaging in the State, he was able to eliminate the item, stating that the rivers would run down their channels without being measured as they had continued to do through the ages. 50/ There was insufficient interest, however,

50/ Statement of J. B. Spiegel to the author.

for the State cooperating agency to obtain limited private contributions of funds, chiefly from the companies that dredged the sand

from the rivers. A knowledge of the flow was important to them, not only in connection with the movement of the water in their sand pits, but also with regard to approaching floods that imperiled their equipment unless it was removed from the flood channel. These contributions were handled by the Water Commission, and the district was continued during the next two years.

George S. Knapp, Commissioner of Irrigation, realized the value of stream gaging as the successful operation of his office depended largely upon such records. He believed that the Water Commission had no future and induced the legislature at its 1927 session to consolidate that Commission with the office of the Irrigation Commissioner in the State Board of Agriculture. When this was done an appropriation of $5,000 annually was made for the next biennium. However, the Survey funds for 1928 were so limited that with the slight interest displayed by the Kansans in their water resources, cooperation was discontinued June 30, 1927. Thereafter, J. B. Spiegel continued in charge of the stream gaging as a State employee until cooperation was resumed in July 1928.

The annual State cooperative expenditures and Survey allotments were:

	State	Survey		State	Survey
1920	$4,010	$3,500	1924	$4,913	$3,500
1921	5,910	4,000	1925	4,956 1/	3,300
1922	3,885	3,500	1926	2,208 1/	3,000
1923	4,004	3,500	1927	1,727 1/	2,325

1/ Including municipal cooperation and private contributions.

Texas.- Cooperation was continued with the State Board of Water Engineers of Texas to which the State funds for stream gaging were appropriated without specifying cooperation. The 1921 floods made Texas more water-conscious than it had been previously, and Governor Neff called upon engineers and others interested to meet in Austin on August 7, 1922, to discuss the control of floods and the conservation of water resources. After that meeting, which was attended by 150, the Governor appointed an advisory council of 13 engineers to assist the Board of Water Engineers in preparing plans for an adequate budget for presentation to the next session of the legislature. A short time later another meeting was held in Waco, and a State-wide organization known as the "Texas Conservation Association" was formed. The Texas Conservation Association was supported enthusiastically by the press and carried on a campaign of education in all parts of the State, particularly in the eastern and central sections, where the citizens were not notably water-conscious. So successful was the campaign that the Democratic platform of that year called on the next legislature to enact laws in harmony with the conservation movement. Accordingly, the legislature enacted the so-called "Texas Conservation Bill" which provided among other things for an appropriation of $100,000 annually during the next biennium for stream gaging. As frequently occurs in States not especially water-minded, public interest subsided after the conservation bill was passed, and although the Board of Water

Engineers continued to request $100,000 annually, the amounts appropriated in subsequent years were greatly reduced, although considerably higher than formerly.

The expenditures from State cooperative funds and Survey allotments were as follows:

Year	State	Survey
1920	$10,280	$4,875
1921	12,895	5,500
1922	14,635	5,000
1923	14,385 1/	5,000
1924	62,992 2/	5,000
1925	72,238	4,300
1926	36,325 3/	4,300
1927	25,036	4,025
1928	32,107	3,400

1/ Includes $315 from county and municipal funds.
2/ Includes $291 from municipal funds.
3/ Includes $686 from State Reclamation Department funds.

Montana.- Cooperation was continued with the State engineer of Montana along the lines started in 1909, and the annual expenditures from State cooperative funds and Survey allotments were:

Year	State	Survey
1920	$3,425	$4,625
1921	5,530	5,500
1922	8,150	5,000
1923	9,986	5,000
1924	6,442	5,000
1925	6,003	4,300
1926	4,953	4,300
1927	4,943	4,025
1928	6,097	3,400

The annual increase in the State allotments from 1921 to 1923 was due chiefly to a revival of interest in irrigation following the dry years at the beginning of this period. By 1924, however, efforts to balance the State budget resulted in the decreases shown.51/

51/ Statement of C. S. Heidel to the author.

Wyoming.- Cooperation with the State engineer of Wyoming which had been resumed in 1915, was continued with actual expenditures from State cooperative funds, as follows:

1920	$4,520	1923	$5,731	1926	$4,570
1921	5,505	1924	6,106	1927	4,826
1922	6,580	1925	4,755	1928	4,501

Referring to the cooperative work, the State engineer wrote: 52/

52/ Sixteenth Bien. Rept. 1921-22, p. 11

> The cooperative method has worked out with success and allows the State to take advantage of the resources, personnel and equipment of this highly organized branch of the Federal Government.

The Survey allotments to the district were not segregated by States, but the bulk of the operations were in Wyoming, and Survey expenditures were about equal to the State expenditures.

Colorado.- In 1919 cooperation with the State engineer of Colorado was limited to the maintenance by the Survey of a few stations chiefly in the Colorado River Basin. In 1922 the State engineer requested the Survey to establish a group of stations in the North Platte River Basin at State expense. These stations were maintained until 1925, when a new State engineer took over the operation of all cooperative stations. A number of Federal Power Commission permits were issued during the later years of the period and, as the district personnel was too limited to operate the gaging stations that were needed, the State engineer offered to perform the work at State expense under Survey supervision. This offer was accepted. A small amount of municipal cooperation was also in effect.

The expenditures from State and municipal cooperative funds were:

Year	State	Municipal	Total
1920	$ 500		$ 500
1921	500		500
1922	800		800
1923	1,300	$200	1,500
1924	1,500	200	1,700
1925	1,500	370	1,870
1926	175		175
1927	806		806
1928	618		618

Idaho.- Cooperation with the Department of Reclamation of Idaho was continued during the period. The importance of the work to the State is shown by the following statement by the Commissioner of Reclamation made in 1922: 53/

53/ Second Bien. Report 1921-22, p. 29.

> Idaho's water supply constitutes her greatest asset and if the greatest beneficial use is to be had from this resource it is highly important that a continuous and dependable inventory of the supply be taken. The State has already suffered great injury and almost unbearable burdens have been heaped upon some of its citizens by the

construction of irrigation works based upon little or no definite knowledge regarding available water supply. * * *

The State is exceedingly fortunate in having the service afforded by the United States Geological Survey in this work (stream gaging).

With the creation of the Idaho Falls office in May 1919 State cooperation was divided between the Boise and Idaho Falls offices. The basis of the division was the number of gaging stations of State-wide interest maintained by each.54/ The State allotments were as follows:

54/ Letter from C. G. Paulsen to the author.

Year	Boise	Idaho Falls	Total
1920	$ 9,685	$1,470	$11,155
1921	10,340	2,165	12,505
1922	17,255	1,933	19,190
1923	14,232	2,677	16,909
1924	12,195	2,175	14,370
1925	13,971	2,825	16,795
1926	13,016	2,201	15,217
1927	11,072	2,789	13,861
1928	14,440	2,540	16,980

The increase in the appropriations beginning in 1921 was due largely to the efforts of the Idaho Reclamation Association, which held annual meetings that were attended by Paulsen and Baldwin. Both were active in the Association and Baldwin served as president one year.

The Survey allotments were divided as follows:

Year	Boise	Idaho Falls	Total
1920	$3,875	$1,000	$4,875
1921	4,300	1,200	5,500
1922	(3,900)	(1,100)	5,000
1923	(3,900)	(1,100)	5,000
1924	3,900	1,100	5,000
1925	3,200	1,100	4,300
1926	3,200	1,100	4,300
1927	3,000	1,025	4,025
1928	2,700	800	3,500

Utah.- Cooperation with the State engineer of Utah was continued throughout the period. Each biennium the State legislature made a cooperative appropriation contingent upon a Federal appropriation of like amount. In addition, the Water Storage Commission which had been organized in 1921 to cooperate with the Reclamation Service in its work of investigating proposed reclamation developments

in Utah, allotted $1,500 for the last biennium of the period. In describing this latter action, the State engineer stated:55/

55/ 16th Bien. Rept. State Engineer, 1927-28, p. 30

> With the increasing expense of maintenance and operation, some of these stations have had to be abandoned and others have not received the full attention had in the past. A special committee of the Water Storage Commission studied this situation as presented by Mr. A. B. Purton, with the result that a set of stations was selected for either revival or more extensive study. To defray the additional expense, $1,500 was appropriated.

The total State cooperative expenditures and Survey expenditures were:

Year	State	Survey
1920	$4,735	$4,875
1921	6,780	5,000
1922	4,425	5,000
1923	4,596	5,000
1924	3,103	5,000
1925	5,815	4,300
1926	6,953	4,300
1927	6,495	4,225
1928	7,470	3,400

The State's requirement of 50-50 cooperation was more than met until 1925, but thereafter the successive reductions in the Federal Survey appropriations made it impossible to match the State funds.

Nevada.- Cooperation with the State engineer of Nevada was continued, and in reference to it the State engineer stated:56/

56/ Bien. Rept. 1921-1922, p. 6.

> The United States Geological Survey has for years cooperated with the State engineer in the stream-gaging work in the State. The work done is extremely important and should above all means be continued. The measurements obtained form the basis for water-right determinations, show the feasibility of projects for the storage of water both for power and irrigation, and materially assist the office in taking action on new applications to appropriate water. The cooperation in the past has been on the basis of $5,000 per biennium from both Federal and State funds. For the past three years the Federal Government has been expending $3,000 annually on the work and will continue to do so. It is therefore urged that a like appropriation of $6,000 for the biennial period be made by the State of Nevada.

Unfortunately, this plea, like those made by other State officials before and since, was ignored by the legislature as Nevada, being primarily a stock-raising and mining State, was not particularly water-minded, and the regular $5,000 appropriation was made. When the appropriation for 1927 and 1928 was made, interest had declined to such an extent that the amount was cut in half. The total State cooperative expenditures and Survey allotments were:

Year	State	Survey
1920	$2,510	$2,500
1921	2,395	3,000
1922	3,115	3,000
1923	2,010	3,000
1924	1,449	2,500
1925	2,596	2,500
1926	3,664	2,500
1927	1,687	2,150
1928	1,148	1,900

Arizona.- The increasing need for a modern method of determining existing water rights and establishing new ones led Arizona to adopt its State Water Code Act on Mar. 26, 1919.[57] This act created the

[57] Laws of Arizona 1919, Chap. 164.

office of State Water Commissioner to administer it. Although that office was the logical cooperating agency, the appropriation of $3,000 annually for cooperative stream gaging during 1920 and 1921 was made to the Director of the State Experiment Station as had been done previously. Like the previous appropriations, it was contingent upon an equal allotment by the Federal government. The next legislature transferred the responsibility for this cooperative work to the Water Commissioner beginning July 1, 1921, and appropriated the same amount annually under the same conditions for the next biennium. Realizing the increasing importance of the records, the Commissioner allotted additional amounts from other funds during those years.

The negotiation of the Colorado River compact[58] increased

[58] p. 99

interest in the possibilities of utilizing the waters of the Colorado River and, in 1922, led to the creation of the Arizona Engineering Commission for exploring those possibilities. E. C. LaRue, the foremost authority on the Colorado River at that time, was made chairman. The report of the Commission, made in the following year, further increased public interest. By that time the contention for the exclusion of the Gila River from the terms of the Colorado River compact before its ratification by the State became one of major importance in the State, and as a result it was realized that more extensive stream gaging was required in the Gila River Basin. There were also other basins to which the work should be extended.

The effect of these influences was a sixfold increase in the stream-gaging appropriations beginning with the fiscal year 1924, divided by law into $7,000 annually for the Colorado River and its minor tributaries, and $10,000 or more for the Gila and other streams in the State. Because of the probable inability of the Survey to match the larger State appropriation, the requirement to allot equal amounts was qualified by the phrase "as far as may be possible."

Year	Colorado River	Exclusive of Colo. River	Water Com. (additional)	Total
1920	$2,985 1/			$2,985
1921	3,015 1/			3,015
1922	3,000 1/		$1,160	4,160
1923	3,000 1/		1,434	4,434
1924	$7,000	$11,800		18,800
1925	7,000	10,000		17,000
1926	7,000	10,000		17,000
1927	7,000	10,000		17,000
1928	7,000	11,682	1,700 2/	20,382

1/ Not segregated in act
2/ Contributed by Colorado River Commission for operation of Lees Ferry station.

The Survey allotments were:

1920	$3,000	1923	$3,500	1926	$3,300
1921	3,000	1924	3,500	1927	3,100
1922	3,500	1925	3,300	1928	2,800

The allocation of additional (non-cooperative) Survey funds and of funds of other Federal agencies to the operation of the Colorado River stations 59/ increased materially the total allotments by the

59/ p. 110

Federal government.

Washington.- A general reorganization of the State government of Washington, effective on April 1, 1921, transferred the duties of the Board of Geological Survey to the newly-created Department of Conservation and Development, and the cooperating State official was thereafter the Supervisor of Hydraulics. At that time the provision that the Survey allot an amount equal to the State appropriation was eliminated from the State agreement. During 1920 and 1921 the State Reclamation Board cooperated in the establishment and maintenance of gaging stations needed for determining the feasibility of a State reclamation project. After obtaining the records necessary for that purpose this cooperation ceased but the stations were continued for some time as a part of the regular stream-gaging program.

Cooperation with Seattle and Tacoma and to a lesser extent with other cities, in connection with municipal water-power development, began in 1922 and continued during the period.

The expenditures from State and municipal cooperative allotments were:

Year	State Board of Geol. Survey	Dept. Cons.& Devel.	State Reclamation Board	Municipal & County	Total
1920	$5,975		$ 96		$6,071
1921	7,621	315	453		8,389
1922		6,336		735	7,071
1923		6,217		1,664	7,881
1924		4,158		695	4,853
1925		5,762		1,730	7,492
1926		5,686		2,088	7,774
1927		6,752		1,372	8,124
1928		7,761		1,393	9,154

The State allotments during 1927 and 1928 included $2,082 and $1,716, respectively, to reimburse the Survey's district office for special studies made in connection with negotiations by Washington with Montana and Idaho for the allocation among the three States of the waters of the Clark Fork and Pend Oreille River. 60/

60/ Letter from G. L. Parker to the author.

The Survey allotments were:

1920	$4,875	1923	$5,000	1926	$4,300
1921	5,500	1924	5,000	1927	4,025
1922	5,000	1925	4,300	1928	3,400

Oregon.- Cooperation with the State engineer of Oregon was continued although in lesser amounts during the later years. A new State engineer in 1924 decided that in those areas where the administration of the water laws required water masters, these latter should operate the stream-gaging stations formerly maintained by the Survey, and that cooperation with the Survey should be confined chiefly to the western part of the State where water masters were not employed. This action reduced the number of stations by 49, or about half. However, the Survey continued to make occasional measurements and to supervise the computation of the records for stations maintained by the State.

The growing interest in the State's water resources during the years following the war resulted in larger appropriations which were reflected in the allotments to the cooperative work until the change in policy in 1924. Thereafter the cooperative funds were materially reduced.

The annual expenditures from State and municipal cooperative funds, and the Survey allotments were:

Year	State	Municipal	Total	Survey
1920	$5,700	0	$5,700	$4,875
1921	7,225	0	7,225	5,500
1922	11,530	0	11,530	5,000
1923	12,019	0	12,019	5,000
1924	6,428	1,751	8,179	5,000
1925	6,452	1,482	7,934	4,300
1926	8,642 1/		8,642	4,300
1927	4,991	1,414	6,405	4,025
1928	7,085 1/		7,085	3,400

1/ Municipal cooperation not segregated.

In addition, an average of $2,000 annually was contributed by Jackson County during the years 1923 to 1928.61/

61/ p. 157

California.- At the beginning of the period the State engineer of California as chief of the Department of Engineering and Irrigation and the State Water Commission were the cooperating State agencies. The 1921 legislature reorganized the State government and merged those two agencies into the newly-created Department of Public Works of which the State engineer was the chief. The Department of Engineering became the Division of Engineering and Irrigation and the Water Commission became the Division of Water Rights.

For several years prior to 1921 there had been state-wide agitation for a comprehensive study of the State's water resources, with special reference to irrigation in the Great Central Valley comprising both the Sacramento and San Joaquin valleys. This agitation culminated in an act by the 1921 legislature62/ appropriating

62/ Chap. 889 of 1921 Statutes.

$200,000 for the State engineer,

> to determine the maximum amount of water which can be delivered to the maximum area of land, the maximum control of flood waters, and the maximum storage of waters, as well as all possible and practical uses of water.

The State engineer was further instructed to prepare a comprehensive plan for the accomplishment of these objectives63/ and the Governor

63/ Rept. Div. Eng. & Irrig. pt. III, Nov. 1, 1922.

was directed to appoint a consulting board to supervise the State-wide plan. A board of ten members was appointed, one of whom was H. D. McGlashan. He was also called upon frequently for advice pertaining to the studies of water supply.

Additional gaging stations were required for this huge program which was continued by later appropriations and larger allotments to cooperative stream gaging were made by both the Division of Engineering and Irrigation and the Division of Water Rights. Part of the State allotments was the continuing appropriation of $9,000 for cooperation with the Survey, which had been made since 1909. This continuing appropriation was abolished in 1928 when the State adopted the budget system. 64/

64/ Letter from H. D. McGlashan to the author.

The annual State cooperative expenditures were:

Year	Div. Engr. & Irrig.	Div. Water Rights	Total
1920	$8,555 1/	$9,394 2/	$17,949
1921	7,637 1/	4,777	12,414
1922	12,185	9,730	21,415
1923	12,602	10,604	23,206
1924	12,583	9,999	22,582
1925	11,535	10,000	21,535
1926	15,167	7,880	23,047
1927	9,727	12,360	22,087
1928	26,094		26,094

1/ Dept. of Engineering.
2/ Water Commission.

The Survey allotments were:

1920	$4,975	1923	$5,500	1926	$4,500
1921	6,000	1924	5,500	1927	4,225
1922	5,500	1925	4,500	1928	3,400

The funds were used almost entirely for stream gaging as the previous procedure of allotting to the Division of Ground Water a portion of the Survey funds was discontinued in 1922 when the State, in view of the new program, preferred that the funds be devoted entirely to surface waters.

Cooperation with the City of San Francisco, Los Angeles County, and the Tri-county association of San Bernardino, Riverside, and Orange counties, was continued. Cooperation was arranged in 1926 with the East Bay Municipal Utilities District whereby three existing stations on the Mokelumne River were equipped with recorders and 11 additional stations were established and equipped with recorders and cables provided where needed as a part of the cooperation between the Division of Ground Water and the East Bay District. These stations were maintained during the remainder of the period. Cooperation was also arranged with a number of cities.

The expenditures from the municipal and county cooperative funds were:

Year	San Francisco	Los Angeles	Tri-Counties
1920	$2,336	$2,600 1/	$1,069
1921	2,431	2,259	2,972
1922	2,646	3,326	2,995
1923	2,638	2,962	2,954
1924	2,501	2,976	2,988
1925	2,508	3,253	2,997
1926	3,222	3,201	2,968
1927	3,283	3,006	2,993
1928	2,794	3,114	2,996

Year	East Bay District 2/	Miscellaneous 3/	Total
1920	0	0	$6,005
1921	0	0	7,662
1922	0	0	8,967
1923	0	3,557	12,111
1924	0	0	8,465
1925	0	1,541	10,299
1926	0	631	10,022
1927	4,329	5,034	18,645
1928	3,681	1,305	13,890

1/ Allotment; expenditures not available.
2/ Does not include construction costs which were paid by district direct.
3/ Includes construction of two stations and operation of three stations for City of Sacramento under terms of Federal Power Commission permit.

Hawaii.- Cooperation with the Commissioner of Public Lands of Hawaii continued during the period, and, in addition, the cities of Honolulu and Hilo cooperated in the maintenance of stations in which they were particularly interested. The expenditures from these sources were as follows:

Year	Territory	Cities	Total
1920	(not segregated)		$26,200
1921	$19,580	$2,000	21,580
1922	28,520	310	28,830
1923	18,415	1,530	19,945
1924	18,440	0	18,440
1925	24,334	0	24,334
1926	32,392	4,461	36,853
1927	26,828	1,080	27,908
1928	29,703	3,680	33,383

The fluctuating amounts of city cooperation were due to the fact that such expenditures were limited to the construction or repair of stations, and did not include operation.65/

65/ Letter from M. H. Carson to the author.

The Survey allotments were:

1920	$4,000	1923	$4,500	1926	$4,500
1921	4,000	1924	4,500	1927	4,225
1922	4,500	1925	4,500	1928	3,400

FEDERAL COOPERATION

The increasing interest in the country's water resources was reflected in the allotments received from various Federal bureaus during the period. Previously, Federal financial participation in the study of water had been limited chiefly to the Bureau of Reclamation, Indian, and National Park Services, with cooperation in the form of services effective with the Forest Service. Direct monetary participation had averaged about $20,000 annually during 1913-19.

The Reclamation Service, which in 1923 became the Bureau of Reclamation, continued its allotments, as did the Indian Service and the National Park Service. The Forest Service continued to furnish services though on a decreased scale, and the Weather Bureau furnished gage heights for about 50 stations. The intensive study by the Army Engineers of the water-power possibilities of the Tennessee River Basin showed the need for additional stream-flow records and cooperation with that organization, started in 1920, continued during the period, and the "308" investigations 66/ were started in the spring of 1928.

66/ p. 51.

The interest of the newly-created Federal Power Commission in the water-power possibilities of the Colorado River resulted in allotments by the Commission to the Survey during the fiscal years 1922 to 1926. International treaties with Canada and Mexico made necessary the maintenance of gaging stations on international streams, and the State Department began cooperation in 1923.

The total Federal (non-Survey) cooperative funds expended annually by the Survey were:

1920	$21,000	1923	$40,812	1926	$33,124
1921	30,690	1924	41,484	1927	36,563
1922	32,286	1925	30,293	1928	88,334 1/

1/ Increase due to enlarged program on Rio Grande, and beginning of Army Engineers' "308" investigations.

In addition to the cooperation represented by the above amounts, Federal bureaus continued to furnish complete records for publication. These decreased from 99 in 1920 to 45 in 1928.

Bureau of Reclamation.- The Reclamation Service became the Bureau of Reclamation on June 20, 1923, by order of the Secretary of the Interior. This was more than a change in name, as Secretary

Work shortly after assuming office decided that more attention should be paid to aiding the settlers along business and agricultural lines, if the projects were to be completely successful.[67] The functions of

[67] 22nd Ann. Rept. Bu. of Reclam., 1922-23, p.

the Bureau were broadened to include these objectives.

In the years of this period (1919-28), the accretions to the Reclamation fund were constantly becoming less. One cause for this was the great reduction in receipts from the sale of public lands due to the poor quality of those remaining. Another and perhaps equally important cause was the reduction in annual repayments of construction costs by the settlers. The depressed condition of agriculture after the war was felt on the reclamation projects, and Congress enacted a number of relief acts extending the time for making repayments. The Board of Survey and Adjustment appointed in 1925[68] recommended

[68] p.

scaling down the repay costs on such project lands as were not of the best quality, and this recommendation was enacted into law. As a partial offset to these reductions, the oil leasing law brought additions to the Reclamation fund beginning in 1920.

In spite of the additions caused by the action of the oil leasing law, the Reclamation fund from which Congress made appropriations to the Bureau of Reclamation, became so small that the Bureau made little provision in its budget for the investigation of new projects. The negotiation of the Colorado River compact in 1922,[69] however, brought

[69] p. 99

to the front the irrigation and power possibilities of the Colorado River, and the Bureau contributed to the maintenance of the gaging stations on the lower Colorado River an average of about $4,000 yearly except during 1923, when the contribution was $11,255, part of which was for the installation of the stations.[70]

[70] p. 110

Cooperation by the Bureau of Reclamation in Montana, which had been more extensive than in any other State during previous years, was reduced from the support of 49 stations in 1920 to two in 1928. This reduction was due to the completion of certain projects for the Indian Service in 1922, and to the assumption by the State Department in 1927 of the cost of maintaining 16 international stations previously maintained at the expense of the Bureau of Reclamation. The largest number of stations for which the Bureau paid the costs was in Idaho, where the Idaho Falls office maintained stations in connection with the administration of water released from Jackson Lake.[71] A few

[71] p. 148

stations were also maintained by Bureau funds in Oregon, Utah, and Wyoming. The total number of stations supported by the Bureau declined from 107 in 1920 to 55 in 1928, of which about 35 were maintained by the Idaho Falls office. Following the custom of previous years, stations needed for the operation of projects were maintained by the Bureau alone, and the records furnished to the Survey for publication. The number of records so furnished declined from 65 in 1920 to 33 in 1928.

The exact figures of funds contributed annually for the maintenance by the Survey of stations for the Bureau are not available, but were about as follows:

1920	$11,700	1923	$23,100 1/	1926	$10,600
1921	14,300	1924	15,800	1927	9,500
1922	14,300	1925	14,000	1928	7,100

1/ Increase due chiefly to installation of Colorado River stations.

In addition to the cooperative stream-gaging program, the Secretary of the Interior in 1923 appointed a special board consisting of the Commissioner of the Bureau of Reclamation and the two Assistant Secretaries of the Interior to make a special study of the Columbia Basin project in Washington. An engineering staff of four, of which G. L. Parker was hydraulic engineer, conducted the investigation, which lasted from May 1923 to February 1924. Expenditures paid by the Bureau of Reclamation on account of Parker's detail were $2,588.

Forest Service.- Cooperation in services continued with the Forest Service during the period. The work in Los Angeles County, which had been started in 1916 72/ through the efforts of the Forest

72/ Follansbee, Robert, History of Water Resources Branch to June 30, 1919, p. 345.

Service, continued and the Forest Service detailed one of its engineers, H. J. Tompkins, to perform the field work under the Survey's supervision. Forest Service employees also furnished gage readings and some assistance in the operation of stations in other western States. These stations gradually declined in number from 39 to 11, exclusive of the 20 stations in the Los Angeles County project.

The cooperation in Alaska, started in 1915, was discontinued in 1921. 73/

73/ Idem, p. 425.

Indian Service.- Cooperation with the Indian Service reached a peak during the early years of the period when a maximum number of 62 stations were so maintained, thereafter gradually declining to 14 in 1928. The stations were situated chiefly in Idaho, Washington, Oregon, Montana, and Arizona. The decline was doubtless a result of the Coolidge economy which was felt severely by the Indian Service.

The approximate annual expenditures from Indian Service funds were:

1920	$9,300	1923	$7,100	1926	$2,900
1921	7,900	1924	6,100	1927	2,400
1922	10,500	1925	4,200	1928	2,300

As a partial aid in financing this program, the annual appropriations for the Indian Service contained items for cooperative stream gaging with the Survey, as follows:

1920	$4,000	1923	$2,000	1926	$1,000
1921	4,000	1924	1,000	1927	850
1922	2,000	1925	1,000	1928	850

National Park Service.- The National Park Service furnished gage-height records for the stations in Yellowstone, Yosemite, and Glacier Parks, established during 1913-19.

In 1921 Horace M. Albright, then Superintendent of Yellowstone Park, became concerned over the pressure being exerted by various Montana interests to store water in Yellowstone Lake. Although the real purpose of such storage appeared to be for irrigation and possibly power in Montana, the grounds on which the plea for such storage was based was the reduction in flood stages in the vicinity of Livingston, and farther downstream. To determine the possible reduction in flood discharge, during 1922 the Boise district installed stations on Yellowstone Lake, the Yellowstone River at the outlet of the lake, Tower Creek at Tower Falls, Lamar River near mouth, and Gardiner River at Mammoth Hotel. The Park Service furnished all materials, assistance, and subsistence to Survey engineers. Park rangers were detailed to furnish records of daily gage heights read from the staff gages with which the stations were equipped. Beginning in 1925 the Park Service made definite allotments for the improvement of the station equipment, as follows:

1925	$ 200	1927	$1,000
1926	1,000	1928	925

A recorder and a cable were installed on Lamar River and a recorder on Gardiner River. As these stations were not situated on main routes of tourist travel, the Park Service did not insist on special structures to harmonize with the surroundings and standard Survey designs were used. The resulting records indicated that storage in the lake would have little effect on flood conditions below the Park, as the damaging floods originated outside the Park boundary and below the Lake. If the stream-flow records had not been available, the Park Service believes that it would have been compelled to permit the development and operation of Yellowstone Lake as a storage reservoir.74/

74/ Letter from C. G. Paulsen to the author.

The shelter on Swift Current Creek in Glacier National Park, which the Park Service had constructed in 1918, was replaced in 1926

by a shelter composed of native stone, roughly rectangular and harmonizing with the retaining wall that was being built along the creek near Many Glaciers Hotel. The work was performed by the Park Service and Bureau of Public Roads.75/

75/ Letter from A. H. Tuttle to the author.

Army Engineers.- The principal cooperation with the Army Engineers was in the Tennessee River Basin, which was under intensive study. The Rivers and Harbors Act of June 5, 1920, contained authorization for a survey of the Tennessee River. The Wilson power dam at Muscle Shoals was then being constructed at Federal expense, and there was considerable controversy over the disposition of the power. Major H. C. Fiske of the Corps of Engineers, who had recently been appointed district engineer for the Tennessee River Basin, advanced the idea of a comprehensive development program, including studies of present and potential water-power development. Thus stream-flow records had greater importance than that pertaining to the usual river surveys for navigation.

G. H. Matthes, an early-day member of the Survey, who was Major Fiske's principal engineering assistant in the Chattanooga district, realized the necessity for many more stream-flow records, possibly an increase of a hundred or more over those obtained from the 27 gaging stations then operated by the Survey in the basin. As Matthes stated further:76/

76/ Letter to the author.

> While fully agreed as to the need for ample stream-flow records as basic to the investigations to be made, I recognized that if I were to undertake to establish and maintain such a large group of stations I would have little time left to devote to surveys, studies, and reports. I recommended that this part of the work be entrusted to the U. S. Geological Survey Water Resources Branch for execution under some cooperative agreement by which the cost of any work done for the Survey of the Tennessee River be reimbursed from Army engineer funds. Altho aware of the difficulties of bringing about cooperation between Federal bureaus I was also aware of the fact that the World War had done much in the way of establishing friendliness of relations between bureaus. It seemed to me a good psychological time to effect cooperation of some sort. Major Fiske was quite disposed to give the plan favorable consideration.

It was doubtless fortunate for Matthes' plan that his chief was the officer who, when he was in charge of the Pittsburgh district in 1915,77/ had previously cooperated with the Survey.

77/ Follansbee, Robert, History of Water Resources Branch to June 30, 1919, p. 347.

The Survey had recently established a district office in Nashville and Warren R. King, district engineer, was invited to confer with Major Fiske relative to possible cooperation. At this conference King indicated the willingness of the Survey to enter into cooperation, and on August 23, 1920, a second conference was held at his office which was attended by N. C. Grover, Wilbur A. Nelson, the cooperating State official, Major Fiske, and G. H. Matthes. At hearings in Washington, Dr. Nelson had been an energetic sponsor of the Tennessee River Survey and he naturally favored any expansion of stream gaging in Tennessee. Cooperation was arranged and, in order to be in close touch with Army Engineers, the district office was moved in September 1920 from Nashville to Chattanooga, where quarters were provided in the Army Engineer office.

Cooperation was started on October 1, 1920, and 31 additional stations were established, including some of those previously discontinued for lack of funds. A considerable number of these were in North Carolina and were operated by that district. Army Engineer funds spent on the cooperative work were as follows:78/

78/ H.D. 328, 71st Cong., 2nd Sess., p. 727.

1921	$6,990	1925	$7,893
1922	3,486	1926	12,523
1923	5,169	1927	16,913
1924	12,772	1928	15,691

The survey of the Tennessee River authorized in 1920 was preliminary in character, and upon its completion authorization for a detailed survey to determine the multiple uses of the waters of the Tennessee River Basin was requested of Congress. This was not granted for several years, and during 1922 and 1923 Army cooperative funds were reduced as indicated above. In commenting on the cooperation during the 3½ years that he was connected with the Chattanooga office, Matthes states that the cooperation worked perfectly, a condition which might be inferred from its continuation throughout the period.

Two more projects in cooperation with the Army Engineers were carried on during the period. One was a study of the water supply of the Potomac River at Great Falls, Va., for which the Army Engineers allotted $1,500.79/ The other was a study of wave travel on the

79/ p. 112.

New River by the Virginia district at the request of the Army Engineers, who paid the field expenses.80/

80/ p. 126.

Cooperation with the Army Engineers, covering nearly all parts of the country, began in the spring of 1928, and a description of it follows in the next period.

Federal Power Commission.- The Federal Power Commission contributed to the cost of installing gaging stations on the Lower Colorado River where the power possibilities were very great and where the delay in ratifying the Colorado River compact prevented the issuance of permits and licenses, 81/ which would have required the holders of

81/ p. 105.

such permits and licenses to install and maintain the needed gaging stations. To meet this situation the Commission contributed the following amounts toward the installation and maintenance of needed key stations on the river:

1922	$4,000	1925	$1,500
1923	6,043	1926	3,201
1924	1,533		

The increase in 1926 was due to the installation of a station on the Little Colorado River.

In 1927 the Commission was not asked to contribute to the maintenance of the existing stations but was requested to contribute $2,500 toward the construction of a station on the San Juan River, an important tributary. The Commission complied with this request but it had to be approved by the Comptroller General, who ruled on February 23, 1927, that the proposed gaging station did not involve directly cooperative work by the Survey for the Commission, and went on to state:

> If information relative to the flow of the San Juan River is needed by the Federal Power Commission in the consideration of applications for water-power development privileges involving the Colorado River and its tributaries, such information should be furnished by the Survey without cost to the Commission * * *. You are accordingly advised that the transfer * * * is not authorized.

Thereafter, the Commission could not contribute funds to the maintenance of stations in the Colorado River Basin, which was the only region in which such action had been taken.

An indirect type of cooperation, far exceeding the Commission's direct expenditures, was the requirement that holders of permits and licenses install and maintain specified gaging stations under the Survey's supervision. The resulting supervision was generally with private interests. 82/

82/ p. 53.

In addition to the stream-gaging program, applications to the Commission required engineering investigations and reports, and many of those in the western States were made by the district engineers in whose districts the projects were situated.

Whenever an application involved a stream which was suitable for purposes other than power development, a joint study was made by the several Government and State agencies concerned. In 1921 the Commission appointed a board to study the Deschutes River, and in 1922 a similar board to investigate the upper Columbia River. F. F. Henshaw, district engineer of the Oregon district, was appointed to both boards.

State Department.- Beginning in 1923 the State Department cooperated in maintaining gaging stations on the Mexican border, and in 1927 on the Canadian border. This cooperation is described under "Operation of international stations."[83]

83/ p. 54.

Weather Bureau.- Weather Bureau cooperation consisted chiefly in furnishing gage heights (generally one reading daily) for about 50 flood-warning stations. In return, some Survey districts checked at irregular intervals the Weather Bureau gages involved and the author's district at least furnished rating tables which were used by the Weather Bureau in forecasting flood flows.

Private Assistance

Assistance, by private interests started in a minor way in the early days of the Branch, generally by the furnishing of gage-height records, was increased very materially during the period as shown by the number of gaging stations on which there was private assistance each year:

Year	No. of stations	Year	No. of stations	Year	No. of stations
1920	417	1923	562	1926	671
1921	431	1924	598	1927	700
1922	515	1925	638	1928	698

The chief cause of this increase was the requirement of the Federal Power Commission that its permittees and licensees maintain, under the Survey's supervision, certain specified gaging stations for the purpose of determining the water supply available to their projects. The Survey established and maintained some of the required stations from funds advanced by the permittees and licensees, and the permittees and licensees furnished all field data for other stations established and maintained by them under Survey supervision. The total amount of such expenditures is not known exactly, but is estimated to have averaged about $135,000 annually for the seven years from 1922 to 1928. Of this amount about $100,000 was expended in California, $11,000 in Oregon, $4,000 in Washington, and the remainder in other States, chiefly in the West.

Similarly, the assistance rendered by other private interests, chiefly those engaged in irrigation and water-power enterprises,

ranged from furnishing complete records for several stations to furnishing for one or more stations a small part of the field data, such as gage heights. It is impossible to estimate the value of such assistance. Complete records, not included in the tabulation given above, were furnished for an average of 292 stations during the period. As many of the records furnished by water-power companies were obtained by computation of flow over dams, and others were obtained by Survey methods at varying costs, it is impossible to estimate even roughly the cost of the records so furnished.

Operation of International Stations

The informal arrangement whereby the Washington district and the British Columbia Hydrometric Survey maintained two stations in the Columbia River Basin[84] was continued. The division of the waters of the St. Mary and Milk Rivers between Canada and the United States under the International Joint Commission's Waterways Treaty of 1909[85] was continued and the measurement of the Rio Grande to fulfill the government's obligations under the treaties with Mexico of 1884, 1889, 1905, and 1906, was taken over by the Survey beginning in 1923.

84/ Follansbee, Robert, History of Water Resources Branch to June 30, 1919, p. 350.

85/ Idem, p. 349.

International Joint Commission.- The participation by the United States in the joint operation of gaging stations on the St. Mary and Milk Rivers and tributaries, and in the division of the waters of these rivers, continued under W. A. Lamb's direction and the costs were paid by the Bureau of Reclamation until 1927. The division of waters between the United States and Canada was started in 1918,[86] under Lamb's immediate supervision for the United States, and an appointed official of the Dominion Water Power and Irrigation Service. The treaty of 1909 provided that the St. Mary and Milk Rivers and their tributaries should be considered as one river, and that the flow should be divided between the two countries during the irrigation season from April 1 to October 31, in accordance with the terms specified. In 1925 Secretary Work appointed a Board of Surveys and Adjustment to investigate all Bureau of Reclamation projects, and in connection with the Milk River project the following recommendation was made:[87]

86/ Idem, p. 350.

87/ H.D. 201, 69th Cong., 1st Sess., p. 31.

> The cost of measuring the waters of St. Mary and Milk Rivers in accordance with the international treaty has been charged to the construction account of the project. It seems to us that this cost should not be borne by the reclamation fund at all, but should be cared for by Congress as an item of general importance to the country.

The recommendations of the Board of Surveys and Adjustment were enacted into law by Congress in 1926 and the Bureau considered that it was prohibited from spending the reclamation fund allotted to the Milk River project for any purpose except operation and maintenance. As the Comptroller General, on July 18, 1924, had ruled that the Bureau of Reclamation's appropriation for cooperative and miscellaneous secondary projects could not be used for carrying out the obligations of the International Joint Commission's Treaty of 1909, no Bureau funds were available for that purpose. It was therefore necessary for the State Department to obtain the necessary funds to meet the international obligations, and in its appropriation bill for the fiscal year 1928, it recommended an item of $10,000 to be transferred to the Survey to carry out the terms of the treaty to be made immediately available and to remain available until June 30, 1928. In justification of this appropriation the following statement was made:

> It is essential to the intelligent consideration by the Commission of the questions pertaining to these projects and to the protection of the extensive American interests to be affected, that systematic gauging of the streams mentioned be undertaken without delay and continued over a period of years.

The appropriation bill was signed February 24, 1927, and the $10,000 was available for carrying on the work during the remainder of this period (1919-28). In February 1927, 16 stations were being maintained jointly with Canada and as soon as the State Department funds became available, 8 stations were added, making a total of 24 international stations maintained jointly by the Survey and the Dominion Water Power and Reclamation Service of Canada.

With the beginning of the State Department appropriations for the work, the Commissioner of Reclamation was replaced by the Director of the Survey as the American representative, or "reclamation officer," charged with the measurement and apportionment of the waters of the St. Mary and Milk Rivers. Local supervision was delegated to Lamb as formerly.

International Boundary Commission.- The International Boundary Commission, United States and Mexico, was charged with the division of the waters of the Rio Grande between the United States and Mexico. The American Section had maintained by means of its own organization the gaging stations allotted to it until 1915 when the disturbed conditions along the border caused it to cease operation except for a short period from September 1919 to March 1920.

In 1922 the Mexican Section of the International Boundary Commission resumed operations and reopened not only the stations it

had maintained previously, but, as the American Section was still inactive, also a number of the American Section stations. This brought home to the American Commissioner, George Curry, the obligation to resume stream gaging on the Rio Grande, but unfortunately he had neither the funds nor the organization to do this. In his dilemma he contacted the Texas Board of Water Commissioners and stated that if the State, cooperating with the Survey, would reopen some of the discontinued stations, he would pledge his word that the money so expended would be repaid by the State Department through a deficiency appropriation, and that funds would be obtained to pay the cost of operation during future years.88/ The Texas district, being

88/ Statement of C. E. Ellsworth to the author.

interested in the records from the Rio Grande stations, agreed to this proposal. During the fall of 1923 and the ensuing winter the Texas district reopened the stations on the Rio Grande at Langtry, Del Rio, and Eagle Pass, and on the Devils River near Del Rio. A recorder was installed on the Devils River near Del Rio and cables were installed on the Rio Grande near Del Rio and Langtry. An engineer was stationed at Del Rio, who operated not only those stations, but others in the vicinity.

In support of Curry's plea for funds, the Survey made representations to the State Department with respect to the need for continuing the stations, resulting not only in a deficiency appropriation of $5,779.11 to reimburse the State of Texas, in the bill signed March 4, 1925,89/ but also in annual appropriations for

89/ 43 Stat. 1340.

continuing the work. The appropriation item for the years 1925 to 1927, inclusive, read as follows:

> To enable the President to perform the obligations of the United States under the treaties of 1884, 1889, 1905, and 1906 between the United States and Mexico * * * provided that not to exceed $6,000 of such sum may in the discretion of the President be used for taking over the water gauging now being done by the State of Texas.

Prior to the discontinuance of the work in 1915 the Commission had carried on its own work. However, Curry had no desire to enlarge his own organization so as to perform the stream gaging himself because the Survey could do the work for less than the appropriation. He therefore continued the arrangement made in 1923, paying the following approximate amounts:

1924	$5,779	1926	$2,900
1925	2,500	1927	3,000

The funds during the period 1925-27 paid for one engineer, whereas those for 1924 included also the cost of station equipment. In addition to paying $3,000 for the regular stream gaging during 1927, a transfer of funds amounting to $1,750 was made in June 1927 for a seepage investigation below Del Rio.

The situation in the lower Rio Grande Valley emphasized the need for additional water during low stages of the river, which could only be obtained by storage, and the water users urged that a treaty for that purpose be negotiated with Mexico. In 1925 President Coolidge appointed a commission consisting of Elwood Mead, Director of the Bureau of Reclamation, Gen. Lansing H. Beach, Ex-Chief of Engineers of the U. S. Army, and W. E. Anderson, a consulting engineer of San Benito, Texas, to negotiate such a treaty. During their negotiations they came to realize that additional stream-flow records were necessary, and the Commission's appropriation for 1928 contained an additional item of $4,000 for gaging stations at San Marcial, N. Mex., and El Paso and Fabens, Texas. However, this was only a small part of the increase in funds provided, as the first deficiency bill for that year carried an item of $21,000 for the State Department, with authority to transfer it to the Survey for work on the Rio Grande during the remainder of the fiscal year 1928.90/ The Commission transferred to the

90/ Water Resources Bulletin, Jan. 10, 1928.

Survey a total of $26,650 during the fiscal year 1928, which was expended in the establishment and operation of 10 additional stations and the assignment of resident engineers at the more important stations. An account of the enlarged program, which was started during the early winter of 1928, belongs to the next period of this History.

Current Meters

Inspection.- The care of current meters and the replacement of parts was continued under G. C. Stevens' direction until the summer of 1925, with minor repairs by Au and major repairs by the factory. The Survey had maintained for some years a section of field equipment which had been concerned with surveying instruments, chiefly those of the Topographic Branch. When the Department inspectors made their economy investigation of the Branch, in the summer of 1925,91/ they decided that the

91/ p.

care and repair of meters should be turned over to the Section of Field Equipment and this was done. However, as that section had no one familiar with meters and their care, the results were so unsatisfactory that on Sept. 1, 1927, the work was turned back to the Branch and assigned to Peterson. The supervision of meter ratings had remained in the Branch.

As an indication of the condition of meters as they were received from the field, Stevens revived the old hand-spinning test which had been used during the years of the per-diem appointments and later discarded. This test was not meant to be an exact measure of the ability of the meters to record accurately, but a rough and ready method of "separating the sheep from the goats." It was described at the 1921 conference and some district engineers ascribed such great value to it that, as Stevens says,92/ they went home and started spinning their meters

92/ Statement to the author.

so diligently that meters of all sorts and conditions began to arrive in Washington. Some were in such poor condition that it was apparent that proper care was not being given to meters in all instances. More or less critical correspondence followed with the less careful engineers, which resulted in greater subsequent care. During and after 1921-28, the spinning test became a fetish in many districts, but finally there was a realization that the spinning test had only a limited application and value in the inspection of a meter that it again fell into general disuse.

Improved meter.- The repair of meters, so far as it could be done without return to the factory, was one of Au's duties and the experience gained led him to suggest several changes in the design of the Price meter. He discussed this subject at the 1925 conference and was instructed to try out his ideas. Accordingly, he redesigned parts of the standard meter, making the greatest changes in the frame and bottom pivot. He inserted two binding posts in the head, one for indicating single, and the other for indicating five revolutions, this doing away with the necessity for having two heads as used with the combination meter. He made the pivot bearing considerably larger, and rounded the pivot point to simulate at the time of rating, the conditions under which the meter would be used in the field.93/ W. & L. E. Gurley, the manufac-

93/ Statement to the author.

turers of the Price meter, adopted these changes and made several such modified meters, sending them to the district offices for trial in March 1926. Field use resulted in some minor changes which were adopted in a later model that came into general Survey use under the name of the

Just as Haskell had condemned the changes made by the Survey in his meter,94/ so Price condemned not only the latest changes, but

94/ Follansbee, Robt., Hist p. 50.

those made previously by the Survey in the Price meter. Writing to Gurley, he stated:95/

95/ Letter of Mar. 29, 1927, to W. & L. E. Gurley.

I cannot comprehend how an engineer, who must have known the conditions under which a meter has to operate, could have designed such a device.

Twenty-five years or more ago, you changed the design of the meter to a form that I believe to be much less efficient * * *.

The upper bearing of this (improved) meter has no air trap to keep out water and grit and the lower bearing is nearly as inefficient. The upper bearing housing is, I believe, four times larger than necessary. * * *

After enumerating further defects he concluded by stating that he would like to have Gurley build at his expense, a meter that he would not be ashamed to have bear his name. Price died, however, before this was done.

Screw-type meter.- For many years every one within the Survey, as well as engineers outside, have realized that there were certain weaknesses in the cup-type meter, as there were in the screw-type meter which was being used not only in Europe but to some extent in the United States, and the Survey had been criticised for ignoring the screw-type meter. The objective sought in the development of the Price meter had been at all times to obtain a meter that could be used with confidence and at reasonable cost of operation under the wide variety of conditions found in stream gaging throughout the country. The screw-type meter had not been so developed, and it appeared that if a meter of the screw-type having universal applicability could be developed, it might have definite advantages over the cup-type meter. If it could be so developed and tested alongside the cup-type meter, one checking against the other, under the wide variety of conditions of the field operations, an answer would be found to many critics.96/

96/ Letter from N. C. Grover to the author.

This matter was discussed at the 1925 conference and as a result Au began work on a screw-type meter. After testing a model as best he could in Washington, he sent it to Lee in Columbus, Ohio, for field use. The results were do disappointing that work on the screw-type meter was temporarily abandoned, and due to the pressing demands for other lines of investigation, was not resumed. As Grover states97/

97/ Op. cit.

The problem still remains with us, therefore, and no one has yet developed a universal meter of the screw type, although I think we are all agreed that we would like to have such a meter.

Improvement in Equipment

Meter cable.- Perhaps the most perplexing problem of field equipment during this period, and one that was not satisfactorily solved, for the time at least, until 1927, was that of meter cable, for use both with hand lines and reels. Owing to the importance of the subject in the practice of stream gaging, the detailed description of that solution appears warranted.

The Van Orstrand cable, in use since 1915, had not been entirely satisfactory for use in hand lines as the soft copper wire broke frequently, thus destroying the return circuit. The 1921 conference recommended the investigation of the possibility of obtaining a new cable of the Van Orstrand type in which the two single copper wires would be replaced by a single strand of copper wire. The Roebling Company was consulted and a small amount of experimental cable was made in 1922. This cable, which had a low breaking strength of 145 pounds, was sent to the various districts for trial but was found to be so unsatisfactory, especially when used with heavy weights, that it was soon abandoned.

The establishment early in this period of additional stations on streams having great depths and high velocities required the use of weights heavier than 30 pounds, and reels were being devised to handle these weights. The Van Orstrand cable, although it had a breaking strength of about 200 pounds, was not satisfactory for use on reels as the insulation was easily abraded. As there was no stock cable on the market having a return circuit wire, Ellsworth had been forced to use airplane strand in measuring the Colorado River at the original Topock station, where three 30-pound weights were used. Similar equipment was used by the hydrographers of the Southern California Edison Co. at Lees Ferry until March 1922 when a 105-pound weight was furnished by the Survey. This means of supporting the meter involved the one-wire system which was not altogether satisfactory in some districts but was accomplished successfully at the Colorado River stations by trailing the return wire in the river. To avoid using the one-wire system with airplane strand, Paulsen in Idaho and Williams in Missouri wrapped a fine insulated return wire around the airplane strand and thus completed the circuit. This method had been in general use before the introduction of the Van Orstrand cable.

Ellsworth appears to have taken the lead in attempting to develop a two-conductor cable for use with heavy weights on a reel after he went to Texas in 1918, where he found the urgent need for such a cable. Through a representative of the American Steel and Wire Co., a special cable was made consisting of an insulated copper core with airplane strand wire wrapped around it. When in use the airplane strand tended to unwind and elongate, thus stretching the copper core. Upon being freed from the weight, the wire would rewind itself and cause the insulated core to buckle and protrude through the outer covering, thus causing a short circuit.98/ In 1923 Kinnison corresponded with the Chicago office of the American Steel & Wire Co. and after

98/ Statement of C. E. McCashin to the author.

some delay the company agreed to consider the manufacture of a special cable. The matter was then referred to Au. The unsatisfactory status

of cables brought forth many complaints from the district engineers. King reported that during the preceding year his district had had difficulty in getting along with such cable as could be bought, begged, or stolen. Kinnison reported that poor meter cables had caused the loss of four meters in four years. Beckman reported the loss of a 75-pound weight.99/

99/ News Letter Sept. 10, 1923.

The following year (1924) Au consulted with various manufacturers regarding cables and as a result Roebling made a special armored cable 0.08 inch in diameter having a breaking stress of 145 pounds. This appeared to be suitable for hand lines and upon being shown at the 1925 conference, the district engineers requested that a supply of it be ordered for trial. An order for 5,000 feet was placed and when received was sent to the field for trial in 1926. This likewise proved unsatisfactory, due chiefly to its low breaking strength, and was discarded.

These efforts had proved unsuccessful and as the Van Orstrand cable was the most satisfactory for hand lines, which constituted perhaps 90 percent of the use at that time in current-meter measurements, another supply was ordered. The use of airplane strand and the one-wire system with reels was perforce continued.

Early in 1927 the Texas district again attempted to obtain a cable satisfactory for use on reels with heavy weights. After some correspondence the American Steel & Wire Co. made up an order of 1,000 feet 3/32-inch galvanized steel strand with an insulated copper core. This cable was found to have a breaking strength of only 400 pounds, as determined by tests made at the laboratory of the University of Texas. In sending samples of this cable to the district offices, Ellsworth stated:100/

100/ Letter of May 25, 1927, to the author.

We hoped when we ordered this cable that it would develop sufficient strength for use on a winch with heavy weights under severe conditions. It does not give the desired strength but we believe it will prove satisfactory for use * * * or on a winch with a 50-pound, or possibly a 75-pound weight.

We are now endeavoring to obtain a cable with approximately double the strength (800 lbs.) using the same type of copper wire.

Finally in September 1927 Ellsworth, while in New England, conferred with Kinnison and they went to the Worcester factory of the American Steel & Wire Co. and laid their troubles before the factory superintendent. Ellsworth, from his experience with the airplane strand wound around a copper core, suggested that the tendency to unwind might be overcome if a second strand was wrapped around the first in a reverse direction. The superintendent agreed with this idea and an order was placed for 1,000 feet of reverse-lay cable having a breaking strength of not less than 1,000 pounds, to be delivered at an early date. The shipment of cable was received at Washington during the conference of Oct. 17-22, 1927. It was later tested by Ellsworth and found to have a breaking strength of about 1,100 pounds.

Prior to the 1927 conference a field-equipment committee, consisting of Ellsworth, chairman, Au, Dickinson, Harrington, King, Kinnison, and Lee, was appointed. In its report to the conference the committee recognized the need for two general types of meter cables and urged the development of (1) a strong, smooth cable for use on reels for deep soundings and high velocities and (2) a rougher, flexible, and perhaps weaker cable for hand lines. For the former, the sample just received appeared to be a good starter; for the latter, a modified form of the Van Orstrand cable having a breaking strength of 400 pounds was recommended. The conference endorsed the committee's report and requested it to continue its effort to develop meter cables suitable for all classes of work, with the suggestion that Kinnison, from his Boston headquarters, supervise the experimental development of these cables at the factory of the American Steel and Wire Co. at Worcester.101/

101/ Minutes of conference of 1927, session of Oct. 19.

The result was the production of two sizes of Ellsworth reverse-lay cable having diameters of .10 and .125 inches, and breaking stresses of 830 and 1,430 pounds, respectively. The larger was the original size, and the smaller was a somewhat later development required in the construction by the Columbus office early in 1929 of some 40 or more of the Lee-Au reels, the threading devices of which were designed for a smaller cable. The reverse-lay cable, although it did not kink, was relatively stiff and was not particularly well adapted for use with hand lines. Therefore, during the development work a direct-lay cable was made which was more flexible and having a rough surface was better suited for hand-line use. This also was made in two sizes, 0.09 inch, the smallest which the factory could conveniently manufacture, and 0.11 inch. The breaking stresses were 520 and 715 pounds, respectively. To distinguish this cable from the Ellsworth reverse-lay, the Survey designated it as the Kinnison cable.

Meter cable accessories.- The use of the new types of meter cable required special connecters for fastening the cable both to the meter and to the superservice cord which had gradually come into use chiefly through Lee's experiments with it in Ohio. The No. 16 size which he recommended had a breaking stress of 460 pounds. Au designed such connecters, which have become standard in the Survey.

Both the Ellsworth and Kinnison cables were used extensively with hand lines. Although these cables were attached to superservice or similar cord, making it easy to handle them when the meter was in place for the velocity determinations, it was necessary to handle the small cables in lowering and raising the meter, and when attached to 30-pound, or perhaps 50-pound weights, this was difficult. As it was necessary to use during any one measurement only a sufficient length of small cable to keep the superservice cord out of the water, a length which varied widely with different gaging stations and different stages, a small reel on which the excess small cable could be wound, was designed by J. H. Morgan in 1928 for insertion between the large and small cables.

Meter weights.- The experience gained in 1921 in measuring the Colorado River showed the great need for weights heavier than the 30-pound weight then in use. Although three 30-pound weights were used, their cross-section offered great resistance to the current, and it was evident that a single weight would be more satisfactory. Accordingly, Au, in 1922, using the 30-pound weight as a model, designed and constructed one weighing 105 pounds. The use of this weight at Lees Ferry during 1922, led to the conclusion that a lighter weight with a supporting cable of smaller diameter and high tensile strength would be just as effective. Au thereupon designed and constructed a 75-pound weight. Tests in the rating flume of the Bureau of Standards to determine the distance the meter should be placed above the weight to be beyond its influence showed this to be 1 foot above the bottom of the weight. During these tests the weight, which had four fins similar to those on the 30-pound weight, swung so far to the side that it was necessary to add a large vertical fin. The mold for the new weight was turned over to the Tacoma district, from which the weights were obtained.102/

102/ News Letter June 11, 1923.

The subject of meter weights was discussed at the conference held Oct. 22-27, 1923, and it was decided that further development work should be done. The Navy Department was making tests of the resistance of various shapes of ship bodies, and Au discussed the Survey problem with Naval officers. It was decided that an elliptical shape was more suitable than the torpedo shape used previously. In the spring of 1924, Au designed a 30-pound weight of the new type and tested it at the Bureau of Standards with different shapes and sizes of vanes. Upon the completion of these tests, patterns for 15-, 30-, 50-, 75-, and 100-pound weights were made and experimental weights cast. After perfecting the design, which included the addition of a vertical fin similar to that used in the earlier 75-pound weights, molds were made. These molds were turned over to the Ohio district, which was able to have the weights made in the University shops. In this connection Lee wrote in 1925:103/

103/ News Letter June 10, 1925.

> Orders have been received for about three tons of weights which will be shipped from Columbus in August. The Washington office has paid $400 from its contingent fund for the weight molds and the top cost of arranging for production here. The Ohio State University foundry and machine shop are doing the work practically at cost.

Reels and booms.- The use of heavier weights required means for handling them. A few reels had been devised and used prior to 1919 but no standards had been adopted. Ellsworth in Texas, beginning about 1919, made use of a stock article described as a "small winch not geared." This had a circumference of 1 foot. The next year he made a drum from an 8-inch well casing on which spiral grooves were cut to the size of the cable in use, and then welded this drum to the stock winch.104/

104/ Statement of C. E. McCashin to the author.

Rice, beginning about 1922, had made locally a metal reel with drum of 2-foot circumference for use at the Colorado River stations. The stock article selected by Ellsworth was used by one or two other districts during the greater part of the period. These reels were used chiefly when making measurements from cable cars and were mounted on the sides of the cars.

There was need for some means of supporting the reel where measurements of large rivers were made from highway bridges, and in 1922 Williams designed what he called "a travelling reel" for use in measuring the Missouri River at Leavenworth. Before the reel was perfected he resigned and Beckman completed it. Early in 1924 King in Tennessee and Lee in Ohio designed, independently, reel supports which the former designated "a frame for using heavy weights when working from bridges" and the latter, "an apparatus for handling the meter outfit." As yet the term "boom" had not come into use in stream gaging. Ellsworth also used his well-casing drum in making arrangements from bridges by attaching it to a 2" x 8" timber which rested on the handrail.

The field-equipment committee appointed for the 1927 conference reported that development work on a "crane" for flood measurements from bridges should be carried on, and as both King and Lee had been working along that line, they were selected to carry out the development work. A sub-committee, consisting of Dickinson, King, and Au, was selected to develop a reel for use on cranes and gaging cars. The outcome of their labors belongs to the next period of this History. The conference decided that "the cost of this development work should be prorated among the various districts in fair proportion."

Lines for wading measurements.- The lines for marking distances across the stream during wading measurements had quite generally been fish lines or Irish flax, marked at suitable intervals in various ways. The California district was apparently the first district to use airplane strand for that purpose, at about 1919. Ellsworth exhibited at the 1921 conference a similar line of 1/32-in. diameter, which was being used in Texas. It was marked at 5-foot intervals by drops of solder. This line met with considerable favor and was used in Ohio and in Tennessee, but its use during the period was not general.

Water-stage recorders

Au recorder.- The outstanding new instrument developed during the period was the Au water-stage recorder. The development of a new recorder was a product of evolution that was not originally contemplated. The recorder had its genesis in the considerable trouble that was given by the clocks on the Stevens and Gurley recorders,--trouble which resulted in a dishearteningly large loss of records. When Au had finished building the integrators in 1921, so much trouble was being experienced with recorders that he was sent on a field trip to New York and New England to inspect the recorders in those districts, and to determine if possible the cause or causes of the trouble. He soon discovered that an important factor in causing loss of records was the clock. Both manufacturers were using a model of Seth Thomas clock, which was not suited to the work required of it;

furthermore, the gears by which the clocks operated the recorders were not standardized on either make of recorder, and thus on neither could a clock be replaced by another. This lack of interchangeability was responsible for a part of the lost records as it was sometimes several weeks before a clock could be repaired or cleaned and replaced on the recorder.

Au suggested the use of the Chelsea clock, which was designed for marine use and apparently was better adapted to recorder use because of its 7-jewel movement. Two of these clocks were purchased for experimental use and Au made drawings for an interchangeable mounting of the clock. A Stevens recorder equipped with the interchangeable clock was exhibited at the 1921 conference and as a result Au was instructed to continue his work on recorders. He equipped several Stevens recorders with the Chelsea clocks and in 1922 the Washington office sent these to various districts for trial. Three were used on the Colorado River stations which were established that year. These stations were so isolated that recorders with interchangeable clocks were necessary to avoid loss of records. The clock on the Lees Ferry recorder was so accurate that the local residents set their watches by that "standard time."105/

105/ News Letter June 11, 1923.

The Stevens recorder was not equipped with a take-up roll on which the paper containing the gage-height record was wound, and considerable loss of record resulted from the failure of the paper to feed properly into the box provided for that purpose. In 1916, while in Alaska, Canfield had devised a take-up roll which, although crude, worked successfully. Au improved on this design and equipped several Stevens recorders with take-up rolls.

The more Au worked with the recorder the more ideas regarding it he had, and the more changes he made. One of the most radical was the elimination of the reversing mechanism and substitution of the rack with two pencils, so designed that when the first pencil reached the top of the chart, the second pencil came into action at the bottom. A general redesign of the large Au (geared drive) recorder eliminated 25 parts. When these changes were decided upon, Au made up the first direct-drive recorder embodying them, and the Washington office sent it to Leupold, Volpel and Co. for inspection, with the thought that the latter would manufacture the new instrument. Some of the changes had previously been suggested to J. C. Stevens by the Survey and although he was unwilling to make them himself (being the Company of Leupold, Volpel and Company) he was willing to have the Survey experiment with his recorder, expecting that the relatively minor changes resulting could easily be adapted to it. However, the recorder that was presented had so many radical changes that it was virtually a new instrument, and to have adopted it would have required the expenditure of a very considerable amount of money to equip the factory with the new machine dies, and a very considerable time to perfect the new design. It virtually meant scrapping his own instrument, for which there was an established market, and he naturally hesitated to take that step. Later, Julien P. Friez and Co. agreed to manufacture the new continuous recorder as the only recorder they were then making was a weekly instrument which had been superseded to a very considerable extent by the newer instruments of Stevens and Gurley.

The first Au recorders, as the new instruments were termed, were manufactured in 1922. At the 1923 conference the district engineers expressed a desire for a recorder which would operate a month and to develop this type Au, in 1923, designed the fuzee by which the rate at which the takeup roll revolved would vary with the quantity of paper wound on it thus attempting to insure uniformity of travel of the paper beneath the pencil. The fuzee recorder as finally developed insured operation for 60 days. Still later, in 1925, an instrument known as the drum type, giving a weekly record, was developed, in which the drum or cylinder was much larger than those in the weekly type of other makes, and the time and gage-height axes were interchanged, giving a much larger time scale. To avoid loss of record if the chart was not changed each week, Au designed an endless screw giving a reversal and hence unlimited stage. This reversal feature was placed on the Fuzee recorder instead of the rack with two pencils. The Fuzee recorder thus equipped became, for a time, the standard Au instrument and the manufacture of the continuous recorder was temporarily discontinued until 1926, when it was again manufactured.

Increase in use of recorders.- The makers of the Stevens recorder, doubtless influenced by the extensive use of the Au recorder, made a number of improvements in their instrument. The Gurley instruments, the only other recorders used extensively, underwent only minor changes.

The increase in available funds caused an increase in the number of recorders from 449 in 1919 to 958 in 1928. Of this latter number 434 were Stevens, 191 Gurley, 75 Friez, 212 Au, and 46 miscellaneous types. As 36 percent of the stations were equipped with recorders in 1919 and 53 percent in 1928, the increase in the number of recorders more than kept pace with the increase in the number of gaging stations.

Gaging-station equipment

Recorder installations.- A total of 525 recorder installations was made during the period, including 16 reinstallations made to obtain higher standards. The total number of recorders in use at the end of the period was 958.

At the beginning of the period the standard plans were those contained in Water-Supply Paper 371, published in 1915, which had in that year been optimistically considered the last word. The Washington district had developed plans for a timber shelter of tongue-and-groove construction which had been published in 1918. The California district had developed standard plans for reinforced-concrete shelters but these had not been circulated widely through the Branch as the other districts had not, in general, been able to build such relatively expensive structures.

The inadequacy of the existing plans was recognized and the program for the 1921 conference contained the following topic:

> Standard plans and specifications for concrete and timber gage houses. Discussion to include intake pipes, maintenance, and precaution to be taken against freezing.

No minutes of this conference are now available, but the ideas expressed were embodied in a mimeographed report prepared in the Washington office entitled "Installation of water-stage recorders," which contained plans for both timber and reinforced-concrete shelters and showed pictures of typical structures. No radical changes from the previous plans were made and the report was published for the purpose of making the existing plans more generally available.

The increase in available cooperative funds made it possible to install so-called permanent stations equipped with recorders, and better standards of construction were sought. The California district had a large amount of State and other cooperative funds and continued to lead in the installation of reinforced-concrete structures, with 50 of that type. Perhaps the most concentrated program was that undertaken in Ohio by Lasley Lee, beginning in 1923. The State appropriations provided for the establishment each year of six or more stations equipped with recorders. As the Ohio district was cooperating with a State official who was a professor of engineering at the State University where the district headquarters were situated, the construction program was so planned as to provide employment for students, thereby concentrating construction activities into the summer vacation period. In order to make the greatest progress in this short season, Lee organized two parties, each consisting of a Survey engineer and three students, and equipped each party with a light Ford truck, a trailer, concrete mixer, and a centrifugal pump. One party had the unusual experience of living on a five-room house boat furnished by the State. The number of Ohio stations installed annually increased from six in 1923 to fourteen in 1926, the total number for the period being 38.

The experience gained during the first two years led Lee to begin a series of reports entitled "Equipment for gaging stations for measuring river discharge," which were issued in mimeographed form. The first, covering plans and specifications for reinforced-concrete house and well, was issued in 1925. The next year's work resulted in a modification of these plans and specifications, the principal change being the enlargement of the inside dimensions of the well from 3'x4' to 3'6"x4'. This revision was issued in 1926. Additional experience resulted in a further revision in 1927 which laid greater stress on the appearance of the finished structure, and on the details of the plans than had the previous issues. These latest plans had an arrangement of cupboard and recorder shelf that had been suggested by the Texas and New Jersey districts.106/ They became standard in Survey practice and were used as a basis at least

106/ News Letter Mar. 10, 1926.

for the 181 concrete shelters constructed during the period. That Lee's work in raising the standard of gaging-station equipment was welcomed by the Branch is shown by the following quotation from the minutes of the 1927 conference:

> The excellent work of Mr. Lee in designing plans and specifications for standard shelter and cable installations was greatly appreciated by the conference. Owing to the considerable time and expense involved in such work it was suggested that the cost thereof be prorated among all the districts.

The Washington district was also active in constructing concrete shelters, and one of its 38 shelters of that type was the second highest concrete structure installed during the period, that on the Skagit River near Concrete Parker constructed a well 49 feet high from bottom to the floor of the house. It was placed in a niche excavated in a rock cliff, and the well was built to fill this niche being, 6 feet square at the bottom, and tapering to the then standard size at the top.

The highest concrete structure was installed by the Tennessee district on the Tennessee River at Riverton and had an overall height of 69 feet. Ten concrete shelters, which were described as being "made more or less according to standard plans" were constructed in that district.

By about 1920 the New York district had found that during the winter months condensation of moisture in concrete structures formed a sheet of ice which made the shelter very damp when the ice was melting, and that in timber houses on concrete wells, this condition was avoided to a great extent. Accordingly, the combination timber-and-concrete structure became the standard in that district. When Hartwell went from New York to New Jersey in 1921, he began to install similar structures. However, after several years' experience, he decided that the winter climate in New Jersey was sufficiently mild to permit the use of concrete shelters without the disagreeable results experienced in New York. He found that all-concrete shelters could be installed as cheaply as the timber-concrete structures and could be maintained at less expense. Therefore, when Lee's standard plans for concrete structures were published, they became the standard for shelters built subsequently in New Jersey. Seventy-four timber-concrete shelters were constructed during the period of which 28 were in New York, 22 in Idaho, and 17 in New Jersey.

Concrete block shelters were used to a limited extent. Hartwell installed four concrete-block wells and one concrete-block house in New Jersey, hoping to reduce the cost of a concrete shelter by eliminating forms. Experience showed, however, that there was no economy in the concrete-block structure and its use was abandoned. At least one concrete-block structure was installed in New York.

Prior to 1920 a number of so-called "pipe wells" were constructed with various types of shelters, but there was no standard design. During the latter part of the period, McGlashan designed and used a galvanized, corrugated-iron well and full size shelter of the same material. As he states:107/

107/ Letter to the author.

> The galvanized corrugated, culvert-pipe well and house was designed to meet a very definite need in this district. The wooden type installation was not very satisfactory and its life was short. On most streams it did not appear that even if funds were available, the construction of concrete wells was desirable. * * *
>
> The culvert-pipe type of installation appears to meet satisfactorily the requirements of low cost, durability, quick installation, good appearance, and can be readily moved.

His plans were mimeographed in 1929. A total of 63 galvanized-iron installations were made by the various districts but the number conforming to the McGlashan type is not known. He constructed 16 in California. The highest pipe well was installed on the Tennessee River at Chattanooga, Tenn., with a length of 60 feet. It is probable that many of the pipe-well installations were surmounted with small timber shelters. In that connection the Arizona district stated:108/

108/ Water Resources Bulletin, July 10, 1928.

> A matter which too frequently escapes attention when discussions are had concerning design of gage houses * * * is the adaptability to local conditions. A recording gage structure which is practical, economical, and beautiful on the wooded bank of a placid stream * * * not far from a town in Ohio, might not be practical or economical in an isolated canyon in Arizona. Certainly some of our iron-pipe wells with little box gage shelters would not look so well along the beautiful (though sometimes odorous) eastern rivers.

There were 150 timber wells and shelters installed during the period and as no new standard plans were prepared, it is probable that those issued in 1921 were followed or were modified to meet particular needs. One of the most satisfactory plans that was used by several districts, was made by Glann L. Parker. It provided for tongue-and-groove siding, which formed a very rigid structure. The first one of these was built by Parker in 1915. A type of timber structure used in 21 installations in Hawaii had the shelter made of composition roofing on a timber frame. Eleven of these "paper" shelters were built large enough (8' x 8') for use as over-night camps. As Max Carson writes,109/ the shelters were in general not

109/ Letter to the author.

up to Survey standards since it was necessary to keep the quantity of materials to a minimum as everything used had to be packed by men over mountain trails.

Miscellaneous structures not included in the foregoing types accounted for 41 of the 525 installations.

The preparation of standard plans served as important inducement to construct better types of shelters in those districts where funds were sufficient for that purpose, and the incentive to follow such plans was undoubtedly strengthened by the wide ranges in appearance of structures of the various districts that was disclosed when photographs were made in 1926 for the Branch exhibit at the Sesqui-centennial Exhibition at Philadelphia. Referring to this comparison, the Washington office stated:110/

110/ News Letter May 10, 1926.

> The lack of uniformity in the construction of the Branch has been made conspicuous, and the general absence of artistic or even pleasing appearance of structures, especially gage shelters, has been very noticeable. While there is no desire to suppress individuality, it is suggested that in general much better results and efforts will be obtained if standard plans for recorder stations are adopted and followed except for the best reasons. * * * In order to promote a higher standard of appearance at gaging stations, a water-stage recorder will be presented next Xmas to the district that submits photographs showing the most artistic water-stage installation made during the season. The award will be based wholly on the general appearance of the station in relation to its environment.

Seven districts submitted photographs in competition for the prize, which was won by Ebert for the station on Mill Creek near Craftonville, Calif.111/

111/ News Letter May 10, 1927.

Flushing devices.- The standard plans issued during the period did not include devices for flushing the intakes, probably because the engineers who prepared the plans were not troubled by streams carrying any considerable amount of sediments. Lee's later plans recognized the troubles that resulted from the filling of intakes and wells in sediment-laden streams and provided for more than one intake, the lowest being placed 8 inches above the bottom of the well, thus forming a sump. The sump was apparently first used on the Rio Grande, where on account of the heavy sediment load, J. L. Saunders installed an intake 1 foot above the bottom of the well. Apparently, several districts began the use of the multiple intake at about the same time, and those districts that had to maintain stations on sediment-laden streams were also developing flushing devices. The first was devised by Parker in the preceding period.112/

112/ Follansbee, Robt., Hist. of Water Res. Br., of June 30, 1919, p. 362.

One type of these flushing devices was equipped at first with 2-inch riser pipes, 6' to 10' long, but this plan was later changed by attaching, at the top, pieces of 6-inch pipe, 3 feet long, to provide greater capacity for the water used in flushing. From this plan the idea of a tank under the shelter floor was later evolved.113/

113/ Letter from Glenn L. Parker to the author.

In 1917, Lamb equipped the station on the Milk River at eastern crossing of the international boundary with a riser pipe having a cut-off valve. The first use was made of a tank in Iowa in 1922. After a force pump with $1\frac{1}{2}$-inch outlet had been tried without success, an ordinary kitchen hot-water tank was attached to the pump and the outlet provided with a gate valve, which proved to be satisfactory. Force pumps were first used by C. E. Ellsworth in Texas in 1920, and by H. B. Kinnison in Kansas and Lamb in Montana in 1922. These pumps did not prove satisfactory and were abandoned in favor of a riser pipe as it was used by Parker. In 1923 Parker equipped the shelter on the Skagit River at Newhalem with a system of pipes and valves connected with a water-supply system. In 1924 Henshaw installed a

flushing device on Lewis River where the intake was equipped with a gate valve and a ½-inch riser pipe, to the top of which was soldered a tire valve. It was expected that the sediment would be forced out by the use of a bicycle pump, but the operation was unsuccessful. A similar device was used by Burchard in North Carolina.

Burchard, in 1928, evolved a flushing device which consisted of a vertical timber riser pipe 4" x 4" in diameter attached to the horizontal 4" x 4" timber intake. A timber wedge placed near the inner end of the intake acted as a gate valve. A wooden block 4 inches square fastened to a rod acted as a plunger to force water down the riser pipe and through the intake.

The lower Colorado River carries such a heavy load of sediment that recorders were installed in wells without intakes that were fastened to the walls of the canyon. The wells had a series of clean-out doors at elevations covering the range of river stage. These doors not only admitted the water to the wells but facilitated the removal from the wells of the accumulated sediment--a major problem in Arizona.114/

114/ Letter from W. E. Dickinson to the author.

Riser pipes gradually came into use during the period. Lee, in his 1927 plans recommended the installation of intake valves and riser pipes. About 25 stations were equipped with riser pipes by 1928.

Another type of flushing device used to a limited extent was devised in the Texas district about 1921. It was a funnel or hollow cone placed on the bottom of pipe wells. The sloping sides helped dump the sediment into the river through the opening at the bottom of the cone.

Cable installations.- In connection with the general raising of standards of Survey equipment, improvements were made in cable installations. Although such improvements were being made in several districts, Lee volunteered to assemble the various changes into a new report on standard plans and specifications, as his continuing construction program impressed on him the value of such action. He called upon the various district engineers for suggestions, and later stated:115/

115/ News Letter May 1923.

> So far only five districts have made suggestions to help us in the work of preparing plans and specifications for cable installations * * *. It will be greatly appreciated if more of the engineers will take the time to look through W.S.P. 371 and let us know what they think of the plans and instructions previously published and what changes they would make to bring them up to the present standard and practice.

These suggestions were the basis for his new plans, which were mimeographed in 1923.116/ Further suggestions and his own

116/ Equipment for gaging stations for measuring river discharge, April 1923.

experience during the next two years resulted in a companion paper containing the specifications for cables and their erection.[117]

117/ Plans and specifications for structures from which measurements of discharge are made, 1925.

Cable installations were discussed at each of the conferences. These discussions and the further experience gained during the ensuing years resulted in another revision in 1928 which was issued, like the 1925 report, in Lee's series of reports under the general title of "Equipment for gaging stations for measuring river discharge."[118] In both reports the diagram for cable sag was based on a

118/ Plans and specifications for structures from which discharge measurements are made, 1928.

formula used by the cable manufacturers. This formula gave considerably greater sags than was indicated by the diagram published in Water-Supply Paper 371 which was based on J. C. Stevens' formula.[119] In both, the

119/ Follansbee, Robt. Hist., p. 228.

factor of safety was taken as six. In justification of this value, Lee stated:[120]

120/ Idem, p. 4.

> In general the factory of safety of six is none too large considering that the cable will deteriorate in time, that trees used for one or occasionally both supports may sway in the wind causing unusual strains, that drift catching on the meter line may exert an excessive pull, or that heavy branches or small trees may fall across the cable.

The suspended sheave advocated in Water-Supply Paper 271, which had found scant favor in most districts, was changed to the sheave fastened directly to the headplate in the A-frame. Water-Supply Paper 371 had specified galvanized plow-steel cable for all sizes of spans, but Lee recommended galvanized cast steel for spans less than 500 feet, and plow steel for spans from 500 to 800 feet. He further recommended that for spans greater than 800 feet galvanized plow-steel tramway cable be used as it is smoother and stiffer and cars can be operated on it with less effort than on the other kinds of cable--a very important consideration for long spans. The use of factory installed sockets was recommended with the tramway cable. The sockets permitted a reduction in the factory of safety from 6 to 5, because they did not decrease the strength of the cable, whereas the clip connectors decreased the cable's strength by about 20 percent.[121] The changing ideas as to proper sizes of

121/ Statement of Glenn L. Parker to the author.

cables to be used to utilize their full strength is shown by the following specifications:

Size	W.S.P. 371	1925 Report	1928 Report
5/8"	Spans under 400'	Spans under 300'	Spans under 200'
3/4"	400' - 600'	300' - 600'	200' - 400'
7/8"	(not used)	600' - 800'	400' - 600'
1"	do	800' - 1000'	600' - 800'

The Lee specifications took into account the effects of temperature changes on cable sag and contained diagrams for use in estimating such effects.

Concrete cable anchorages were coming into more or less general use and perhaps the greatest advance was the preparation of detailed plans for such anchorages for use under varying conditions. The necessity for concrete piers on which to rest the A-frame sills was also stressed, and plans for such piers were prepared. Plans for A-frames for heights up to 33 feet were prepared and 8"x8" timbers were recommended for all heights. Water-Supply Paper 371 had contained plans for A-frames up to 20 feet and had recommended timbers varying in size from 2"x6" to 8"x10".

Although about 310 cables were installed during the period, few were notable in length or character. The longest was on the Columbia River at Kettle Falls, Wash., where a 1-inch galvanized plow steel cable of 1,538-foot span was installed in August 1921 by the Washington district. It was supported at one end by a wooden tower 38 feet high and was anchored directly into a steep hillside at the other. The clearance thus afforded was not sufficient and the cable was later reinstalled. The gaging stations on the Cumberland River at Celina, Tenn., required a cable of 850-foot span, and towers 100 feet high. The Army Engineers with whom King was cooperating, made these installations, using steel concreting towers which were available.[122] Two other cables of about 800-foot span were installed, -

122/ News Letter, May 10, 1924.

one, in 1922, on the Current River at Eminence, Mo., in connection with a Federal Power Commission project, and the other, 820 feet long, in 1924, on the Skagit River near Concrete, Wash. A notable feature of this latter installation was the 46-foot A-frames constructed of 12" x 12" squared timbers 50 feet long without splices.[123] This installation was one of the first in which the so-called "trapezoidal" type

123/ Letter from G. L. Parker to the author.

of concrete anchorage with the connections above ground was used. This type was developed as a result of Parker's experience with reinforced concrete logs. Rapid corrosion that could not be prevented either by several wrappings of burlap saturated with asphaltum, or by galvanizing the cable occurred in the portion of cable underground.

Artificial controls.- The stream-contour type of artificial control which had been used extensively prior to 1919, when 45 controls were constructed, fell into disfavor for a variety of reasons and only 12 of that type were constructed during the present

period. Most of the streams on which controls were built, seemed to require some form of low weir, with or without a low-water section, and 34 controls of that type were constructed.

Hawaii continued to lead in the construction of controls, with 23, and the successful operation of those structures led Burchard to construct nine controls in North Carolina after his return from Hawaii. Hartwell constructed five in New Jersey, and Harrington three in New York. The California, Texas, and Oregon districts constructed two each.

Of the 23 controls constructed in Hawaii, seven were of the concrete and boulder type, following the contour of the stream bed, eight were concrete dams, roughly parabolic in longitudinal section, and eight were rectangular weirs with metal crests - six constructed of concrete and two of timber. The average length of these controls was about 40 feet. Not all of the controls were for the sole purpose of stabilizing the stage-discharge relation. Floods were so flashy in character as to make it almost impossible to rate some of the stations by current meter, and three weirs, at least, which acted as controls, were installed primarily to make possible the computing of flood flows by use of a weir formula.

In New Jersey, Hartwell built five controls. The first was on Absecon Creek at Absecon within tidal effect. A weir 30 inches high consisting of 2-inch planks set on edge on a concrete foundation of triangular cross section, 49 feet long, formed the control. It was high enough to eliminate all but the peaks of high tides which were easily recognized on the charts. Another was the gaging station on Lawrence Brook at Patricks Corner where there was serious effect caused by aquatic growth. A concrete weir 2 feet high for a length of 5 feet and 2.5 feet high for a length of 20 feet, was constructed on the sill of an old timber dam just below the station. A third was at the gaging station on Batsto Creek at Batsto, about 150 feet downstream from the tailrace of a power plant. Canoeing was a popular sport on this stream and the control structure must necessarily be such that it would permit the passage of canoes and would not cause backwater in the tailrace. Accordingly, two rows of light interlocking steel piling, 5 feet apart, capped by a 6-foot slab of 6-inch concrete, were constructed. The top of the slab conformed roughly with the original stream bed. A fourth was a low concrete control 55 feet long built on the Passaic River near Millington, and a fifth was 42 feet long on the Mullica River at Batsto where the control was a wooden sill 6 inches wide and 12 inches high on a concrete apron 6 feet wide. This station was within tidal effects.

Of the nine controls in North Carolina, six were built of masonry and three of reinforced concrete, all installed by Burchard with one or two assistants. Most of them were constructed on rough mountain streams where it was necessary to improve the natural measuring conditions by reducing the velocity for medium and high stages, and to provide proper conditions for accurately measuring low flow. Dams were therefore so constructed as to form pools, and, in these dams, weirs were installed by means of which the low flow was measured.

The control first constructed (1924) in North Carolina was situated on Morgan Creek at Chapel Hill. This station was maintained in cooperation with the University as a stream-gaging laboratory for the civil engineering students. The natural rock control was adequate but it was on a route frequented by pedestrians who placed crossing planks on the control, which affected the stage-discharge relations. To remedy this situation, Burchard built a rubble-masonry control 50 feet long and 3 feet high, with a 2-foot rectangular, sharp-crested steel weir in the center having a free fall of nearly a foot. The top of the weir sloped toward the center from each bank and was flat on top to serve as a footwalk. Rather than step across the 2-foot opening, the pedestrians again resorted to the use of planks to bridge it, but fortunately these were washed away by every rise in the creek and had little or no effect on the records. In 1925 two more controls of the same general type and about 25 feet long were built. In these, V-notches were used instead of rectangular weirs. The top of each was practically level across the stream, making the control relatively insensitive at low and medium stages.

One of these controls was situated on Flat River at Bahama at the site of a natural, wide, rock control which, however, was seriously affected by aquatic growth. A rubble-masonry dam, 100 feet long and 3 feet high, was built with a sharp-crested weir 10 feet long and 1 foot deep near one end and a notch 2 feet deep and 1 foot wide at the other end so designed as to afford a low-water control. In 1926 two more controls were built. One of them, on the South Fork of Mills River at the pink Beds, was a rubble-masonry dam 38 feet long with two 10-foot sharp-crested rectangular weirs, one set 0.6 foot lower than the other. The other, on Bee Tree Creek near Swannanoa was a relatively high masonry dam sloping toward the center where a 2-foot Cippoletti weir was placed in the bottom of a 4-foot rectangular weir. A 12-inch "blow-off" valve facilitated the removal of light material from the pool behind the control, but it was necessary to take out heavy gravel and boulders by wheelbarrow. This completed the construction by Burchard of rubble-masonry dams with weir controls for low-water flow.

Three more controls built by him during the period were reinforced-concrete dams about 2 feet high of triangular cross-section and down-stream aprons. Twelve-foot lengths of 2-inch angle irons were embedded in the crest of the controls, and had a slight slope across the streams. The first of these was built on the North Fork of the Swannanoa River near Black Mountain. Because of its length (90 feet) a notch for low-water flow was provided at one end. The second was 50 feet long and was built in a dredged channel having a soft bottom in Little Sugar Creek near Charlotte; and the third was 70 feet long built on Scotts Creek at Sylvia, where the natural control was badly shifting due, in part, to a heavy load of factory wastes. This type of control proved to be remarkably self-cleaning as the sharp edge of the crest did not catch the debris. Its chief disadvantage was the fact that its height above the stream bed created a scour downstream and a fill upstream, and these changes affected the rating for intermediate stages.[124] A model, known as the "Asheville type" was tested later

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124/ Letter from E. D. Burchard to the author.

at the National Hydraulic Laboratory, but the results were not as satisfactory as those for other types of control tested at the same time.

In Southern California the two controls installed on Rogers Creek near Azusa, and Eaton Creek near Pasadena during the fall of 1919 were of the type constructed in California prior to 1919, except that there were two barriers of concrete boulders 15 feet apart to form a pool between. After 1919, work on controls was limited to repairing and strengthening the existing structure.125/

125/ Letter from F. C. Ebert to the author.

In Texas Ellsworth constructed a reinforced-concrete control 14 inches thick on bedrock foundation in the Nueces River at Three Rivers. It had a total length of 73 feet, and had a notch 10 feet long and 10 inches deep for the low-water control. The control was built to a height of 3 feet at the notch in order to make it effective over a considerable range of stage, and to prevent submergence by the deposition of sand and silt below it.126/ The station on

126/ Letter from C. E. Ellsworth to the author.

the Guadalupe River at New Braunfels was above an old concrete road slab of the kind commonly used in the southwest to give firm traction at a ford. On this slab Ellsworth built a reinforced concrete structure 12 inches square in cross-section and 160 feet long, with 35-foot opening near the middle for the low flow.

Three controls were constructed by Harrington in New York. The control constructed during 1920, to replace a timber control built prior to 1919 on Little Tonawanda Creek near Linden was a timber structure 13 feet long with a flat crest. Low flow was confined to a sharp-crested rectangular weir with a crest elevation 0.67 foot lower than the main control. A timber control was built also on Otter Creek near Glenfield with a flat crest 30 feet long. The base was rock-filled timber cribbing. The control was intended to be a temporary structure and considerable leakage developed around and under it. The third control was constructed between the abutments of a bridge on Conesus Creek near Lakeville. It was about 25 feet long with crest parabolic across the stream and of rectangular cross-section. It was 1 foot above the stream bed at its lowest point.

The Oregon district constructed two log controls, one on Sandy River near the Mt. Hood highway, and the other on Zigzag River at Twin Bridges. At each station a notch 3 feet long was cut into each bank, and a log 1 foot in diameter was placed across the stream with the ends in the notches. Brush weighted down by sand and rocks was placed on the upstream side of the log, to prevent water from flowing under it and a log 6 inches in diameter was placed alongside the control log on its downstream side to prevent scour below.127/ The Washington district also constructed a log

127/ News Letter May 10, 1926.

control on East River near Elbe. Two 12-inch logs were laid crosswise the stream bed 6 inches apart extending into the bank at each end, and anchored to upright timbers set in the banks. The logs extended a few inches above the stream bed. A third log was placed across the stream about 4 feet downstream to serve as the foundation for the lower end of the timber apron on the downstream side of the control. Sheet piling was driven into the stream bed at the upstream side of the control to prevent water from flowing under it. Notches were cut in the center of the logs to carry the low flow.

The controls described were those constructed by the Survey. During the period, other gaging stations were built above artificial controls which had been constructed by other organizations, for that particular purpose or for other purposes, as rating flumes and permanent checks or drops in canals. These constituted perhaps a majority of the artificial controls so constructed.

One drawback to the successful operation of controls of the stream-bed contour type was the deposition of gravel and silt above them. To remedy this condition, Carson, early in 1928, built a small "scour" dam above the intakes, forming a pool between this upper dam and the lower, or control dam. Water falling over the upper or "scour" dam washed the gravel past the lower dam and kept the pool clean. This method was suggested by Ebert, who had tried it in southern California.128/ However, Ebert discontinued the use

128/ News Letter May 10, 1928.

of this type of control because of the hydraulic characteristics whereby, during low stages, the gage height might decrease with an increase in discharge when there was change from tranquil to "shooting" flow through the pool in which the intake to the recorder well was, of course, placed.129/

129/ Letter from Ebert.

Improvement in field methods

The development of heavy weights and strong meter cables, making it possible to measure velocities at 0.8 depth, led to the virtual abandonment of the sub-surface method of obtaining velocities at flood stage on the large rivers, particularly in the eastern districts, where the stream beds were less subject to scour than in some other parts of the country. One exception to this, however, was the practice continued in the New England district, where velocities at the 0.2 depth were observed during floods. Coefficients to reduce the 0.2-depth velocities to mean velocities were obtained by extending the curve of 0.2 depth coefficients based on vertical velocity curves made for lower stages.

Two-table method.- At gaging stations where stream beds scour and fill soundings are necessary for each discharge measurement. Soundings made in the usual manner are in error at medium and high stages if the depths and velocities cause downstream drift of the sounding equipment. If an increase in sounding weight and a decrease in diameter of sounding line will not produce the desired

result, a close approximation of the vertical depth may be obtained by making some additional observations and applying correction tables to the observed sounding. This procedure which became known as the "two-table" method of sounding was developed from the experience, gained in the operation of the Colorado River gaging stations, particularly Lees Ferry, during the years 1921 to 1923.

The experience at Lees Ferry went through the following phases:

(a) Followed the practice of "lopping off" a few tenths of a foot from soundings that were obviously too large.

(b) Measuring or estimating the vertical angle of the sounding line and applying the cosine of the angle to the observed depth. This became known as the "cosine method."

(c) Use of the Shenehon correction table. This, from Shenehon's description, was known as the "static method of sounding."

(d) Development of the "air-correction" table and its use with the Shenehon correction table which became known as the "water correction" table.

While making high-water measurements at Lees Ferry in the early part of 1922, with velocities of 9 to 12 feet per second and depths of 40 feet, I. G. Cockcroft, the hydrographer of the Southern California Edison Co. found that with a 105-pound weight on a single wire, the current carried the weight so far downstream as to form great angles between the wire and the vertical. This situation caused him much concern and he reported it to Rice who advised him to measure these angles by means of an angle-graduated board held against the line and correct his measured depths by means of the horizontal-angle coefficient prepared for correcting velocities of flow that were not at right angles to the measuring section. This procedure which became known as the "cosine method" was used in the original computations during the high water season of 1922.

As the records for the Lees Ferry station were very much in demand the measurements and computations for 1921 and 1922 were sent to Washington early in 1923 for checking and review. During this process B. J. Peterson noted that the high-water measurements as computed by Cockcroft's "cosine method" were subject to error because the cosing was applied to the observed depth, not to the wet-line depth, and no consideration was given to the bowing of the sounding line under water. A. H. Horton then introduced the "static method of sounding" which had been devised by F. C. Shenehon and C. B. Steward for use in making soundings of Niagara River. The Shenehon method provided a means of finding the true depth from the wet-line depth and the angle of the line at the water surface. Peterson then computed the first "air-correction" table which was needed to determine the wet-line depth from the observed depth if

the support for the sounding equipment was an appreciable distance above the surface. To use the "air correction" table the height of the support above water must be known. This distance and the vertical angle of the sounding line at or above the water surface when weight is in the sounding position are the additional data needed for use of the "two-table" method of sounding. A more appropriate name would have been the "Peterson-Shenehon method".

Stevens and Peterson then proceeded to revise the high-water measurements of 1922 so far as the necessary data were available, and prepared a description of the "two-table method" and suggestions for using it in the making and computation of high-water measurements. Before the resulting instructions reached the field, Cockcroft at Lees Ferry had been supplied with a copy of Shenehon's correction table and was instructed to use it. This he did for measurements made during April but he applied the corrections to observed depth, not to the wet-line depth. In his monthly reports for April and May he expressed concern over the fact that his measurements were not plotting 10 to 20 percent larger than the rating curve developed during the high water of 1922. Sometime during June Cockroft and his assistant, J. E. Klohr, solved the problem, worked out an "air correction" table, and when Dudley arrived about July 4 to instruct them in the proper use of the two-table method, they had already recomputed their June measurements.

In 1923 Stevens visited the Colorado River stations with D. A. Dudley and studied operation of the two-table method. The following winter Dickinson was in Washington, and in consultation with Stevens worked out a procedure for the fieldman's use in making soundings and in placing the meter for velocity readings. With the increased need for the two-table method on other rivers, the Survey issued it in mimeographed form in 1931.130/

130/ Method for correcting soundings of deep, swift rivers, by G. C. Stevens.

Tag-line method.- The development of heavy weights, reels and strong meter cables and the virtual abandonment of the sub-surface method of obtaining velocities at flood stages, caused a revival and wider use of the tag-line method of obtaining soundings. The tag-line method has two advantages: it eliminated (1) the necessity of reeling the entire length of wetted line to get the observed depth, and (2) the necessity for making an air-correction. However, if depth and velocity were such that a correction to the wet-line was necessary, the angle of the line would need to be measured and a water-correction table used.

In the Middle West, J. B. Spiegel and E. L. Williams were strong advocates of the tag-line method which had also been used in the Tacoma district for several years. The relative merits of the "tag-line" and "two-table" methods were discussed at conferences and by contributions to the Water Resources Bulletin.131/

131/ Water Resources Bulletin, May and September 1931.

Flood investigations

The practice of publishing annual reports on the floods throughout the country, which had been inaugurated by E. C. Murphy in 1903 and followed by him in 1904, and 1905,[132] was discontinued

[132] Follansbee, Robt., Hist., p. 132.

when he was transferred to the special debris investigations in California. The funds were too meagre to permit the making of general investigations during the ensuing period, but when exceptional floods occurred, one or two of the districts made special investigations and reports. These reports were not segregated into separate water-supply papers, however, but were contained in the regular annual reports of the measurement of stream flow. It was not until 1913 that a flood report was again published separately. This report related to the severe floods which occurred in the Ohio River Basin during March and April 1913, caused by heavy rains and the melting of deep, wet cover of snow. A. H. Horton was making a special study of the Ohio River Basin at that time, and the Army Engineers and Weather Bureau were maintaining stations on the main river and principal tributaries, at which daily gage heights were being observed. The stations on the main Ohio had been maintained for many years, and the Army Engineers had measured the discharge at both flood and low stages in the past. The channel of the Ohio is fairly stable, so it was possible to construct rating curves for the Ohio River stations and compute the discharge during the flood period. Horton, assisted by H. J. Jackson, computed the records, not only for the 1913 flood, but also for several previous floods. Data obtained on flood losses throughout the Ohio River Valley indicated that in the 1913 flood 415 lives were lost, and that property had been damaged to the extent of $181,000,000. The results of the study, which included an account of the storm that caused the flood and the damages resulting therefrom, were published as Water-Supply Paper 334.

The only other special flood study during the period 1913-19 was that of the Southern California floods of January 1916, which were caused by torrential rains. About 35 lives were lost and property was damaged to the extent of $10,000,000. Comparison with previous floods indicated that the 1916 flood was the greatest recorded up to that time in that region. Ebert attempted to make measurements during the flood but, because of the loss of bridges and highways, was unsuccessful and was marooned at Escondido from January 26 until February 5, when he was able to proceed after having a four-horse team drag his car across the San Dieguito River. In March McGlashan and Ebert visited the devastated regions and by means of well-defined high-water marks were able to obtain slope-area measurements and other relevant data. This flood destroyed equipment at more than half the gaging stations in the region. Water-Supply Paper 426 contains the results of this investigation.

The next special study, and the first during the present period, was that of the Arkansas River flood of June 3-5, 1921, in Colorado, the greatest of record in the upper part of the basin. More than 80 lives were lost and property losses amounted to $19,000,000. The flood was caused by a series of cloudbursts[133] on

133/ As an example of the intensity of the rainfall during a cloudburst an alleged experience near Tulsa, Okla., is cited. During a cloudburst rain a barrel with both ends knocked out was lying on its side with the bung hole on the upper side. The rain came in through the bung hole faster than it could escape through the two ends and the resulting pressure on the sides burst the barrel.

tributary streams. There were no gaging stations on these streams and the flows were of such short duration that it was not possible to make either current-meter measurements or computations of peak discharge by means other than the slope-area method. E. E. Jones was making a power survey of the headwaters of the Arkansas134/ at that time, and was

134/ p. 196.

directed to cooperate with the author in making a flood study. Within a comparatively short time Jones began his slope-area measurements, which he made on the main river, and near the mouth of each tributary within the area. He obtained other pertinent data also. The result of this study was published in Water-Supply Paper 487. This was the first flood investigation made by the Branch in which the slope-area method was used almost exclusively.

Heavy rains in south-central Texas during the period Sept. 8-10, 1921, produced severe floods in streams of that region which caused the loss of more than 200 lives and property damage to the value of $10,000,000. Immediately after the flood, Ellsworth made slope-area measurements at several critical points and some time later made other measurements. He computed also the flow at the regular gaging stations within the flood area during the flood. These results, with meteorological and other pertinent data, and comparisons with the 1913 flood in that region were published as Water-Supply Paper 488.

The investigations of the Pueblo flood excited the author's interest in floods and he investigated a number of the floods in Colorado and Wyoming which occurred during 1922 and 1923. With the exception of the floods on the Big Horn and Powder Rivers in Wyoming, caused by general rains over large areas, the floods were of the cloudburst type and occurred on small streams. The results of these flood studies were published in Water-Supply Paper 520-G.

Considerable interest in flood studies had thus been aroused and the general subject was discussed at the 1923 conference. The author was instructed to prepare a statement regarding the methods used in making such studies, including the points brought out at the conference and the data to be obtained. This statement was presented in the News Letter of Oct. 10, 1924.

In 1922 the Washington office suggested that the district engineers establish slope gages at typical stations and obtain the slope of the river when discharge measurements were obtained. Data for nine stations were obtained and in connection with an investigation of critical velocities, B. E. Jones of the Conservation Branch computed the value of "n" in Kutter's formula for some of these stations.

Unfortunately these data referred chiefly to stages when the streams were confined to their channels, and gave little information relative to the actual values of "n" during extreme floods when large overflow areas were involved which had hydraulic characteristics that were entirely different from those of the main channels. The net result of this investigation was to leave the field engineer where, as before, he was compelled to rely on his judgment largely in selecting the values of "n" for use in flood studies.

The slope-area method, with its recognized uncertainties and possibly large errors, was viewed with skepticism by those districts in which cloudburst floods were of rare occurrence, and where floods could be measured by more orthodox methods. This skepticism gave rise to the following skit entitled "Movie of an engineer computing discharge by the slope method."135/

135/ News Letter Jan. 10, 1920.

Scene I - Engineer sits down and has before him the results of a field survey to determine the flow of a stream. After careful thought and study, assumes the factors to be used in his trustworthy formula.

Scene II - Computes the discharges from these field measurements and assume factors. Finds that computed discharge looks unreasonable and much different from what he had expected.

Scene III - After much further deliberation selects a new set of factors (profiting by his previous errors) and recomputes discharge. Finds new result to be satisfactory.

Scene IV - Throws hat into the air, kicks up the earth, and shouts joyously, because slope method gives such excellent results.

Parker took exception to this skit as applying to the Washington district and cited the results of a slope-area measurement made after a severe flood on a large stream, and checked by the contracted-opening method. This check showed agreement within 3 percent. He admitted, however, that he was afraid to make further comparisons between the two methods for fear of losing the 3 percent record.136/

136/ News Letter Feb. 10, 1925.

No other flood investigations were made until 1927, when torrential rains of November 3 and 4 in much of New England caused the greatest floods of record over an extensive region. The loss of life in Vermont alone was 84, and property was damaged to the extent of $28,000,000. Losses in the other States were considerably less, but specific data are not now available. Kinnison was able to obtain actual measurements of the floods at some Massachusetts stations, but it was necessary to wait until the highways became passable before sending parties farther afield. Within the affected areas 60 gaging stations were being maintained, and only a few of them were destroyed. Another favorable factor in determining peak flows was the presence of many dams on the streams flooded, most of which escaped destruction and over which flows could be computed. Peak flows were determined at about 50 gaging stations by extensions of rating curves

and at an equal number of places by computing peak flows over dams. The slope-area method was used at 12 points, and the contracted-opening method at four points. Water-Supply Paper 636-c contains the results of this investigation.

Methods for correcting measurements for the effects of rising or falling stages[137]

137/ Based on data furnished by C. H. Pierce.

The series of high-water measurements made on the Allegheny and Ohio Rivers by Grover and Murphy in 1907 showed clearly the effect on the discharge of the greater slope during rising stages and the lesser slope during falling stages. These measurements, which covered the rise and fall of the two rivers during a flood period, defined loops for the upper parts of the rating curves.[138] Although

138/ Follansbee, Robt., Hist., p. 134.

this condition was recognized, measurements on rising and falling stages were generally too few to define loop curves, and little effort was made to correct the records for such changes in stage.

Apparently the first attempt to devise a method which would correct the observed velocity and discharge at changing stages to determine the corresponding values for use in constructing a rating curve for normal or constant stages was made by B. E. Jones in 1915, and published in Water-Supply Paper 375, pp. 117-127.[139]

139/ Idem, p. 377.

This required the determination of slope at constant stages, and as this information was generally unavailable, the method was not generally used. In 1925 W. C. Wiggins attacked the problem from a different angle, and devised a method which determined, by use of the Bazin or Manning formulas, the slope at the time of measurement, and the relation between the measured discharge and the discharge for a constant stage at the same mean gage height. This method was used quite extensively and experience showed that some modification of the coefficients originally used was required.

The Jones and Wiggins methods were concerned only with measurements made at or near points where gage heights were observed. Many measurements during changing stages are made so far from the place where the gage height is determined that channel storage becomes an appreciable factor. In 1924 T. A. Slack devised a method for correcting for such channel storage, during moderate changes in stage and this method was published in the News Letter.[140]

140/ News Letter, Nov. 10, 1924.

At that time Wiggins had not developed his method for correcting the discharge due to rapid changes of stage, and the Slack method does not utilize such corrections.

Use of automobiles

Automobiles proved so satisfactory that their use steadily increased as funds to purchase them became available. During previous years the use of passenger cars or trucks had been optional and depended not only on the needs of the service but also, and quite as much, upon the personal preference of the district engineer. However, there was a growing feeling in Congress that Government automobiles were used more or less for personal business. To prevent so far as possible this assumed abuse, the item for the Survey in the appropriations acts, beginning with that for the fiscal year 1919 and repeated in succeeding acts, limited the amount of money that could be used for the purchase, hire and maintenance of "motor-propelled or horse-drawn passenger-carrying vehicles." No limit was placed on trucks. One repercussion of this action was the following terse item in the News Letter:141/

141/ July 24, 1909.

> Wanted: To trade one Ford touring car for a truck as a result of the recent limitations imposed by Congress.

The limit set in that year for the entire Survey was $10,000 for purchase of passenger-carrying vehicles and $15,000 for hire and maintenance. The limit was increased to $30,000 for hire and maintenance for 1920 and 1921. These limits, proved so low that on July 3, 1920, the Chief of the Branch issued instructions that142/

142/ Instructions 2, Series 1919.

> Future purchases of automobiles from Federal funds for Survey work must be trucks instead of passenger-carrying vehicles unless there is an excellent reason to the contrary.

Realizing that conditions requiring the use of automobiles differed in the several districts each district engineer was asked as to the practicability of following instructions in his district. These instructions resulted in a more wide-spread use of trucks, particularly in those districts having construction programs of considerable size, as trucks were better suited to that type of work than to routine stream gaging. However, the use of trucks was not as great as it might have been without the available State funds, as, in general, trucks were not popular, and in many instances needed passenger-carrying automobiles were purchased from State funds. About 1924 "slip-on" truck bodies appeared on the market and thereafter some automobiles with such bodies were purchased from Survey funds and carried in the records as trucks. This practice continued until 1929, when the Comptroller General ruled that such vehicles were not trucks within the meaning of the law.

As a further inducement to use trucks instead of passenger-carrying automobiles, the Survey item in the appropriation bills beginning with that for the fiscal year 1925 authorized the

exchange of worn-out passenger-carrying vehicles for freight-carrying vehicles. But to this day (1939) no authorization has been given to exchange worn-out trucks for passenger-carrying automobiles.

Beginning with the appropriation act for 1926 the Director was authorized to pay not to exceed 7 cents per mile for use of personally-owned automobiles when travel costs would be reduced thereby. In 1933 this mileage rate was reduced to 5 cents by a proviso in the Treasury-Post Office Appropriation Act of 1934.

At first practically all automobiles were Fords as at that time Ford had no serious competition in the low-price field -- the only one in which the Survey was interested. Gradually, however, as other automobile manufacturers entered the field of low-price automobiles, the district engineers began to purchase other makes such as Chevrolet, Dodge and Overland. Perhaps a majority of such purchases were made from State funds, where the obligation to purchase the lowest priced automobile offered in competition was not as compelling as in the Federal service. Some higher-priced automobiles, however, were purchased from Survey funds. All automobiles at that time had a sliding or rotary gearshift except the Ford, which had a planetary transmission and it was found possible to prepare specifications, excluding planetary transmission which excluded the Ford from competitive bidding. This was a case of "beating the devil around the bush," and was tolerated rather than approved, until the Comptroller General rendered a decision on Feb. 25, 1927, that the designation of the particular type of transmission as planetary or selective was not authorized.

In 1926 Pierce sent inquiries to a numberoof motor companies asking for a discount on parts for Survey automobiles. From one company he received the following telegram:143/

143/ Water-Resources Bulletin, May 10, 1926.

> Providing the United States Geological Survey is a department of the United States Government, they are entitled to twelve percent.

Other makers were not so suspicious of the Survey's status and readily granted the governmental discounts.

If the "trading in" of automobiles had not been authorized the district engineers who had worn-out Fords might have been in the position of the man described in the following verse from "Town Topics:"144/

144/ News Letter May 22, 1920, p. 7.

For Sale

One Ford car, with a piston ring,
Two rear wheels; one front spring.
Has no fenders; seat made of plank.
Burns lots of gas; hard to crank.
Carburetor busted half way through;
Engine missing - hits on two.
Only three years old, four in Spring;
Has shock absorbers 'n ev'r'thing,
Ten spokes missing, front axle bent;
All tires punctured - not worth a cent.
Got lots o' speed, will run like the duce,
Burns either oil or tobacco juice,
If you want this car, inquire within -
Helluva good car for the shape it's in.

About 1921 the practice of using complimentary State license plates was discontinued and Survey automobile tags were issued. These plates were of metal with a heavy porcelain face bearing the inscription

U. S. (Number) G S

This plate was superseded (in 1935) by one bearing the inscription

U S Geological Survey
(Number)

To distinguish Survey automobiles more conspicuously, the placing also of decalcomania transfer designs bearing the Department seal on the doors of automobiles was started about 1926.

The use of automobiles leads to accidents sooner or later and the Government's long-established policy of no insurance threw the burden of liability for damages to other automobiles or to persons upon the Survey operator. In 1925 John McCombs, a per-diem employee of the Survey in Hawaii, collided with another automobile, which was badly damaged, and this resulted in a suit against the Survey employee which was defended by the U. S. District Attorney. He won the suit except that the costs were assessed against the defendant. The district attorney took the position that his duties required him to defend only the government's interest and that he was entitled to a fee for defending the personal interests of the driver of the automobile -- an instance of the well-known legal hair-splitting. Thereafter, the district engineer in Hawaii personally carried public liability insurance on the automobile covering anyone legally driving it.

In the fall of 1926 H. F. Hill, Jr., while operating a Survey automobile on official business in New Hampshire, struck a small boy, causing minor injuries. Although apparently not at fault, he took the boy to a hospital and offered to pay all expenses. This settlement was refused and Hill was sued for $5,000. He was defended by the U. S. District Attorney, but the suit itself was non-federal, as it was against an individual, and the case was finally settled out of court at a total cost of $176.50 to Hill.

The following year, in August 1927, B. L. Bigwood, while returning by Survey automobile from a field trip, at a street intersection in Albany, struck a pedestrian who was crossing the street against the line of traffic, inflicting minor injuries. The injured man brought suit for $20,000 damages. This suit also was defended by the U. S. District Attorney, but before the case came to trial a settlement was made whereby Bigwood personally paid $200.

Although the defendants in these cases escaped payment of heavy damages, they were put to very considerable inconvenience and expense. The above experiences indicated clearly that it would only be a question of time before a member of the Survey would be assessed heavy damages for an automobile accident. As individual policies covering personal liability were relatively high, about $25 per year, an investigation was made to ascertain if a group policy covering Survey employees could be obtained at a lower rate. Such a policy was arranged at a cost of about $5 per man, and all Survey engineers were advised to make use of it for self-protection.145/ This low-rate

145/ Memorandum dated Mar. 8, 1927.

policy was used by many but not all the engineers, and to bring the laggards within the fold, the chief of the Branch issued the following instructions:146/

146/ Sept. 17, 1927.

> In view of the fact that the most careful drivers have accidents and of the certainty that accidents will occur so long as automobiles are driven which may result in serious inconvenience and expense both to the individual and the government if liability insurance is not carried, it is hereby ordered that no employee of the Water Resources Branch be permitted to operate an official or other automobile in connection with official work unless he has protected himself by liability insurance.

These instructions have been followed each year by a reminder of them and of the necessity to renew the insurance. Grover says that legalists have sometimes asked him what authority of law he had for making such a rule. His reply has been that as administrative head of the branch he was authorized to assign duties to individuals, and that such authority necessarily extended to what they should not do as well as to what they should do. Anyway, he says, it is an excellent rule based on good common sense, which has been thoroughly appreciated by every one in the Branch who has had an accident. In the aggregate there are many who have had reason to be thankful that the rule has been made and applied. The doubts as to authority have not been expressed and the inquiries have not been made within the Branch but by representatives of other governmental agencies who apparently were lacking in the fortitude needed for making and enforcing such a rule against the pressure of employees who did not want to pay for insurance and the argument that the United States should pay the costs of accidents on official work. Although Grover

expresses sympathy with the argument, much time is sure to elapse before Congress provides authority and funds for the payment of such costs; meantime accidents will surely happen.

Annual reports

The principal change made in the annual reports consisted in condensing in those for 1927 the information relative to each gaging station. The descriptive matter was reduced from ten headings to five, and the list of discharge measurements was omitted. By so doing it was possible to present the records for each station on a single page and thus to reduce not only the time required for preparing the manuscript but also the size and cost of the published reports. This change had been discussed at the 1925 conference, but did not then meet with favor. It finally was adopted because of the great increase in work of the Branch which occurred at about the time when the 1927 reports were being prepared. It did not result immediately in reducing the delays of publication. Beginning with the report for 1924 the illustrations of current meters and various types of water-stage recorders were discontinued as a matter of economy but the introductory matter remained substantially unchanged.

Conferences

The results derived from conferences of district engineers in earlier years had demonstrated their necessity in an organization as decentralized as the Water Resources Branch. It was felt, however, that futureconferences should be held every two years and should be of such length as to afford sufficient opportunity for full discussion of new problems and developments. This program was followed during the period. The first conference of the period was held Oct. 13-18, 1919. No set program was prepared in advance, but the notice of the conference stated that the principal topics of discussion would be the questions of policy related to the work of the Branch and the pertinent administrative and technical details. Apparently no program was prepared at the beginning of the conference, which was more informal than usual. The social feature was a dinner-dance at 2400 Sixteenth Street.

The 1921 conference was postponed until December 5-10, as Grover did not return from Haiti until the end of November147/

147/ p.

A program was prepared in advance by the Washington office, but topics were not assigned, the thought being that each district engineer would discuss at full length those subjects in which he was particularly interested. The first item on the program for Monday, December 5, was: "Roll call at 10 a.m. All those late will be penalized." It was not recorded that anyone was so penalized.

Since the preceding conference the Federal Water Power Act had been passed and discussion of cooperation with the Federal Power Commission had a prominent place on the program. The interrelated topics of cost of living and reclassification of salaries were given prominence for in those days the number of resignations was at its peak. Au's new recorder was on exhibition and the resulting

discussion of the instrument brought out valuable suggestions for its further development. The need for heavier weights and suitable reels for handling them was becoming felt and these subjects appeared on the program, as did the census of developed water power that was being undertaken by the district engineers for the Division of Power Resources. The subject of standard plans and specifications for concrete and timber shelters was on the program in recognition of the need for a revision of the standard plans for recorder shelters, on the basis of developments made in various districts. The recently completed film "Story of Water" was shown, followed by a talk on Haiti by Grover. A dinner-dance was held at the Roosevelt Hotel.

The program for the conference held Oct. 22-27, 1923, was prepared in advance by the Washington office, and each subject was assigned to an engineer especially qualified to discuss it. The improvements that were being made in measuring and gaging-station equipment were reflected in the program, which allotted much more time to those subjects than had been done previously. The conference appointed two committees for the next two years to investigate subjects of outstanding interest and importance, - one, composed of McGlashan and Parker, for preparing an office manual, the need for which was generally recognized and the other, composed of Warren Hall and G. C. Stevens, for investigating methods of making discharge measurements. R. R. Woolley gave an illustrated talk on the Green River survey. The social feature was a picnic at The Oakes, a private estate in Maryland on Chesapeake Bay. The use of this place was obtained by J. C. Hoyt.

Before the next conference, held Oct. 19-24, 1925, the Washington office appointed a program committee consisting of Lee, McGlashan, and Pierce. After having called on the district engineers for topics which they wished discussed, the committee prepared a program in advance, assigning a district engineer to lead the discussion on each topic. A chairman for each half-day session was also appointed. Heretofore such chairmen had been appointed at the opening of the conference. In announcing the program the committee stated:

> The conference is in many respects the most important event of the Branch in the biennium, as it affords an opportunity for the district engineers to meet and discuss their problems with each other. * * *
>
> In order to expedite the presentation and discussion of papers, and enable all present to have opportunity to present their views, it is suggested that the reading of papers be limited to about 15 minutes, and discussion by any one person to 5 minutes, the same person not to speak a second time on the same subject until all others have had an opportunity to speak once.

A conference secretary, A. H. Horton, was appointed whose duty it was to make notes of the principal points brought out by the discussions, and to record any actions taken. A sergeant-at-arms was appointed to collect what had become the customary fine of 25 cents from those who were late at any session. The reports of the

committees appointed at the 1923 conference were presented, and the conference directed that those reports be mimeographed and sent to the district engineers for study and comment. The improvements made in measuring and gaging-station equipment were described, and those pertaining to water-stage recorders and current meters were shown by exhibition of the instruments.

A motion was adopted providing for a fine of 25 cents for the first failure of a district engineer to contribute to the News Letter, to be increased in the geometric ratio of two for each succeeding failure during the calendar year. Another motion was adopted providing that a list of more common articles required in stream-gaging work be prepared, with view to stocking these articles either in Washington or in some district office. The movement which had been started by engineering organizations to have Congress make an appropriation for a survey of the water-power resources of the country was described and advocated by Grover and Hoyt in a paper presented by the latter. A copy of this paper was ordered sent to each district engineer. Methods to be used in bringing the work of the Branch before the public were discussed. In general, it may be stated that few, if any, new subjects were discussed at the 1925 conference, with the exception of a suggestion that data to be published in the annual series of water-supply papers be so condensed as to be included on one page for a station. By so doing the expense of printing would be reduced and the publication of the reports, which were about three years in arrears, expedited. No action was taken at that time. A dinner-dance was held at the Roosevelt Hotel.

Following the precedent set in 1925, a committee was appointed to prepare the program for the conference held Oct. 17-22, 1927, consisting of Lee, Dickinson, and Paulsen. The committee made the following announcement:

> There are several matters of importance to the Branch which have been discussed at recent biennial conferences but which for lack of time during conference week have not been put into such shape that definite action could be taken or full benefit derived therefrom. There is a great need at this time for committee work to unify office and field methods, to advance our general knowledge of rating curves and publish the excellent studies already made, and to study and improve our field equipment.

No committees having been appointed at the 1925 conference, the program committee appointed committees on field methods, office methods, rating curves, field equipment, and automobile cost data, with the request that they submit reports at the conference. The program committee announced also that as no satisfactory metallic return-circuit cable had as yet been obtained, Grover had requested that the subject of the single-wire suspension be thoroughly discussed at the conference. The district engineers were requested to devote some time to experimentation with that method before the conference. A chairman was appointed for each half-day session, and, in recognition of the great amount of work required in keeping the minutes of the conference, a different secretary was appointed for each session.

The most important results of this conference came from the reports of the committees, particularly the one on field equipment, composed of Ellsworth, Au, Dickinson, Harrington, King, Kinnison, and Lee, as out of it grew the needed improvements in reels and metallic return-circuit meter cable and the continued improvements in other articles of equipment. These latter improvements were due in large part to a motion adopted by the conference that the field-equipment committee continue its work during the next two years. This committee, with full power to act, was to work in cooperation with Au in the planning and development of new field equipment and to prorate the costs among the districts.

The committee on office methods, composed of Parker, Hartwell, McGlashan, Paulsen, and Soule, realized the general need for an office manual and presented an outline, but stated that no member of the committee was willing to assume responsibility for preparing a draft of it. All agreed that steps should be taken in that direction. Following the usual custom, the committee was continued, and in order to assure himself that real progress would be made, the chairman assigned to each of five non-committee members one of the five parts into which the proposed office manual was divided. Of the five parts, only those dealing with computation rules and instructions, assigned to Peterson, preparation of manuscript, assigned to G. C. Stevens, and operation of the integrator, assigned to McGlashan, were prepared. As the enlarged stream-gaging program, begun in 1928, required so much of the time of the district engineers to whom the other parts were assigned, the Branch is still (1939) without a complete office manual. The author makes bold to suggest that a course be followed similar to that later adopted for the preparation of a field manual,148/

148/ p.

to wit, assign one man to the job of preparing a complete draft; relieve him of other work until the draft is completed; mimeograph his draft and distribute it throughout the Branch for critical examination, and constructive suggestions for revisions; and thereafter assign some one to study the criticisms and reduce the suggested revisions to final form for publication.

The committee on field methods, composed of Burchard, Baldwin, Carson, Dirzulaitis, Grosbach, and Purton, presented an outline of a field manual and it was suggested that, like the office manual, the several sections be assigned to those best qualified, and that the resulting papers be grouped to form the field manual. Assignment of the several sections among the engineers of the Branch for preparation brought no direct results at that time for the same reason that the office manual did not materialize.

The committee on rating curves, composed of Peterson, Beckman, Henshaw, Horton, Lamb, Stevens, and the author, reported on the best procedure for constructing rating curves, and showed the limitations of logarithmic extensions, which had begun to find renewed favor. It made the point that

> No method has yet been developed which makes it possible to take a few measurements covering a small range of stage for any station and then produce a correct rating curve for the entire range in stage.

The discussion of the single-wire system of measuring depth and velocity showed its limitations and the general belief was that its use should be optional. The one-man committee on automobile costs, Harrington, indicated surprisingly consistent mileage costs for Ford (Model T) and Chevrolet cars -- practically identical average operating costs of 2.7 cents per mile, and considerably higher costs for the Dodge, Hupmobile, Chrysler, and Overland. New topics discussed were: methods of measuring water other than by current meter, duration curves, sediment samples from the Colorado River, and gains and losses of water by seepage in stream reaches.

One day was devoted to an inspection of the Conowingo hydro-electric plant on the Susquehanna River, then nearing completion, a bus being chartered for the trip. On the return a stop was made at the Friez factory in Baltimore where the Au recorder was seen in various stages of manufacture, this being followed by a dinner tendered the conference members by Lucien Friez. Instead of the usual dinner dance, a luncheon for the engineers' wives was given at the Cosmos Club and the engineers attended a smoker at the Cosmos Club in the evening.

Water Resources Bulletin

The News Letter, in the form into which it had developed during the previous years, continued to appear regularly about the 22nd of each month until September 1920, with the exception of the issues for September and December 1919. The December issue was omitted as the editor was on vacation and could find no volunteer substitute. The contributions for that issue were included with those for January. Beginning with the issue of Apr. 24, 1920, the News Letter carried at the top of the front page the statement:

> A monthly memorandum for the official use of members of the Water Resources Branch of the U. S. Geological Survey.

With no pressure on the district offices to contribute regularly, and with little technical discussion to keep up the professional interest, the district engineers became more and more lax in their contributions. So few were the contributions in 1921 that the February, March and April issues were combined in one which appeared in April. During the remainder of that year the News Letter was dropped, apparently from lack of interest.

At the conference held Dec. 5-10, 1921, the district engineers decided to revive the News Letter themselves and, in January 1922, issued a typewritten number. The renewed interest thus made apparent, caused the Washington office to resume the monthly issues in March 1922. The issue for that month carried for the first time the list of applications for preliminary permits and licenses received by the Federal Power Commission. In that issue also, Beckman made the suggestion that if the number of

contributions by each district within the year to date were to be shown in each issue, the effect of the "deadly parallel" would increase the contributions by delinquent districts in future issues. This procedure was adopted with the April issue. As a further stimulus to obtaining regular contributions, the conference held Oct. 22-27, 1923, passed the following resolution:

> Beginning with the issue of January 1924, each district engineer is to be fined for each failure to contribute to the News Letter. The fine for the first failure to contribute is to be 10 cents and is to be doubled for each subsequent failure. The number of failures is to be based on the "official batting average" as published in the News Letter. The batting averages are based on each year's contributions. The fines, if any, for each of the two years are to be collected at the next conference and the fund utilized as the conference may wish.

In making this announcement in the News Letter,149/ a table of fines

149/ Nov. 10, 1923.

was appended showing the failure to contribute at least once during the year would result in a total fine of $409.50. The combination of these two steps was successful in increasing the number of contributions, but as to the quality, the editor stated:150/

150/ News Letter Mar. 10, 1924.

> There is an apparent tendency of district engineers to give no thought to items for the News Letter until it is nearly time for the mail to close and then hastily to write a few notes, perhaps description of an inclosed picture, and forget the whole thing until the next month. It is respectfully suggested that this procedure is not conducive to the continuance of a good monthly news letter.

The 1925 conference increased the fine to twenty-five cents.151/

151/ p.

The News Letter was issued regularly until August 1925. That issue contained the following statement:

> During the past month the Water Resources Branch has received the attention of the inspectors from the Secretary's office and we hope for many new economies.

At that time the Secretary ordered an investigation of all bureaus in the Interior Department with a view to eliminating expenses wherever possible. The Department inspectors investigated the Water Resources Branch and its activities, including the preparation and distribution of the News Letter. The contents consisted largely of personal items, comments on the weather, and descriptions of hydraulic and irrigation projects in the various districts that were not directly connected with the Survey's work, -- but only relatively small amounts of strictly technical discussion pertinent to the work of the Branch. Many of the

contributions - from both the district and Washington offices - were written in a humorous vein. The inspectors took their work so seriously that such humor was apparently taboo. Perhaps the following bit of dialogue contributed by one district engineer caught their eye:152/

152/ News Letter Aug. 11, 1924.

> Two newspaper reporters spied the district engineer making a discharge measurement from a bridge.
>
> Said A to B, "What's the guy doing?"
>
> B. "D--d if I know."
>
> The district engineer turns toward them while attentively counting the revolutions.
>
> A. "What are you doing mister?"
>
> No response from the district engineer who is busy counting.
>
> B. to A. "Ah, the bird's deaf."
>
> A. "Guess so, he's got a sound amplifier."
>
> The district engineer finishes counting and records the notes. At the same time A. observes the cable attachment and says to B, "Guess he's testing some freak radio hookup."
>
> Of course, at the earliest conveninet time the curious ones were engaged in conversation and the mission explained.

In any event, inspectors decided that the continuance of the News Letter, which involved an average annual expense of several hundred dollars for photo-lithographing an average of 50 copies of each issue, was not justified and recommended its discontinuance. The recommendation was approved in the latter part of August 1925 by the Secretary during the absence of Director Smith from Washington. Immediately on his return, he appealed personally to the Secretary for a reconsideration of the action. There was evidently protracted discussion with the inspectors because the matter was not settled until the conference held Oct. 19-24, 1925, when the district engineers adopted a resolution requesting the continuance of the News Letter as a mimeographed bi-monthly circular. Shortly thereafter authorization was given to continue a medium of exchange of ideas and information between the districts with the understanding that it would be restricted to information required for the proper transaction of public business.153/

153/ Letter to the author from Washington office, Nov. 8, 1937.

The presentation of information required for the proper transaction of public business took the form of the Water Resources Bulletin, which first appeared in mimeograph form Jan. 10, 1926, and bi-monthly thereafter during the remainder of this period. The change from the photo-lithographic form of the News Letter to the mimeograph form was made as a matter of economy, as the mimeographing could then be done at no expense to the Branch. Before the first issue appeared, a reminder was sent to the district engineers that future contributions were to be in accord with the official nature of the medium of exchange of ideas as authorized by the Secretary and frivolous comments, personal information, extended

reference to weather and subjects not directly pertinent to the work of the Branch were to be avoided.154/ To set the proper tone for suc-

154/ Circular Letter Dec. 9, 1925.

ceeding issues, the first started off with a reference by Grover to a statement made by an outside engineer relative to the phenomenon of surge or pulsation in the stage and discharge of flowing rivers, and requested comments. These were received from practically every district, most of which were published in the succeeding issue. In commenting on this first issue, Grover stated:155/

155/ Letter of Jan. 28, 1926.

> The first issue of the Water Resources Bulletin has, I think been fairly satisfactory * * *. It is difficult to prepare such a bulletin that will have enough of human interest to accomplish its main purpose and at the same time avoid criticism because of an excessive amount of space devoted to personal items and the weather. Each of us must have this problem in mind with the realization that, at the start at least, each copy will be scrutinized and criticized.

Approval for mimeograph requisitions was given by the Chief Clerk and on his own initiative he deleted items which did not in his opinion meet the new requirements. The transition in subject matter was not accomplished suddenly, however, and repeated failures to meet the new specifications finally caused the Director, in May 1931 of the next period, to appoint Dr. Sears, the Administrative Geologist, as censor. Under his supervision the Bulletin became a real medium for exchange of technical and administrative information, with personal items limited to those pertaining to changes in assignments or to other official actions. The "deadly parallel" showing contributions from the several districts appeared in each issue and was as efficient in keeping up the contributions as it had been for the News Letter.

It was not until the issue of Sept. 10, 1926, that the Bulletin carried the statement that it was published by direction of the Secretary. This should have been carried in the first issue of the new publication, but the omission was not discovered until the September issue was prepared.

Federal Water Power Act

The passage of the Federal Water Power Act on June 10, 1920, had a considerable effect on the work of the Survey, both in imposing new duties upon it and in opening up a new field of cooperation in stream-gaging.

Power sites subject to the provisions of the Federal Water Power Act are those located on boundary waters, navigable streams, or public land adjacent to streams having sufficient fall for power. In addition, if power plants on headwater streams affect the flow in navigable reaches of the river, such plants are subject to the provisions of the act. A limited amount of

water-power development on navigable streams and on public land had taken place before 1920 but the legal conditions with respect to the use of such power sites discouraged wide-spread development. For each project on navigable streams it was necessary to obtain an act of Congress, which stipulated, inter alia, that locks and dams must be maintained for the use of navigation even though navigation might be almost nonexistent. The procedure was slow and compliance with the requirement was expensive. Most public land is situated in the western States and much of this land is adjacent to power sites in national forests. The authority to grant permits for power development outside the forests was vested in the Interior Department and that for development within the national forests in the Agricultural Department. If a project was on public land both in and adjacent to a national forest, it was necessary to deal with both Departments.

In 1901 Congress enacted a law authorizing the executive departments to issue permits for power development on public lands including reservations. To safeguard the public interest, these permits were revokable at the discretion of the executive departments making them. Such uncertainty of tenure made financing difficult and expensive and was seriously objectionable to private enterprise, so only a few developments were made, despite the enthusiasm for "white coal" that was created by the conservation movement.156/ This unsatisfactory condition so retarded development

156/ Follansbee, Robt., Hist. of -- etc., pp. 195-7.

that, with the growth of the conservation movement, several unsuccessful attempts to enact more satisfactory laws for power development on public lands were made in the years following 1910.

The great increase in power demands resulting from the World War focused attention upon the dormant water-power possibilities, both on navigable rivers and other streams on public lands. At President Wilson's direction the Departments of Interior and Agriculture studied the problem through a group consisting of E. C. Finney, chairman of the Board of Law Review for the Interior Department, G. O. Smith, N. C. Grover, Herman Stabler and W. B. Heroy of the Survey and O. C. Merrill of the Forest Service. This group prepared a draft of a comprehensive act to cover the development of both classes of water-power sites that come under Federal control. The President transmitted this draft to Congress in December 1917, with the recommendation that legislation be enacted which would encourage development.

The President's recommendation was referred to a Congressional Joint Water Power Committee which held extensive hearings from Mar. 18 to May 27, 1918, during which fifty witnesses were heard. That this number was unexpected is shown by statement of the chairman at the beginning of the hearings that the committee would like to conclude the hearings in a week's time and believed that six 5-hour sessions would be sufficient to allow all interested persons and organizations to express their views. The witnesses were chiefly representatives of Government bureaus and power companies, with a few spokesmen for municipalities. The feature of the proposed bill which aroused the most discussion was the provision for recapture of power plants at the expiration of the licenses which generally were to run for 50 years.

On June 28, 1918, the Joint Committee reported a water power bill which had as its basis the draft submitted by the President, but the session came to a close before it had been acted upon by both houses. The water power bill was again reported in the next Congress on Sept. 12, 1919, and was finally enacted on June 10, 1920, ten years after serious efforts had been started to obtain such a law.

By the terms of the Federal water-power act[157] the Federal

157/ 41 Stat. 1063.

Power Commission, was created consisting of the Secretaries of War, Interior, and Agriculture, whose duty it was to issue licenses for the development of water power, for definite periods not exceeding 50 years, and for which an annual fee based on power capacity (horsepower developed) was to be paid. The Commission had but one employee whose salary was paid from its own funds -- the executive secretary, O. C. Merrill. The remaining personnel - engineers, accountants, and clerks -- were detailed to the Commission by the three Departments concerned. The first Survey engineers so detailed were R. W. Davenport, Oct. 1, 1920, and D. J. Guy, Nov. 3, 1920. The latter resigned later and was succeeded by J. G. Mathers, Aug. 1, 1927.

Although the law defined the objectives to be sought by the Commission, the regulations whereby those objectives would be attained remained to be framed, and for that purpose an interdepartmental committee consisting of General Enoch Crowder, Herman Stabler, and O. C. Merrill was appointed. It was recognized that reliable and adequate records of stream flow would be required in the administration of power projects, and that the responsibility of obtaining such records rested with the permittees and licensees. The records must, of course, be collected by standard methods which would make them acceptable to the varied interests involved in their use and interpretation. The general policy was therefore adopted that the stream-flow records must be collected under the superision of the Geological Survey, but at the expense of the permittee or licensee. The detailed arrangements for collecting such records varied widely according to circumstances, from little participation by the Survey where the licensee or permittee could perform the work satisfactorily, to complete performance by the Survey, all funds being provided by the licensee or permittee. Much of the procedure is of the latter kind.

The regulations required that before an application could be acted upon by the Commission, the project must be examined to determine not only its feasibility but also whether the proposal was best suited to that particular site. To keep out, so far as practicable, fly-by-night promoters, the financial ability of the applicant to construct the project was also investigated. With three departments interested, it was, perhaps, natural that each should desire as large a share of the new work as possible, and it seemed to the representatives of the Interior Department that the other two departments contemplated that the Survey's participation (the active agent of the Interior Department) should be limited to

the determination of the available water supply for each project. This would be chiefly an office study. The Commission finally decided to allot the projects on navigable streams to the War Department, on public lands in the national forests to the Agricultural Department (Forest Service), and on public lands outside the national forests to the Interior Department (Geological Survey).

Within a few months after its creation the Federal Power Commission had received applications for the development of a million horsepower. The first application considered by the Federal Power Commission was that of the Dixie Power Company for developing power in Arkansas. This application had been received by the Department of the Interior prior to the enactment of the Federal Water Power Act.

The Colorado River Compact

The Colorado River compact, negotiated in 1922, led to an expanded stream-gaging program in the Colorado River Basin; to the development of equipment and methods for use in measuring deep, swift rivers; and later, to the development of the concept of Colorado River base stations for which a specific item was included in the Survey's annual appropriations beginning with the fiscal year 1929. The inclusion of the compact, with some modifications, in the text of the Boulder Canyon Project Act led to the passage and approval of that Act in December 1928, thus paving the way for the construction of Hoover Dam and the All-American Canal. An account of the events leading to the compact and a description of the compact itself appear, therefore, to be pertinent.

Because of the serious menace of floods in the lower Colorado River to the residents of Imperial Valley, studies of the river by State and Federal agencies had been conducted for many years, particularly after the floods of the winter of 1904-05 when the Colorado River broke into Imperial Valley and re-created Salton Sea to a maximum depth of 78.5 feet before the break was closed in February 1907. In about 1912, E. C. LaRue began the first comprehensive study of the problems of the utilization of the Colorado River and brought together for the first time the pertinent available data. The results were published by the Survey in 1916.158/

158/ Water-Supply Paper 395

With an appropriation of $50,000 for the purpose, the Reclamation Service in 1914159/ began a general study of storage possibilities in the Colorado

159/ Follansbee, Robt., Hist. of Water Res. Br. 343

River Basin, and in 1915 the study was extended to include an examination of irrigable lands in the Green River Basin in Wyoming, for which the State of Wyoming entered into a cooperative agreement with the Service. Although the various studies did not thoroughly cover the entire upper Colorado River Basin, they brought to light a number of possible reservoir sites.160/ The Act of Congress approved May 18, 1920, (41 Stat. 600),

160/ Eighteenth Annual Report Reclamation Service, 1919, pp. 391-409.

and known as the "Kinkaid Act," directed the Secretary of the Interior to report on irrigation in Imperial Valley and related subjects. The report titled, "Problems of Imperial Valley and Vicinity," and known as the "Fall-Davis" report, was sent to Congress in February 1922 and printed as Senate Document 142, 67 Congress, 2d Session.

In the meantime, the flood menace to the Imperial Valley continued and there were recurrent periods of insufficient water supply. Congress was besieged by petitions asking relief by various methods. Such relief had to be provided by the construction of a reservoir as near as possible to the point on the river where the greatest flood menace would occur, which was near the head of the Delta. The heavy sediment load carried by the Colorado made necessary a reservoir of great capacity to insure many years of usefulness before it would become filled with sediment.

The rapid increase in population of Southern California made it apparent that development of irrigation in that section would proceed at a much more rapid rate than in other sections. The Upper Basin States feared that if a large reservoir were constructed on the lower river as proposed, the rights acquired to the use of the stored water might deprive them of the use of Colorado River waters at a later date when upper basin development would take place, and that such a condition would lead to interstate litigation. In an attempt to avoid such a situation, the Governor of Utah called a meeting of the representatives of the seven Colorado River Basin States at Salt Lake City, Jan. 18-21, 1919. At this meeting a permanent organization known as "The League of the Southwest" was formed. Beyond passing some general resolutions with reference to the use of water and to Federal reclamation, little was accomplished. A second meeting was held at Los Angeles, Apr. 2, 3, 1920, when similar resolutions were passed. A third meeting was held at Denver, Aug. 25-27, 1920, at which the desirability of encouraging the construction of large reservoirs in the canyon of the Colorado River for flood control and power and irrigation uses was discussed, and Director of the Reclamation Service declared that such reservoirs need not interfere with the future development in the upper part of the drainage basin. Delph E. Carpenter, special counsel for Colorado in interstate river matters, presented a proposal to make use of the constitutional treaty-making powers of the States in the negotiation of an interstate treaty relative to the use of the Colorado River whereby costly and long-drawn-out litigation would be avoided. This idea was endorsed and the following resolution adopted:

> Resolved, That it is the sense of this conference that the present and future rights of the several States whose territory is in whole or in part included within the drainage area of the Colorado River, and the rights of the United States to the use and benefit of the waters of said stream and its tributaries, should be settled and determined by compact or agreement between said States and the United States, with consent of Congress, and that the legislatures of said States be requested to authorize the appointment of a commissioner for each of said States for the purpose of entering into such compact or agreement for subsequent ratification and approval by the legislature of each said States and the Congress of the United States.

Each State authorized the appointment of a commissioner at the 1921 session of its legislature, and at the request of the governors of the seven States, Congress, on Aug. 19, 1921, authorized the negotiation of a treaty by those States.[161]

161/ 42 Stat. 171.

In accordance with the terms of the Congressional Act, President Harding appointed Herbert Hoover, then Secretary of Commerce, as the Federal representative. Hoover was selected because he was an engineer, and it was realized that the problems confronting the Commission were preeminently engineering, involving the physical ability of each State to utilize the waters of the Colorado River. The members of the Commission were as follows: W. S. Norviel, Arizona; W. F. McClure, California; Delph E. Carpenter, Colorado; J. G. Scrugham, Nevada; Stephen B. Davis, New Mexico; R. E. Caldwell, Utah; and Frank C. Emerson, Wyoming.

The Commission met in Washington on Jan. 26-30, 1922, to organize and outline its duties. It was found that sufficient information was not available in Washington to serve as the basis for a compact, and it was decided to hold hearings in various parts of the basin at which those interested could present their views and wishes, and supporting data. During March and early April, six hearings were held. At the conclusion of these hearings, it was decided to hold a final session in the following November at which a compact was to be negotiated. Accordingly the Commission met Nov. 11, 1922, at Bishops Lodge near Santa Fe, New Mexico, and, after 14 days of formal and informal sessions, completed the final draft of the compact which was signed by the commissioners and chairman Hoover on Nov. 24, 1922.

Article III of the compact contains the principal provisions on the apportionment of the water. Paragraphs (a), (b), (d), (e), and (f) are quoted entirely and paragraphs (c) and (g) are briefed.

> (a) There is hereby apportioned from the Colorado River system in perpetuity to the upper basin and to the lower basin respectively the exclusive beneficial consumptive use of 7,500,000 acre-feet of water per annum, which shall include all water necessary for the supply of any rights which may now exist.
>
> (b) In addition to the apportionment of paragraph (a), the lower basin is hereby given the right to increase its beneficial consumptive use of such waters by 1,000,000 acre-feet per annum.
>
> (c) (If hereafter the United States recognizes rights of Mexico the supply shall come from surplus over quantities in (a) and (b), and if surplus is insufficient the deficiency shall be borne equally by the upper and lower basins.)
>
> (d) The States of the upper division will not cause the flow of the river at "Lee Ferry" to be depleted below an aggregate of 75,000,000 acre-feet for any period of ten consecutive years reckoned in continuing progressive series beginning with the 1st day of October next succeeding the ratification of this compact.
>
> (e) The States of the upper division shall not withhold water, and the States of the lower division shall not require the delivery of water which cannot reasonably be applied to domestic and agricultural uses.
>
> (f) Further equitable apportionment of the beneficial uses of the waters of the Colorado River system unapportioned by paragraphs (a), (b), and (c) may be made in the manner provided in paragraph (g) at any time after October 1, 1963, if and when either basin shall have reached its total beneficial consumptive use as set out in paragraphs (a) and (b).
>
> (g) (Procedure for further apportionment after October 1, 1963.)

By the time of the Santa Fe meeting great interest in the proposed compact had been aroused throughout the southwest. When the

Commission met, the attendance of a large number of unofficial advisers so handicapped the deliberations of the members that Chairman Hoover limited the attendance at sessions to the Commissioners and their immediate official advisers.

Two of the Commissioners brought drafts of compacts to Santa Fe with them. Norviel of Arizona presented one based on priorities, and Carpenter of Colorado one based on allocation of water between the States. The Commission decided in favor of the latter and proceeded toward that objective. The hearings had brought out a mass of claims by each State as to future use to be made of the Colorado River. In some of the States little definite information regarding possibilities was available and as a result the claims were excessively high in order to play safe. Colorado had made a reconnaissance study of its possibility, the Reclamation Service had made a more detailed study in Wyoming and a still more detailed study in Imperial Valley California. The other States had few actual data. As the total claims were obviously in excess of the flow of the Colorado River, it was necessary to scale them down. The Commission realized that it would be impossible to negotiate a compact (as the proposed treaty was called) providing an allocation to each State. They found, however, that it would be possible to allocate an annual quantity to the group of Upper Basin States, consisting of Colorado, Wyoming, Utah, and New Mexico as a unit, and a similar quantity to the group of Lower Basin States, consisting of Nevada, California, and Arizona. Each of the two groups of States was expected to allocate the water to each of the States comprising the group.

The dividing point between the Upper and Lower Basins was designated as at "Lee Ferry" a point on the main stream of the Colorado River one mile below the mouth of the Paria River. The location and spelling of "Lee Ferry" was apparently taken from the Echo Cliffs quadrangle map of the Geological Survey, edition of November 1891. The original ferry was below the mouth of the Paria River. In later years ferries were maintained above the Paria River and reached on the left bank by means of the "Dugway" road. The spelling "Lees Ferry" came into general use and was adopted by the Geographic Board as the place name of the locality.

Although the proposal to apportion the water equally between the Upper and Lower Basins apparently met with the approval of all the Commissioners, the specific amount to be apportioned was not so readily agreed upon. The estimates of total water (the reconstructed river), varied from about 17,000,000 to 20,000,000 acre-feet. As a future apportionment of surplus water was to be provided, the Commission proposed to make the current apportionment in the amount of 15,000,000 acre-feet, 7,500,000 acre-feet to each basin. At the Santa Fe meeting Arizona was willing to accept the apportionment of 7,500,000 acre-feet to the Lower Basin provided the Gila River was either excluded from the Colorado River Basin, or its water not included in the apportionment. The solution of this problem was the inclusion of paragraph (b) in Article III of the compact apportioning an additional 1,000,000 acre-feet to the Lower Basin. Paragraph (b) does not mention Arizona or the Gila River but it was the understanding that the 1,000,000 acre-feet was for Arizona's use, and that Gila River was a part of the Colorado River Basin.

Before the compact could become effective it had to be ratified by the legislature of each signatory State and finally by Congress. The compact was presented to each State Legislature and all ratified except Arizona. Although the compact commissioner for Arizona had succeeeded at Santa Fe in having paragraph (b) inserted in Article III of the compact, the delay in the formulation of any apportionment schedule among the Lower Basin States led to the belief among the people of the State, and consequently in their legislature, that the compact was not entirely satisfactory from an Arizona standpoint. A new governor took office early in 1923. Also the death of the California commissioner seemed to lessen the cooperative attitude of that State.

The Arizona legislature finally acted but did not ratify the compact. One report is that they failed to ratify by one vote, another report is that they ratified with amendments and the governor vetoed the legislation. Arizona insisted that before she ratified the compact it should first be determined what portion of the 7,500,000 acre-feet she would receive, and the status of the Gila and its tributaries must be definitely determined.

Arizona objected further on the ground that whereas the compact eliminated the application of the doctrine of prior appropriation between the Upper and Lower Basins it left it in force between California and Arizona putting the latter State in the menace of great priorities in California as a result of diversions through the All-American Canal 162/

162/ The Hoover dam power and water contracts and related data, Dept. of Interior, 1933, pp. 7, 8.

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which was proposed to be built by the Federal government. The refusal of Arizona to ratify the compact blocked its ratification by Congress.

The ever-present menace to Imperial Valley of floods on the one hand, and shortage of water for irrigation on the other, caused California to press Congress for the construction of a large reservoir on the Colorado River near Boulder Canyon and the so-called All-American Canal. Bills sponsored by Senator Hiram Johnson and Representative Phil Swing of California were introduced into Congress for that purpose. The upper basin States viewed with alarm such construction before the ratification of the Colorado River compact, and succeeded in blocking the enactment of the proposed legislation. Congress took the attitude that until the States of the basin could agree among themselves nothing should be done, and the bills introduced into successive sessions of Congress failed of passage. In the meantime irrigation companies operating in Mexico were expanding their irrigated areas and so were using more and more of the Colorado River water, thus acquiring and perfecting prior rights.

During the years 1923 to 1927 all efforts of Arizona and California to reach agreement on the major items of a tri-state compact had resulted in failure. In 1927 the Governor of Utah sponsored a conference of the governors of the seven states for discussion of the Colorado River problems. This conference held several sessions at Denver during the months of August, September, and October 1927. During 1928 many of the suggestions from the Denver conference were incorporated into the current "Swing-Johnson" bill which became the Boulder Canyon Project Act when it

was finally passed by Congress in December 1928. The Colorado River compact, with some modifications, was included in the Act. The principal modifications were, the compact must be ratified by California and five other states; the California legislature must pass a limitations act, the principal feature being that she agree to consumptive use of not more than 4,400,000 acre-feet of the 7,500,000 acre-feet apportioned to the lower basin by paragraph (a) of Article III of the compact. The disputed paragraph (b) of Article III of the compact was not eliminated in the Project Act, but Arizona was given the consumptive use of the Gila River and tributaries within the State.

The Project Act was to become effective six months after its approval, provided six states, including California, ratified the compact as modified and the California legislature passed the required limitations act. These conditions were fulfilled within the time limit and the Boulder Canyon Project Act, approved December 21, 1928[163] became

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163/ 45 Stat. 1057.

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effective June 21, 1929.

Gaging stations on lower Colorado River

When the states and Federal government accepted the idea that the development of the Colorado River must be based on a general plan, treaty or compact of some sort, they were faced with the fact that actual data on the resource to be apportioned were truly few and far between. What has been popularly known as a great river carrying plenty of water became an insufficient source when estimates of future uses of the water were accumulated. Prior to 1917 the only flow records on the main river between the mouth of Green River in Utah and Yuma, Arizona, were $2\frac{1}{2}$ years of records collected near Hardyville, Arizona, during 1905-07. With the assistance of the Reclamation Service records were started at Topock, near Hardyville, in February 1917. When the compact negotiations were authorized no flow data were available for any points in the canyon section, where the potential power and reservoir sites were situated, as was also the proposed division point between the upper and lower basins.

Neither the states nor the Federal agencies interested acted promptly in the establishment of gaging stations in the canyon section and it remained for private power interests, encouraged by the passage of Water Power Act in 1920, to take the first steps leading to the establishment of two important gaging stations, those at Lees Ferry and at Bright Angel Creek. The history of these stations and of the Cisco station on the upper Colorado River and the improvement of the Topock station are believed to be of sufficient importance to be recorded in this history. The Bluff station on San Juan River in southern Utah was re-equipped and placed in operation near the end of this period of the history, as it was believed that records of the San Juan River would be useful in the study of Colorado River problems.

Lees Ferry station.- Interest in the development of the lower Colorado River had been growing during the latter years of the previous period, due in a large measure to the publication of LaRue's first Colorado River report in 1916[164]. Because of the rapid increase in population

164/ Water Supply Paper 395.

of Southern California, the Southern California Edison Company began to seek additional sources of power, and in December 1920 made application to the Federal Power Commission for a preliminary permit to investigate a reservoir site on the Colorado River in the Glen Canyon in northern Arizona. Although no action was taken on this application pending the negotiation of the Colorado River compact, the company established a gaging station in May 1921 at Lees Ferry above the Paria River and five miles below the site of the proposed dam. LaRue selected the site for the gaging station, the Survey supervised its operation and computed the records. The entire cost except the current meters was borne by the power company[165]. The operating cost was high as the shifting character

165/ Letter from R. C. Rice to the author.

of the channel made it advisable to maintain a resident engineer and a helper in order that measurements could be made almost daily. A cable of 610-foot span was erected and gage heights were obtained by means of staff gages. Late in the next year the company built a concrete shelter at the Dugway, and in January 1923 installed a recorder which was furnished by the Survey.

The proposed Colorado River compact required the measurement of the Colorado River at "Lee Ferry" to record the amount of water delivered from the upper to the lower basin. Although the compact was then far from completion it was evident that the Lees Ferry station and its records would be of great value to the Colorado River Basin States. In order to technically satisfy the terms of the compact a record of the flow of Paria River was needed. Accordingly a gaging station was established on that stream near its mouth in November 1923.

The Arizona district funds were very materially increased beginning with the fiscal year 1924 and the Survey was able to take over the actual operation of the Lees Ferry station on Sept. 1, 1923, with substantial financial assistance furnished by the Southern California Edison Company. This arrangement continued until June 30, 1927, when the passage of an act by Congress prohibiting water-power development on the Colorado River prior to the ratification of the compact, caused the power company to withdraw its support of the gaging station. Funds at the disposal of the Survey were insufficient to maintain the Lees Ferry station, so all the States in the basin, and other interests, were called upon to assist. The resulting contributions[166] enabled the Survey to

166/ p. 110.

operate the station during 1928. The Interior Department appropriation Act for 1929 carried a sub-item by which $50,000 was made available.

"For operation and maintenance of the Lees Ferry, Arizona, gaging station and other base stations in the Colorado River drainage."

So important did the Lees Ferry station become that by Executive Order of January 18, 1933, President Hoover reserved for the use of the Geological Survey the public land on which the gaging station was situated.

Topock station.- The gaging station on Colorado River near Topock, Arizona, which had been started in 1917, was operated with insufficient funds and personnel, and with inadequate equipment during the years 1917 to 1920. When the district office was reestablished in Arizona in April 1921 more attention was given the station. However, most of the discharge measurements were still made by the local observer-hydrographer who was handicapped by illness, a gaging cable without sufficient clearance at high stages and faulty operation of the recorder installed over an inclined gage well.

The principal cooperative support had come from the Reclamation Service which saw the need for records which would be useful in studies of dam sites in Boulder Canyon, and also serve as a check on flow data for the vicinity of Laguna Dam. Early in 1922 the Reclamation Service and other agencies interested in the lower Colorado River agreed to assist in a more intensive program for the coming season and also in the construction of a new station at a more favorable site downstream. Accordingly, D. A. Dudley was assigned to the station as resident engineer and took charge of the station on May 21, 1922. After the high water season Dudley proceeded with the plans and construction of a completely new station at a site about one mile downstream. The old station was continued until the new station was in complete operation on December 3, 1922. At the new site a 40-foot concrete well and recorder shelter were constructed and a cable of 549-foot span was installed. The cable was equipped with a 2-man stand-up car known as the Colorado River type. More for moral effect than for actual necessity, the car carried two life preservers, each marked "U.S.G.S. Topock, Ariz." A telephone line $3\frac{1}{2}$ miles long was built later connecting the station with the local system at Topock for flood warning service to Yuma and other points. A wooden building to serve as office and living quarters for the resident hydrographer was constructed on the Arizona side of the river near the cable anchorage and recorder shelter.

Grand Canyon station.- Early in 1921 the National Park Service completed the erection of the Kaibab suspension bridge over the Colorado River at the mouth of Bright Angel Creek in the Grand Canyon National Park. The possibility of using this bridge for a gaging station was the basis for a suggestion by the Survey to the Reclamation Service that the two bureaus join in the expense of an investigation of the site for a gaging station in the Grand Canyon. It was also suggested that a station at this site would be of more value for studies of dam sites in the Boulder Canyon section than the existing Topock station which had not proven very satisfactory up to that time. The Reclamation Service was agreeable but the reconnaissance of the site at Bright Angel Creek was not made until November 1921.

At the same time the Federal Power Commission had under consideration an application from James B. Girand of Phoenix, Arizona, for a power site on Colorado River in the vicinity of Diamond Creek, about 135 miles downstream from Bright Angel Creek. Mr. Girand, however, was loath to spend money on the installation and operation of a gaging station at his site until he had definite assurance of the status of his project. Rice made a reconnaissance for a gaging station near Diamond Creek in September 1921, but after a reconnaissance of the Bright Angel Creek site in the following November he reported very strongly in favor of the latter site. The Federal Power Commission later amended Girand's temporary permit to relieve him of the installation of a gaging station at Diamond Creek provided the necessary data for his project could be collected at the Bright Angel Creek site. If so he would be required to share in the expense of the establishment and operation of the station at the Bright Angel Creek site. The prospects thus appeared much better for a gaging station at the Bright Angel Creek site and plans were made for its installation. The Federal Power Commission and the Reclamation Service as well as other agencies assisted in the cost. Girand, however, did not contribute and his application was never finally approved.

Rice's visit to the Bright Angel Creek site in November 1921 disclosed that the Kaibab suspension bridge would not be suitable for discharge measurements. The roadway of the bridge was too narrow to accommodate pack animals while discharge measurements were being made and the sides of the bridge were covered by a high wire fence. It was necessary, therefore, to plan for a cableway and a recording gage structure. During the spring and summer of 1922 materials were ordered and delivered to the south rim of the Grand Canyon. The Fred Harvey Company was engaged to do the packing to the river after the tourist travel slackened in September.

In June 1922 the Washington office borrowed F. C. Ebert from the California district and placed him in charge of the construction work. Ebert and Rice visited the site July 25-27, 1922, and made the final plans for the construction. The first discharge measurement was made November 12 and daily records from a staff gage were started on that date.

Ebert reported that 70 working days were required for the job which was done by 8 men, including the camp cook and hydraulic engineer. All construction materials, except rock and sand, and camp equipment and supplies were brought in by pack mules from the south rim. Rock was available at the site but sand was packed about 2 miles. Ebert reported that a little more than 800 mule-days were required for packing on the entire job. The mule loads were limited to about 150 pounds by weight and not over 6 feet in length. The cable was brought down by a mule at each end and 8 men distributed between.

As the gaging station site was located in plain view of the Kaibab trail crossing in the Grand Canyon National Park, the standard plans for concrete shelters were modified to provide a rubble facing of native rock which would be inconspicuous and not detract from the scenic beauty of the canyon. The nearness of the Park Service telephone line made it possible to install a telephone at the station and thereby furnish daily-stage reports to the outside world. The form lumber left over

from the construction job was used the following winter in the construction of a rock cabin to serve as office and living quarters for the resident hydrographer. The cabin was built on the boulder delta at the mouth of Bright Angel Creek and was made similar in appearance to the buildings at Phantom Ranch. In October 1923 a staff-gage station was installed on Bright Angel Creek and the operation of that station was added to the duties of the resident hydrographer.

Cisco station.- The Survey had previously maintained a gaging station at Fruita, Colo., near the Colorado-Utah State line but because of lack of funds for adequate field work, the records were unsatisfactory. During the summer of 1922 while the preliminary negotiations of the compact were in progress it was evident that a record of the discharge of the Colorado River at or near the Colorado-Utah line would be required for any final division of the waters between Colorado and Utah. Although Utah was cooperating with the Survey at that time, Colorado was not and the funds of the Colorado district were too meager to bear half the cost of the new station as the Utah district could do. In this dilemma the State engineer of Colorado felt that the State's interest in the proposed station was sufficiently great to warrant a contribution to its construction and agreed to such action. With the necessary funds assured, a reconnaissance was made in September 1922 of two possible sites for the new station, one the Fruita site and the other at the Dewey Bridge below Dolores River about 11 miles south of Cisco, Utah, where a station had been maintained during 1915 to 1917. The latter site was found to be preferable, and a timber recorder shelter was constructed and a cable of 602-foot span was installed that fall by W. E. Dickinson of the Utah district. The cost of this station was $2,210, of which Colorado contributed $1,049 and the Utah district $1,161.

Bluff station on San Juan River.- A reconnaissance of San Juan River in the vicinity of Bluff, Utah, was made during 1926 by the district engineers of Arizona and Utah and the State hydrographer of Colorado. It was decided that the former station at Goodridge Bridge, about 25 miles downstream from Bluff should be reestablished and the Arizona district undertook the planning and the construction of a station to be equipped with a recorder and two measuring cables. Construction started in February 1927 and records began in March of that year. The complete installation was delayed until 1930 by scarcity of funds. The stream gaging was done in the usual manner by the Arizona and Utah districts until the latter part of 1928 when the station became a "Colorado River base station" and a "residency" under the Utah district. Equipment for silt sampling as well as stream gaging was provided.

Operation of stations.- The gaging stations established on Colorado River during 1921 and 1922 presented operation problems in addition to those met with at ordinary gaging stations. The selection of sites for gaging stations was controlled almost entirely by accessibility to the river. The streambeds at cross-sections suitable for discharge measurements were obviously subject to scour and fill and the stability of visible control sections was unknown. The large amount of silt carried by the river indicated that the recording gage wells would require much attention during falling stages. After a few years of operation it

was demonstrated that the Paria Rapids at Lees Ferry and the Bright Angel Rapids at the Canyon Station did afford fairly stable control sections. At the Lees Ferry and Topock stations the area of the cross-section at the measuring cable increased from low stage to high stage as much by scour of the river bed as by rise in the water surface. Station operations which would produce data of the needed degree of accuracy obviously required the full-time service of a combination observer-hydrographer and an assistant during the high-water season.

The operation of the Colorado River stations required heavier sounding weights and these were designed in 1922 and redesigned in 1925[167].

167/ Page 63.

The use of heavier weights required a reel and a special type of gaging car which was developed by Rice and Gardner during 1922 and followed the general design of the stand-up type of car provided by Ellsworth for the Topock station in 1918. On these cars the reel, two feet in diameter, was mounted on the upstream side of the car and the sounding line controlled by one or two guide rollers at the bottom of the car. A canvas top was placed over the car to protect the operator from the intense heat of the Arizona sun.

The experience at Lees Ferry during the high-water season of 1922 demonstrated that another accessory to the equipment of the gaging car was needed. This was some means or device by which the vertical angle in the sounding line could be measured when needed for correcting soundings. During 1922 Cockroft obtained angles by holding a graduated board with a level or plumb bob against the sounding line beneath the car. While working on the "two-table method" during the early part of 1923, Stevens conceived the idea of using a light, swinging frame mounted on the axis of the lowest guide roller and on the downstream side of the sounding line. The movement of the frame by the sounding line was to be transferred to a weighted protractor on which the vertical angle could be read. The idea was sent to the district office in April 1923 and the three stations were equipped by Dudley during the next three months with angle measuring devices incorporating Stevens' idea.

Operations were carried on during the remainder of the period substantially as described. Living conditions for the resident engineers were primitive but were improved during later years. These conditions were described by Dickinson.[168]

168/ Letter from W. E. Dickinson to the author.

"Each station is in charge of a well-qualified engineer (who has) during the high-water season a junior engineer helper. The most strenuous field work occurs during the hottest part of the summer at low altitudes in Arizona. It is hard, exacting work in trying heat, and in the past under somewhat primitive conditions of living. I have had at times and in particular cases many misgivings about sending men into it, but invariably they have come out healthier, huskier, and enthusiastic. That must be the magic of stream gaging."

The employment of resident engineers needed to obtain accurate records at stations difficult of access on a river having a badly shifting bed was expensive and resulted in an annual operating cost of about $6,000 per station. To finance the cost of construction and operation, funds were received from the following sources:

Available funds for Colorado River stations in addition to those expended by the Survey and State of Arizona under regular cooperative agreements.

Year	Geol. Survey	Reclamation Service 1/	Federal Power Commission	Weather Bureau	City of Los Angeles
1922	$2,704	$2,776	$4,000	$500	
1923	1,635	11,255	6,043	200	$1,339
1924	-	4,278	1,533	200	166
1925	1,320	4,182	1,500	200	1,491
1926	682	4,181	3,201	200	756
1927	3,012	3,000	-	-	1,531
1928	300	3,000	-	-	3,717

Year	So. Calif. Edison Co.	State of Calif.	Miscl.	Total
1922	-	-	-	$9,480
1923	$130	$1,170	-	22,072
1924	1,250	720	-	8,147
1925	2,037	222	-	10,952
1926	1,216	398	250	10,884
1927	744	553	460	9,500
1928	-	678	200	7,895

1/ Reclamation Service became U. S. Bureau of Reclamation on June 20, 1923.

In addition the Colorado River Basin States and other interests contributed to the operating costs of the Lees Ferry station during the fiscal year 1928 as follows:

Arizona-Colorado River Commission	$1,700
Wyoming	1,000
Utah	673
New Mexico	500
City of Pasadena	200

The city of Los Angeles increased its contribution during 1928 for the same purpose.

The film "Story of Water"

The film entitled "Story of water" was a cooperative undertaking. The Reclamation Service was desirous of popularizing its work, particularly in the eastern part of the country where little was known

regarding it, and decided upon a moving-picture story starting with a mountain stream originating in a snowbank high up in the canyons, showing its boistrous progress through canyons to the valley where it was harnessed for irrigation. To make the picture as realistic as possible and to give it the desired scenic background as a further aid in arousing public interest, Yosemite Valley in California was selected as the site. C. J. Blanchard, statistician, and R. B. Dame, photographer, both of the Reclamation Service, went to San Francisco in September 1920 and enlisted McGlashan's cooperation in the enterprise.

The following week all three went to Yosemite Valley and obtained a moving picture of C. J. Emerson making a discharge measurement from a cable car at the gaging station on Tuolumne River below Hetch Hetchy dam site. Another moving picture was obtained in Yosemite Valley showing McGlashan making a wading measurement. Incidentally, the speed with which these measurements appeared to be made when the film was shown, cast some doubt on their accuracy. Another moving picture showed Emerson visiting a recorder shelter and performing the routine work of such a visit at a phenomenally high rate of speed. Pictures of irrigation structures and scenes on completed irrigation projects were obtained elsewhere, the whole being made into a two-reel film giving the story of water chiefly from the irrigation standpoint.

The film was first shown publicly at the 1921 conference and aroused so much interest among the district engineers that within the next few years many of them borrowed the film and exhibited it to groups in their districts. The writer recalls showing it to the Nebraska Irrigation Association in 1931, at which time the presiding officer commented on the speed with which McGlashan and Emerson appeared to do their work, and stated that at last he had seen government men who were really hustling on their jobs.

In 1924 the Story of Water was condensed into one reel and shown on occasions where the two-reel film would be too long. The first week after its condensation the reel was used by the visual education instructor in the District of Columbia and shown to 63 sixth grade classes having a total attendance of 2,290.169/

169/ News Letter Feb. 11, 1924.

Potomac River at Great Falls

A special study of the water supply of the Potomac River at Great Falls was made during the latter part of 1920 in the Washington office under J. C. Hoyt's direction.

The recently created Federal Power Commission had been directed by Congress to make an investigation and report on the development of Great Falls for water power and increase of water supply for the District of Columbia. The Commission delegated the engineering studies to the Army Engineers, and on July 27, 1920, the Chief of Engineers requested

the Survey to report on the water supply. It was to be an office study and an allotment of $1,500 was made for the purpose.[170]

170/ Letter from N. C. Grover to the author.

The study was started in August 1920 by the computing section and completed in the following December. The natural flow of the Potomac River at Great Falls was computed for the 23-year period 1897 to 1919, based on records of the Potomac at Point of Rocks, Md., and of the Monocacy at Frederick, Md., the combined drainage area of which was 90 percent of that above Great Falls. Comparative studies of short-time records within the remaining 10 percent of the area were made to serve as a basis for estimating the runoff from that area. As the study related primarily to power, extensive use of deficiency tables was made. Floods were also studied. To determine the increased flow during low-water periods that might be obtained by storage, reservoir sites were selected on topographic maps, their capacities measured, and the runoff available at each site was computed by use of the unit runoff determined for various parts of the Potomac River Basin.[171] Advance data were fur-

171/ News Letter Jan. 25, 1921.

nished to the Army Engineers as the computations progressed.

The report on water supply by Hoyt and Stevens was transmitted to the Army Engineers and was published, with their findings,[172] many of

172/ Sen. Doc. 403, 66th Cong., 3d Sess., 1921.

which were based on the Survey study of the water supply. In commenting on the Survey's report the Army Engineers stated:[173]

173/ Op. cit, p. 29.

> This report is so thorough a study of all runoff records and of storage reservoir possibilities that the amount of water available for the development of power is in no sense conjectural. The United States Geological Survey, through its topographic branch and surface water division, has at all times during this investigation most cheerfully cooperated by furnishing all available topographic and runoff data.

During the general investigation, J. H. Levering, an engineer of Los Angeles, presented a scheme for power development, and appealed to the Secretary of the Interior to have it investigated by the Survey. The Secretary requested a report on the Levering scheme, and in order to have the report express the views not only of the Survey but of the entire Department, representatives from all engineering groups of the Department were called in. The adverse report, which was written on one page to give emphasis to it, was signed by Grover, J. C. Hoyt, Horton, G. C. Stevens, and Davenport of the Branch, and by four engineers from

the other groups of the Department. It was published on page 6 of the Army Engineers' report to which reference has been made above.

Stream gaging in Haiti

Although the stream-gaging work which was started in Haiti during the period was not carried on under the Survey's supervision, nor supported in any way by Survey funds, Grover made a study of the situation and made recommendations, former members of the Survey started the work and carried it on for two years, and monthly contributions from engineers in Haiti appeared regularly in the News Letters. Therefore, it appears fitting to give an account of the beginning of the Haitian work.

During the years 1912 to 1914 Haiti had a succession of presidents and was in a continual state of turmoil. These presidents borrowed money by means of four separate issues of internal bonds in order to provide funds to pay the "extraordinary expenses" incident to their election and subsequent maintenance in office. These bonds were secured by specific customs duties and were taken largely by local German merchants and representatives of German banking institutions. Fearing for the safety of these investments, the German government took preliminary steps early in 1914 to obtain exclusive control of the Haitian customs and obtain a naval base - both in defiance of the Monroe Doctrine - but the outbreak of the World War in the summer of 1914 caused Germany to withdraw her attention from Haitian affairs. The United States, during these years of strife, had kept watch of the proceedings through the presence of one or more warships stationed in the harbor of Port-au-Prince.

Finally in 1915, during another of the recurring revolutions, our naval forces intervened to protect the lives and property of foreigners. This intervention led to the negotiation of a treaty, Article I of which stated:

> The Government of the United States will by its good offices aid the Haitian Government in the proper and efficient development of its agricultural, mineral, and commercial resources, and the establishment of the finances of Haiti on a firm and solid basis.

This treaty was effective in 1916 and the United States took over the management of Haitian fiscal affairs. Being on the ground, the Navy Department was given the task of carrying out the terms of the treaty.

The only treaty activity pertinent to this history was related to the efficient development of agriculture, and as much of the plains region is desert in character, a system of irrigation was required. In the Colonial days the French had constructed an irrigation system, but this had been neglected after the country became independent and was in general no longer usable. As the development of an irrigation system was an engineering task, it was undertaken by the Haitian Department of Public Works. When Commander A. L. Parsons became engineer-in-chief

of the Department in 1919 he realized that irrigation plans must be preceded by a knowledge of available water supplies and came to the Survey for advice. Knowledge of available water supply must be based on a stream-gaging program but before specific advice could be given it was necessary to become familiar with the local conditions. Accordingly, Grover was detailed by the Survey to the Navy Department at the expense of Haitian funds, spending the period from September to November 1921 on that detail. In his report to Commander Parsons, Grover showed the need for a stream-gaging program and made specific recommendations for the organization of such work, as follows:

> The engineering personnel for stream gaging as finally organized in the Republic should consist of a hydrometric engineer, an assistant hydrometric engineer, two or more district engineers, an office engineer, and several assistant and junior engineers. For at least several years after the beginning of the work, the hydrometric engineer and his principal assistant should be selected from the group of experienced engineers employed in the stream-gaging work of the United States Geological Survey. As soon as their services can be utilized, young Haitian engineers of good education should be employed and developed by experience and selection, serving first as junior or assistant engineers and advancing through the higher grades in accordance with their integrity and their ability to accept responsibility and to direct the work of others.

Although he did not pick out specific sites for gaging stations, he listed the streams for which records should be obtained and gave general locations and general recommendations for types of installations.

As a result of Grover's recommendations, stream gaging was started the following summer (1922) and J. F. Kunesh and J. W. Bones resigned from the Survey to accept positions under the Department of Public Works of Haiti. Kunesh was made chief hydrographer of the newly created Division of Hydrography July 30, 1922, with Bones as his principal assistant and two Haitian assistant hydrographers. These latter spoke English as poorly as Kunesh spoke French on his arrival.[174]

174/ Letter from J. F. Kunesh to the author.

Work was started immediately with reconnaissance surveys of 22 streams and the installation during the first month of 10 gaging stations equipped with vertical staff gages. At the end of the first year 34 stations had been installed and one discontinued - an indication of the thoroughness of the reconnaissance. Two cables and three footbridges were installed. During the second year the number of stations had been increased to 41, three of which were equipped with recorders in concrete shelters, five with cables, and one with a masonry control. The construction work was carried out under conditions which were both trying and amusing. During the hundred years of their independence, the natives had, as Kunesh expressed it,[175] deteriorated to the point where the

175/ Op. cit.

simplest tools furnished for the work were looked upon as toys, and it was necessary to teach them the use of the tools. More than one native took his first hold of a cross-cut saw with both hands on the steel blade and the teeth pointed upward, pushing and pulling upward to cut a tree or log. The masonry control was built by Kunesh, with only native helpers, and as he had practically no tools, it was necessary for him to mix the sand and cement with his bare hands to bind the native rock constituting the control.

When work was started it was so strange to the natives that they had the greatest respect for it, and Kunesh was able to obtain the leading men in the communities to act as observers, or in his own words,[176]

176/ News Letter Nov. 10, 1922.

> At most places we have access to mayors, judges, habitation superintendents, etc. Some take their jobs very seriously and are quite mathematical.

Although the official language of Haiti is French, this is only spoken by the few educated people and 95 percent of the people speak "Creole", a patois of French origin, having about 1200 words with no particular conjugation of verbs or declension of nouns. In carrying on their field work it was, of course, necessary for the American engineers to learn Creole.[177] Before Kunesh accepted the Haitian position, he spent

177/ Statement of J. F. Kunesh to the author.

his entire time for several months studying French. This knowledge made it easy for him to acquire Creole, at least to a degree that was satisfactory to all the natives concerned. This knowledge of what almost might be termed two languages (French and Creole), caused Kunesh's spoken French to sound very Haitian. It was necessary to prepare forms in French for both field and office work and complete instructions in French for the use of the educated native assistants. As the metric system was used, the unit of flow was the cubic meter per second and to simplify the computations, current meters rated for the metric system were obtained from the Gurley Company. The wading rods, which were in half-meter lengths, were graduated to centimeters, decimeters, and half-meters, as were the staff gages. Two Au recorders adapted to the metric system were installed during the second year. Their records showed the effects of the daily rains during the rainy season. These rains occurred in the late afternoon, causing a sudden rise which reached its crest at the gaging stations about midnight. By morning the stages would again be normal.

Haiti is a mountainous country with arable land in the plains and river valleys. At first practically all stations were constructed on streams in the plains, and the highways constructed after American intervention made the stations accessible to the Dodge car which was furnished for the field work. Kunesh felt that it was wise to make measurements more frequently than would have been practicable if less accessible sites had been used. In the mountainous sections it was necessary to traverse the steep trails by means of saddle horses, using

pack mules to transport equipment. What may be considered a record 1-day trip was 40 miles long over the roughest ground imaginable. As the area of Haiti is only 10,200 square miles, the distances were not great, and the most remote station was only 225 miles from the headquarters in Port au Prince.

A knowledge of the rainfall was essential and early during the first year a compilation was made of the records obtained at 26 rainfall stations, most of which had been started in 1905 and kept by the priests of the College-Seminare St. Martial. Seventy additional rainfall stations were established, of which the Haitian-American Sugar Co. maintained 32 and the Division of Hydrography, 38. Another line of activity was the determination of seepage losses in the old French canals, in order that the worst sections might be found and repaired.

Not only was it possible to obtain the leading men in the villages to act as observers, but on one occasion the president of the country was given a demonstration of the stream-gaging work, and counted the clicks during a measurement of the Artibonite River, made by West, who had succeeded Bones. The president was much amused as well as interested in the proceedings. As Kunesh describes the incident:178/

178/ News Letter Apr. 10, 1923.

> During the operation considerable champagne was disposed of, and while Mr. West reports that the measurement plotted right on the curve, he also affirms that the scale was such that it had to plot right for the president.

In describing the natives Kunesh wrote that 95 percent of them are descended from African negroes, with French contact, with the most sympathetic hearts imaginable and hospitable to the point of starvation. They are optimistic and happy-go-lucky, and caused many a white person to envy them their enjoyment of life. That the American engineers were not immune to the local sports is shown by the following statement:179/

179/ News Letter Jan. 10, 1923.

> Fifty cents was recently won by the hydrographic service in a cock fight here but immediately lost shooting the "bones."

The water year beginning October 1 was chosen for the Haitian work, not because it was the water year, but because it was the fiscal year in Haiti, and the Department wished the two years to coincide. The first report, written in French, was entitled Bulletin Hydrographique No. 1, and in general conformed to the annual reports of the Survey except for the use of the metric system, and the omission of discharge measurements and footnotes. Hectare-meters were substituted for acre-feet. The familiar Survey illustrations showing current meters under the title Moulinets Price, a typical gaging station, station type de jaugeage, and water-stage recorder, enregistreur automatique, appeared in this first report.

Kunesh remained in Haiti until July 10, 1924, when he resigned and was succeeded by Paul Lee, a former Reclamation Service employee who was in Haiti. Bones resigned in January 1923, and was succeeded by R. W. West, who left the Texas district for Haiti and remained until January 1924. In addition to the American engineers a staff of young native graduates from the local engineering college and the French universities was built up. They seemed to have a mania for scientific precision and gave promise of carrying on the work satisfactorily. During the second year of the work the Division of Hydrography was held to a budget of $1,500 per month, or $18,000 annually.

The account of the Haitian work stops with Kunesh's resignation which was made effective when he felt that he had placed the work on a firm basis. The following is quoted from a letter to him from Commander Parsons:180/

180/ News Letter Aug. 11, 1924.

> I desire to express my appreciation of your two years' work with us. During this period you have organized and placed in successful operation the stream-gaging service. The importance of such a service to Haiti in the consideration of its irrigation problems is unquestioned. You can justly take pride in the part you have taken in this important development.

To complete briefly the account of American participation in the Haitian work it may be stated that by 1928 responsibility was being placed on the Haitians with only general supervision by the American engineer in charge, and this supervision ceased in 1932 when American occupation was terminated.

District operations

New England.- The New England district comprised the New England States but the Maine operations are described separately because Maine was cooperating more extensively than any of the other States in the district, and it was organized as a sub-district with headquarters in Augusta.

The years 1919-1928 were a period of relative stability in the New England district as the total number of stations (exclusive of Maine) varied only between 40 and 48. The chief interest in New England streams related to water power until near the end of the period when the severe floods of 1927 aroused interest in flood protection. Active interest in water power was generally limited to the operating power companies, who felt that the stream-gaging program was sufficient and so did not advocate increased appropriations. Water power was not a political issue and so the State officials were not interested in increasing the work. In fact the Massachusetts officials stated at the beginning of the period that they did not care to have any additional stations established.181/

181/ Statement of C. H. Pierce to the author.

New Hampshire was the only State in which private assistance constituted a factor in the district operations. The assistance by private interests in that State, which took the form of direct payment of gage observers and of costs of installations of gaging stations, was of such magnitude that it was possible to increase gradually the number of New Hampshire stations from 12 to 17. Twenty-three gaging stations in the district (exclusive of Maine) were equipped with recorders.

Trains were used extensively in carrying on field work during the early part of the period and livery rigs were hired to reach stations distant from the railroad. On one occasion a livery horse decided he had waited long enough at a station and returned home without the engineer, losing a dilapidated laprobe en route. Consequently, the following letter was received from the livery owner:182/

182/ News Letter May 22, 1920.

> You say the hoss ran away but I haint got nuthin to do with dat. If you haint never had nuthin to do wit no hoss you shood take someone with you what doze. If you dont send me seven dollars rite aweigh I will su you.

When the laprobe was recovered it had two new holes in it and the claim was settled at the rate of $1.50 per hole.

A special slope study between two gaging stations 11 miles apart was made in the fall of 1922 on the Connecticut River. This indicated that the value of "n" in Kutter's formula was not constant as generally assumed but varied with the stage, the range being from 0.037 at a discharge of 5,580 second-feet, to 0.032 at 18,000 to 20,000 second-feet, and to 0.035 at 35,400 second-feet.183/

183/ News Letter Oct. 10, 1922.

The severe ice conditions on power-regulated streams in the district led Pierce to make a study of the effects of backwater from ice on river discharge. This study indicated that for a constant ice condition the amount of backwater varied with the stage. In the standard procedure developed by W. G. Hoyt and published in Water-Supply Paper 337 the change of backwater with stage was not recognized. In order to verify this indication, Pierce's field men volunteered during the winter of 1923-24 to obtain additional current-meter measurements at low stages on power-regulated streams, two or more measurements on the same day being obtained on such streams. These results indicated that the amount of backwater decreased with stage, becoming zero at zero flow. As a result of this study, Pierce modified the standard method of computing winter records in New England by varying the gage-height correction for ice according to the stage, using what he termed a "variation diagram."184/

184/ News Letter June 10, 1924.

As this method is applicable chiefly to power-regulated streams, it had but limited use.

Pierce became interested in studies of backwater through his contacts with Prof. H. S. Boardman, dean of the college of engineering, and later president of the University of Maine, who was a frequent visitor to the Boston office. Prof. Boardman realized the educational value to senior engineering students of an exhibition and description of stream-gaging equipment, and arranged each year to have those students visit the Survey office during the Easter vacation. They spent an hour or so in the office examining the equipment and listening to a lecture on the work of the Branch by the district engineer or his assistant. It is not to be doubted that this contact with the Survey induced some students to become members of that organization after graduation.

C. H. Pierce, district engineer, resigned November 15, 1925, and was succeeded by H. B. Kinnison, who was transferred from the Kansas district. The remaining personnel during 1919-28 were:

M. R. Stackpole	July 1, 1919 to Oct. 15, 1920
B. L. Bigwood	July 1 to Nov. 30, 1919
J. L. Lamson	July 6, 1919 to Oct. 7, 1920
H. S. Price	Oct. 20, 1919 to June 5, 1920
H. I. Granger	Oct. 1, 1922 to Jan. 30, 1923
W. E. Armstrong	Dec. 13, 1920 to Sept. 1, 1923
H. F. Hill, Jr.	Jan. 8, 1923 to Apr. 30, 1928
E. W. Downs	Oct. 11, 1923 to Sept. 1, 1924
K. K. Hoyt	July 6 to Sept. 11, 1920
O. D. Mussey	May 1 to June 30, 1928
D. S. Wallace	May 15 to June 30, 1928

The annual Survey allotments to the district, including Maine, were:

1920	$6,475	1923	$6,500	1926	$5,000
1921	7,000	1924	6,500	1927	4,700
1922	6,000	1925	5,500	1928	3,900

Maine.- On the return of J. W. Moulton from military service on Aug. 1, 1919, he was detailed to Maine, relieving A. F. McAlary, a State employee, who had been maintaining the stations in that State. Moulton resigned Oct. 14, 1920, and was succeeded by M. R. Stackpole. When the Maine Public Utilities Commission became the cooperating State agency in July 1923[185] Stackpole was given the title of assistant engineer

185/ p.17.

in charge of the Water Resources Division of the Commission. On Sept. 1, 1928 he was designated district engineer for the Geological Survey.

The program of stream gaging for this period was intensive rather than extensive. Although cooperative funds were increased, only three additional stations were established, but in order to improve the accuracy of the records seven recorders and ten cables were installed. Water-power interests contributed towards the maintenance and operation of ten of the 19 stations maintained at the end of the period and furnished complete records at seven dams.

Not only did chain gages give trouble from stretching but they sometimes had an irresistable attraction for passers-by as shown by a letter from one observer:186/

186/ News Letter Oct. 24, 1919.

> The new chain you send me i place it on the gage and someone stold it * * * you will have to arriange the gage some way so i can carride the chain with me back and fourth for i donth think we can keep a chain there now they tacken two away and they tacke the next one.

Another observer, upon being given additional instructions regarding his duties, stated that he was instructed by Mr. N. C. Grover in 1903, and didn't believe in making changes. (A true conservative Yankee). A third observer is believed to hold the record for length and faithfulness of service. A. D. Harlow read the gage on the Piscataquis River near Foxcroft from its establishment by Grover in 1902, until failing health due to his age of 84 years, compelled him to resign in 1927. During those years he read the gage regularly except for a period of a few weeks when he was in the hospital.

The winter days were so short in the northern part of Maine that it was not uncommon to make a measurement by the light of the moon and a humble lantern. No report on the accuracy of such measurements is available.

New York.- The post-war period was one of great activity in water-power development, which was the chief factor in bringing about an expansion of the stream-gaging program in New York. Stations required for the operation of the Barge Canal had been established previously and little expansion took place in that group.

To obtain assistance for the establishment of additional stations, Covert, during the three years that he continued in charge of the district, endeavored to show the power companies their need for additional records.

In 1920 an association of water-power interests, known as the New York Water Power Investigation, was formed and a consulting engineer employed to make a reconnaissance for gaging stations on some of the more important power streams on which there were no stations. The Survey was requested to assist in the work and make recommendations.187/ The results

187/ News Letter May 22, 1920.

of this investigation and of Covert's efforts were not immediately apparent as the number of gaging stations remained at about 55. In 1924, however, the number of stations had been increased to 70, and at the end of the period to 83. That this increase was due largely to the greater amount of assistance received from the power companies is shown by the number of stations maintained partly by private assistance, which increased from 18 in 1923 to 48 in 1928. The increase in the number of

stations was not the full measure of increasing private contributions as assistance was also rendered in equipping stations with recorders, the number so equipped increasing from 17 in 1919 to 54 in 1928. As the district personnel was too small to make these installations and keep up the necessary field work, the engineers of the power companies made most of the installations, under general supervision of the Survey. The installations were generally timber shelters on concrete wells.[188] Thirty-one cables were erected and three artificial controls

188/ p. 68.

were constructed.

One result of the participation by the power companies in the stream-gaging program was the study they gave to the stream-flow records. The larger companies quite generally had been keeping their own records of flow through their plants, and in 1927 some of the operators questioned the accuracy of the records of the Watertown station on Black River, which did not agree with the power-plant records. As the Watertown station was one of the best in the district, Harrington felt that the criticism constituted an indictment of Survey practices generally. He therefore suggested that a disinterested Survey engineer from another district make a study of the situation. This was agreed to and J. H. Morgan spent a month in an investigation which proved the accuracy of the Watertown records. That this conclusion was accepted by the power companies is shown by the attitude of one of their representatives, who stated:[189]

189/ News Letter June 10, 1927.

> I consider this work a remarkable vindication of the accuracy and thoroughness of the work of the U. S. Geological Survey.

A gaging station on Poesten Kill near Troy was established in cooperation with the Rensselaer Polytechnic Institute, the civil engineering students of which used it as a laboratory in stream gaging. Cornell University had for some years maintained a station on Fall Creek near Ithaca. This station was taken over by the Survey and rebuilt, affording the Cornell civil engineering students a laboratory in stream gaging.

Unusual ice conditions were experienced on the Raquette River. The station at Piercefield was situated in a bay where the velocity was usually so low that ice 3 feet thick would form across the river. A mile downstream rapids remained open and the gage heights were not affected by backwater. The lack of backwater effects of ice cover above an open control had first been pointed out by Adams in 1911.[190]

190/ Follansbee, Robt., Hist. of --- p. 243.

One of the few fatalities in the Survey occurred Mar. 3, 1923, when B. F. Howe, Jr., was drowned while making an ice measurement of the Delaware River near Port Jervis as a result of the breaking of the ice.

Covert was district engineer until he resigned Aug. 19, 1922. He was succeeded by A. W. Harrington, who had been office engineer. The thoroughness with which Covert trained his assistants created a demand for them in other districts. As a result of this demand and also of the lure of outside employment, there were many changes in personnel during the years Covert was in charge of the district. Seven, W. G. Hoyt, G. H. Canfield, O. W. Hartwell, C. H. Pierce, E. D. Burchard, M. H. Carson, and A. W. Harrington became district engineers, either immediately after being transferred, or later.

The engineering personnel during 1919-1928 was:

C. C. Covert	July 1, 1919 to Aug. 19, 1922
O. W. Hartwell	July 1 to November 1919
M. H. Carson	July 1 to August 1919
A. H. Davison	August 1919 to June 1920
Otto Lauterhahn	Nov. 1, 1919 to July 31, 1921
A. W. Harrington	Nov. 1, 1920 to June 30, 1928
H. I. Granger	Mar. 7 to Oct. 1, 1922
B. F. Howe, Jr.	September 1919 to Mar. 3, 1923[191]
A. E. Johnson	July 1, 1923 to June 30, 1928
W. B. Mifflin	February 1925 to Apr. 30, 1926
E. B. Shupe	-- 1920 to Mar. 15, 1925
K. K. Hoyt	June 1, 1926 to Apr. 29, 1928
J. L. Lamson	October 1920 to Aug. 18, 1926
B. L. Bigwood	Oct. 1, 1926 to June 30, 1928
H. F. Hill, Jr.	May 1 to June 30, 1928
S. M. Currier	June 4, 1920 to June 10, 1921

191/ Drowned.

New Jersey.- When the New Jersey district was established on July 1, 1921, O. W. Hartwell was transferred from Pennsylvania and appointed district engineer, with headquarters at Trenton. He established a temporary office in an old residence which had been acquired by the State as an office building. The cooperating State official turned over to him the records at the 20 stations which had been established in 1919, some of which had been maintained by the Survey prior to 1906. These records consisted chiefly of gage heights and were contained in what Hartwell termed two big black books. The only station that was being maintained by the Survey was on the Delaware River at Riegelsville, which the author had established in July 1906.

Hartwell's first work was to inspect the gages which had been established by the Water Supply Commmission and examine sites for new stations suggested by H. T. Critchlow, the cooperating State official. Of the stations inspected, only four were found to be suitable for permanent maintenance and the remaining 16 were dropped and others substituted. Staff gages were utilized at all but two stations at which cooperating interests installed recorders using Survey plans. Stream gaging was an unfamiliar activity to most of the Jerseyites, and the first observer employed wanted to know if it was "another of those things to keep the taxes up."[192] It is evident that Hartwell had a campaign of

192/ Letter from O. W. Hartwell to the author.

education ahead of him.

During the second year seven additional stations were established and during 1924 four more. This practically completed the list of stations contemplated at that time. As Hartwell's policy was to maintain a comparatively few stations in first-class condition, no more stations were installed until 1928, when three were added. Only two stations were discontinued, which is an indication of the care with which the original sites were selected. The drainage areas of all stations but those on the Delaware River were so small that 85 percent of the measurements were made by wading.

As funds became available the work of installing recorders was started. At first timber shelters were constructed on concrete wells, though later as experiments, three wells and one complete structure of concrete block were used. Still later standard concrete shelters were built. By the end of the period 37 recorders had been installed. As the streams were spanned by numerous bridges it was necessary to install only one cable and one footwalk of 75-foot span suspended on two cables. The one cable was used only a few years and then removed. Ninety-five percent of the 39 stations were equipped with recorders in standard shelters, and 12 stations had artificial controls. Thus Hartwell's policy of maintaining a comparatively few first-class stations was largely realized.

The range of stage at some of the stations was slight and to make the recorders more sensitive 20-inch floats were used on two of them. However, as these floats were found to be cumbersome and more liable to damage than the regular 10-inch floats--drawbacks which outweighted the slight increase in accuracy--the use of 20-inch floats was not extended.

The Weather Bureau had maintained a gage on the Delaware River at Trenton since 1913 and a start toward rating it was made, although at the time it was believed to be within tidal influence. Measurements, however, indicated that tidal influence did not extend above the station control. In 1927, when negotiations to divide the waters of the Delaware were in progress between New Jersey, New York, and Pennsylvania, the city of Trenton became interested in that station to the extent of paying for the installation of a recorder in a concrete shelter.

The investigation of ground water in the Atlantic City area[193/]

193/ p. 168.

involved the installation of a station on Absecon Creek within tidal influence. The difficulties were resolved by constructing an artificial control that eliminated all but the peaks of the high tides, which were easily detected on the recorder charts. In connection with the operation of that station it was necessary to measure the loss in head through a wood-stave pipe 9,800 feet long and 12-inch float tanks were constructed at each end, in which natural-scale recorders were placed. The loss of head was used as an index of discharge diverted through the pipe line. The rating was determined by making current-meter measurements in an open channel at the lower end.

Four other artificial controls were constructed to eliminate effects of aquatic vegetation. Thus five artificial controls were constructed by the Survey. Seven other stations had artificial controls of various types, constructed primarily for other purposes by private interests.

Hartwell was active in arranging cooperation with municipalities and in seeking assistance by private interests. During those activities he learned of the existence of several long-time records which had not been published. The city of Newark had maintained a record of flow of the Pequonnack River at the Macopin intake dam since Jan. 1, 1892. This station, equipped with a recorder, had been established by John R. Freeman, consulting engineer, who had rated it by means of a weir installed above the dam. The East Jersey Water Co. had maintained a record of Rockaway River at the intake dam near Boonton since Jan. 1, 1906, and the Society for Establishing Useful Manufactures had maintained a record of the Passaic River at a hydro-electric station near Paterson since Aug. 16, 1897. As a matter of historic interest it may be added that the Society for Establishing Useful Manufactures had been organized in 1790 by Alexander Hamilton and associates. The flow of the Passaic River is regulated by six storage reservoirs and reduced by diversion for several municipal water supplies and for the Morris Canal. Since records of such storage and diversion were available, and Hartwell spent considerable time in making the necessary additions to and subtractions from the Paterson record to show the natural flow, these long-term records were published in the Survey's annual report.

As the chief value of records in New Jersey related to municipal and industrial uses, most of the requests for data came from those sources. However, the reason for one request was most unusual. A marine insurance company wished to know the probability of floods occurring on a certain stream, in order to compute a rate for insuring a farm against damages caused by overflow. Hartwell's reply has not been recorded.

Hartwell became a loyal Jerseyite and resented the remarks about the New Jersey mosquito, remarks which have been made by non-Jerseyites since the early days of the Republic. He declared that much-maligned insect to be no more vicious than the mosquitoes he had encountered in other eastern States. These latter, of course, may have been Jersey mosquitoes who had wandered from their native heath.

The engineering personnel during 1921-28 was:

O. W. Hartwell	July 1, 1921 to June 30, 1928
Otto Lauterhahn	Aug. 1, 1921 to June 30, 1928
J. W. Bones	Jan. 22 to Sept. 15, 1923
H. C. Barksdale	Jan. 7, 1924 to Jan. 1, 1926
R. B. Letcher	Feb. 4 to May 19, 1927
Walter Voght	June 15, 1927 to Feb. 25, 1928
R. E. Marsh	Apr. 7 to June 30, 1928

Middle Atlantic States.- The Middle Atlantic States district was contracted materially in area during this period and the operations in that smaller area were carried on intensively. The reduction of area

came about with the division of the district into three districts and the transfer of the five stations in Kentucky to a fourth recently-created district all because substantial cooperation became effective with a number of States.

In 1919 the district comprised all or parts of the States of New Jersey, Maryland, Virginia, the District of Columbia, West Virginia, Ohio, Michigan, and Kentucky, a large region in which some 33 stations were being maintained. The district was operated from Washington as an adjunct of the Computing Section, and since the stations had relatively stable controls and the available funds were only sufficient for the pay of the gage observers, little field work was done.

The Tennessee district was created in January 1920, and the few Kentucky stations were transferred to it. When the New Jersey and Ohio districts were created in July 1921 the lone New Jersey station and the two Ohio stations were turned over to those districts. The interest in Virginia's water resources reached a point where cooperation was started in February 1925 and a sub-office was established at the University of Virginia with J. J. Dirzulaitis in charge. The Virginia stations constituted a part of the Middle Atlantic district until Mar. 1, 1926, when the Virginia district was created. These amputations reduced the Middle Atlantic States district to Maryland, West Virginia, and the District of Columbia, with 30 gaging stations, of which 7 were equipped with recorders.

On July 1, 1921, A. H. Horton, chief of the Power Resources Division was put in charge of the district. Dirzulaitis, transferred from the computing section on Aug. 1, 1922, constituted the field personnel. Before his transfer, engineers from the Computing Section were detailed to visit the gaging stations once or twice a year. After the establishment of the office at Charlottesville, Va., in 1925, the field personnel was W. C. Wiggins, June 3 - Nov. 30, 1925, and J. H. Hofmann, Dec. 15, 1925 - June 15, 1926.

A small amount of cooperation was in effect with the U. S. Engineer Office at Pittsburgh for work in the Ohio River Basin in West Virginia. This cooperation was a continuation, on a reduced scale, of that started in 1915. A number of West Virginia stations were situated at navigation dams, where the delapidated lock gages permitted considerable leakage. So serious was the leakage at lock 15 on the Monongahela River, where it constituted a large percentage of the low flow, that in 1924 B. J. Peterson and J. H. Morgan devised a volumetric method of measuring it 194/which was used by Morgan during the remainder

194/ Letter from J. H. Morgan to the author.

of the period. The army Engineer gradually repaired the lock gates, reduced the leakage and made it unnecessary to continue the use of the method.

The difficulty of conducting stream-gaging operations in Kentucky with the district office at Washington, D. C., is illustrated by a trip made in advance of a storm with the expectation of obtaining flood stages at stations in the Cumberland River Basin. The storm skipped the basin and measurements were made at close to minimum stages after travelling by train some 600 miles.

The Survey allotments were:

1920	$ 800	1923	$3,000	1926	$3,600
1921	1,500	1924	4,000	1927	5,876
1922	3,000	1925	3,600	1928	5,500

Virginia.- The history of the Virginia district begins on Feb. 21, 1925, when the sub-office was established in Charlottesville, with J. J. Dirzulaitis in charge, and Karl Jetter as his assistant. Thirteen stations were in operation, but within the next seven months 18 additional stations equipped with chain gages were installed.

The program was one of rapid expansion, to meet the needs of the State, and by the end of the period 58 stations were being maintained, of which eleven were equipped with recorders, installed chiefly in concrete shelters. Power companies were naturally interested in the stream-gaging program and contributed to the installation of the recorders and to the maintenance of the stations afterward. One power company, however, could see no need for stream-flow records when one particular station was established. However, 15 months later when the increase of load on its plant made necessary an enlargement of its facilities, the company became so greatly interested that it detailed one of its engineers to the district office to assist in computing the records in order that those records might be available as soon as possible.[195]

195/ News Letter Nov. 10, 1926.

The establishment of the district office on the campus of the University of Virginia created considerable interest in the Survey's work among the engineering students, and Dirzulaitis gave a series of lectures to the seniors.

A special study was made of the rate of travel of released water in the New River in 1927. The Army Engineers planned to install two movable dams on the Kenawha River and wished to learn the effect at these dams of the operation of a storage reservoir for power plants situated some 200 miles upstream. They installed temporarily six recorders and one staff gage (the latter read hourly by a lockmaster). After these installations had been made the Army Engineers sought the assistance of the Survey and Dirzulaitis operated the stations from August to December 1927, during which time the stations were completely rated. The records of daily discharge and the recorder charts were turned over to the Army Engineers for their use in determining the rates of wave travel. The cost of this study, exclusive of salaries, was paid by the Army Engineers. A more elaborate study of a similar nature was made after 1929.

In 1927 Dirzulaitis and G. C. Stevens compiled all available Virginia records, which were published by the Virginia Geological Survey.[196]

196/ Water Resources of Virginia Bulletin 31.

Dirzulaitis was in charge of the district from its separation from the Middle Atlantic States district on Mar. 1, 1926. He was also the chief engineer of the Virginia Conservation Commission's Division of Water Resources and Power, the cooperating agency.

The engineering personnel during 1925-28 was:

Karl Jetter	Feb. 9 to May 17, 1925
O. D. Mussey	Mar. 27, 1926 to Apr. 30, 1928
F. C. Christopherson	Apr. 9, 1926 to Dec. 11, 1927
M. T. Thomson	Dec. 13, 1927 to June 30, 1928
N. B. Usler	Sept. 26, 1927 to Dec. 20, 1928

South Atlantic States.- The transfer of C. G. Paulsen from the South Atlantic States district to Boise in June 1919 left an interim of about a month with no district engineer before Warren E. Hall returned from the Army on Aug. 1, 1919. A. H. Condron was in charge during that short period. With Condron's resignation in July 1920, the district again became a one-man organization except for a part-time assistant. The creation of the Tennessee district in January 1920 reduced the number of gaging stations from 34 to 17. A year later cooperation with North Carolina resulted in the moving by Hall of his district headquarters from Atlanta, Ga., to Asheville, N. C. The few stations in Georgia and Alabama were transferred to the Tennessee district, and the South Atlantic States district came to an end after a life of 26 years.

North Carolina.- North Carolina, which had been a part of the South Atlantic States district, became a separate district in January 1921, when Warren E. Hall moved the Survey office from Atlanta to Asheville and relinquished to the Tennessee district the stations in the other States except a few in Georgia that were being maintained by power companies. Within two years a few stations were established in South Carolina as a result of assistance by power companies and that State may be considered as having been added to the North Carolina district. Hall remained in charge of the district until Aug. 4, 1924, although from January to August of that year he devoted only a part of his time to Survey work. E. D. Burchard became district engineer on Aug. 4, 1924.

The nine North Carolina stations previously maintained by the South Atlantic States district were the nucleus of the stream-gaging program. The first year's cooperation of the Tennessee district with the Army Engineers required the establishment of 18 stations by the North Carolina district. No other stations were established during the first year. L. R. Hall, a per-diem appointee, who had previously been employed in Georgia, performed the field work required in the operation of these stations.

The increase in State funds, beginning with the fiscal year 1922, made it possible to start on the State's program. As water power constituted the State's chief interest in the program, sites on the streams in the mountainous central part of the State were selected. Beginning in 1926, water supply and sewage disposal problems of various municipalities brought about the establishment of stations to meet those needs. The number of stations being maintained increased to 57 in 1926 and then decreased to 51 in 1928. Of these, 26 were equipped with recorders.

Although many of the stations were maintained primarily for water power, few power companies in North Carolina assisted in the work, as they believed they had sufficient records for their own needs. Federal Power Commission permittees installed and operated at their own expense, under Survey supervision, four stations during the latter part of the period.

One of the early stations established was on Morgan Creek at Chapel Hill which the engineering department of the University of North Carolina used as a stream gaging laboratory. The recorder was placed at an elevation that was well above any existing high-water mark, but within a year a 10-inch rain which fell within a few hours raised the creek 15 feet higher than the oldest inhabitant could recall and destroyed the station. With that as the horrible example, later installations had a much wider margin of safety.

In 1926 Burchard began the construction of artificial controls and installed nine during the remainder of the period.[197]

197/ p. 74.

In South Carolina cooperation with power companies that were permittees of the Federal Power Commission resulted in the establishment of six stations. Burchard established and maintained these stations at the expense of the power companies. A few of the Georgia stations were continued by power companies. As these were quite completely rated and were on streams with fairly permanent controls, little or no field work was performed except during the drought year of 1925 when a round of the stations was made for the purpose of obtaining low-water measurements. The records for most of the stations were computed in Asheville.

In addition to Hall and Burchard, the engineering personnel of the district during 1925-28 was:

L. R. Hall	(per diem)
J. H. Morgan	May 17, 1925 to June 6, 1926, Nov. 17, 1926 to May 14, 1927 and June 11 to July 16, 1927
Karl Jetter	July 3, 1927 to June 30, 1928

Tennessee.- The Tennessee district was started on faith and a shoestring when W. R. King opened the district office in Nashville in January 1920.[198] Within eight months cooperation was effected with the

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198/ p. 27.

Army Engineers who were making what turned out to be a water-power survey of the Tennessee River Basin and the office was moved to quarters furnished by that organization in Chattanooga. During the first four years the cooperative funds fluctuated widely as State cooperation increased slowly and Army Engineer funds for a continuation of the work varied between $3,500 and $12,800 annually. So uncertain was the future

of the district that in February 1923 King stated it was very much in the balance.[199] During these years of uncertainty King enlisted the support

199/ News Letter Feb. 10, 1923.

of private interests, chiefly water-power companies, some of which had Federal Power Commission permits. This assistance was not altogether an unmixed blessing as it carried with it the expectation by each contributor that the station or stations in which he was interested would be the first to have its records computed. As King states:[200]

200/ News Letter Dec. 11, 1922.

> This office is having its troubles trying to satisfy all of the various interests who are contributing to the support of our work. We have 11 such parties and each is worrying the life out of us for reports and current data. Find it requires more diplomacy to satisfy cooperating parties than it does to get financial cooperation in the beginning. One thing is certain, we will soon have to cease field work and spend all our time on reports.

Finally Congress authorized the continuation of the Tennessee River survey in 1924, and thereafter Army-Engineer funds in comparatively large amounts became available each year. Also, in 1925 the State increased its annual appropriation from $4,000 to $10,000, and later to $13,000. The continuity of adequate funds placed the district on a firm basis.

The foundation for the stream-gaging program was the 17 stations turned over to the new district by the South Atlantic States and Middle Atlantic States districts. Within the next few months six additional stations were established. The Army-Engineer cooperation resulted in the establishment of 33 stations in Tennessee, and 7 in the Tennessee Basin in Virginia. Thus by the end of the fiscal year 1921, 43 stations were being operated. A few more stations were installed during the next few years. Beginning in 1926, when there was a large increase in cooperative funds, 18 additional stations were established bringing the total to 61. This number was reduced to 59 at the end of the period. Twenty-six stations were equipped with recorders and the remainder with chain gages. Beginning in 1927 the chain gages were replaced by vertical or inclined staff gages, the latter anchored to concrete piers.

King's introduction to his new field of activities was made by A. H. Condron of the South Atlantic States district who accompanied him to the 17 stations soon after his arrival in Nashville. These stations were situated chiefly in the mountainous section of the State, a section famous for its moonshine activities and for the natives' intense distrust of strangers who were looked upon as possible "revenoors." Condron carefully warned King to avoid trails leading to caves in the hills and other secluded spots. King later passed along the warning to his assistants as the force was increased, and to its faithful observance may be ascribed the avoidance of fatalities. The good roads movement had not reached the mountains of Tennessee, and as much of the Survey work was in that section it was found advantageous to have one or more sub-districts, each in charge of an engineer. Once a stranger was known to be anything but a revenue officer, the naturally hospitable mountain-folk were friendly and helpful. King gives the following side light on work in one sub-district:[201]

201/ News Letter Dec. 11, 1922.

> Mr. Livingston who has been assigned to the work in the Cumberland River (sub) district has a big program. The people in that section are trying to assist him to get in a full day, as he reports that yesterday morning the people overslept and he didn't get breakfast until 4:45 A.M. The essential requirements for a popular hydrographer in this territory are that he shall be able to chew Browns Mule, drink white mule, and ride any old kind of a mule.

Cooperation with power companies made it possible to install a majority of the 26 recorders in operation by 1928. Ten installations were made more or less according to standard plans for concrete shelters, nine were corrugated galvanized-iron pipe wells fastened to cliffs or bridge piers, and the remaining seven were of miscellaneous timber construction. The highest concrete structure had a 60-foot well, costing $2,300, and the highest pipe well was also 60 feet, costing $1,000. This difference in cost explains why standard concrete structures were not used exclusively. At one of the stations, the Ocoee River at Parksville, a Stevens long-distance recorder was installed. An oddity in intakes, brought about through force of circumstances, should be mentioned. A recorder shelter on Caney Fork River at Rock Island, 300 feet below a power plant, was installed in an excavation blasted through 10 feet of solid rock, the trench for the 40-foot intake was being likewise blasted through solid rock. Subsequently the power company deepened the station control to lower the tailrace, leaving the intake out of water at low stages. Rather than lower the intake itself, the well was lowered and the outer end of the intake fitted with an elbow and short length of pipe reaching beneath the water surface. In order that the intake could act as a siphon, a valve to release accumulated air was also provided. It was reported that the siphon action was satisfactory,202/ but no mention was made as to the length of

202/ News Letter July 10, 1926.

time that it remained satisfactory.

Eight cables were installed, the longest of which was 850 feet. 203/ This was not the longest cable used, however, as at the station on

203/ p. 73.

Tennessee River at Loudon, a ferry cable 2,000 feet long was used to span both the main channel and an overflow channel. Part of the cable spanning the main channel was 110 feet above low water and was supported by chestnut poles about 50 feet high, guyed in three directions. A standard car was placed on the ferry cable. As there was but little traffic over the ferry, measurements were usually made without interruption, but occasionally it was necessary to stop and pull back to the nearest bank to permit the hand-operated ferry to cross.204/

204/ Letter from Duncan Charlton to the author.

The first Survey measurement of the lower Mississippi River was made by the Tennessee district in July 1927. As cooperation was effective

with the Army Engineers, although only in the Tennessee River Basin, the Army-Engineers' Memphis office felt free to call upon the Survey, and requested a measurement at Memphis to check their float measurements. The river was at 36-foot stage and as the depths in the main channel were about 125 feet with velocities of 9 feet per second, the available equipment was insufficient to make soundings and only surface velocities could be obtained. In the overflow channel, however, soundings in water 50 feet deep were made by means of 80 pounds of lead on airplane strand cable. The estimated discharge at that time was about one million second-feet. Some time later, when the river reached a lower stage, soundings were made in the main channel which were used to compute the July measurement. Two additional measurements were made and a provisional rating curve was constructed. No further measurements were made.[205]

205/ Letter from C. E. McCashin to the author.

At the Hales Bar station on the Tennessee River, the nearest bridge available was 25 miles upstream at Chattanooga. As the river was 840 feet wide a cable was not then considered feasible. The current-meter measurements were made from a motor launch held in place by a light cable stretched across two channels of the river with the tension of the cable relieved by idling the motor in the swiftest parts of the channel. The distance of each measuring point from the initial point was measured by stadia.

In 1925 King compiled all Tennessee stream-flow records and records of precipitation. This compilation was published by the State geologist[206] with the financial assistance of the Army Engineers, to whom

206/ King, Warren R., Water Resources of Tennessee, Department of Education, Division of Geology, Bulletin 34, 1925.

the publication was of great assistance.

The half dozen stations in Alabama and on the Chattahoochee River in Georgia, which were inherited from the South Atlantic States district, were maintained by means of either the small State cooperative funds available or contributions by power companies, as no Survey funds were available for their maintenance. Later, Federal Power Commission permittees paid for the installation and maintenance of additional stations which were established beginning in 1922. By the end of the period 15 stations were being maintained in Alabama and 7 in Georgia. The Army Engineers cooperated by furnishing a few records.

Permittees and licensees of the Federal Power Commission paid for the establishment and maintenance of nine stations in Florida during the last two years of the period. One company proposed to develop power by creating a reservoir in the Okefinokee Swamp and installing power plants at various sites on the Suwanee River, one of the outlets of the swamp. The Suwanee River is fed by large springs throughout its length and the Survey made in May 1927 what amounted to a seepage study of the river from its source in the swamp to tidewater in order to determine the flow at various possible sites. Two parties equipped with boats and camping equipment were used in making the study. M. T. Thomson with an engineer of the company and a guide covered the upper river, finding and measuring the flow of every visible spring entering the river, and measuring the river itself every few miles. P. R. Speer and P. E. Hanson made a similar

investigation of the lower river. The work lasted about ten days and demonstrated that the springs increased the flow of the river several fold. It was later found that during high stages the springs diverted water from the river and discharged it into the underlying limestone caves. The author was curious regarding the fauna and upon asking one of the engineers whether many snakes were seen in a region notorious for such reptiles was told "Not as many as we expected", a reply not fully enlightening.

The district personnel during 1920-28 was:

W. R. King	January 1920	to June 30, 1928
Warren Withee	Nov. 18, 1920	to June 30, 1928
Reginald Waldo	Nov. 5, 1920	to May 31, 1921
D. A. Dudley	Mar. 1, 1921	to May 14, 1922
P. E. Hanson	July 3, 1922	to June 30, 1928
P. P. Livingston	Sept. 20, 1922	to July 20, 1924
	Dec. 5, 1927	to June 30, 1928
J. J. Clawson	July 1, 1923	to Oct. 31, 1926
J. S. S. Jones	July 15, 1923	to Aug. 17, 1925
D. B. Ventres	Sept. 23, 1923	to Mar. 7, 1925
E. H. Morgan	Apr. 15, 1925	to Sept. 15, 1926
D. S. Wallace	Apr. 15, 1925	to Apr. 7, 1926
	June 1, 1927	to May 18, 1928
P. R. Speer	Nov. 27, 1926	to June 30, 1928
M. T. Thomson	June 1, 1926	to Dec. 12, 1927
Duncan Charlton	Nov. 15, 1921	to June 30, 1928

Ohio.- When the Ohio legislature, in 1921, made an appropriation for cooperative stream gaging,[207] Prof. C. E. Sherman arranged cooperation

[207] p. 28.

with the Survey and a separate district with headquarters at the State University was created. Lasley Lee was appointed district engineer, beginning duties in that capacity on July 11, 1921.

At that time the Middle Atlantic States district was maintaining two stations in Ohio and was publishing the gage heights for ten stations that were maintained by the Army Engineers in connection with their study of flood prevention in the Ohio River Basin.[208] The Miami Conservancy

[208] Follansbee, Robt., Hist. of, p. 399.

District which had been created after the disastrous flood of 1913, was maintaining ten stations and municipal and private interests were maintaining five stations in various parts of the State. Within a few months Lee and one assistant established 26 stations equipped with chain gages. He obtained the records collected by the Miami Conservancy District since the establishment of their stations and the records collected by municipal and private interests for the five other stations. The Army stations had generally been discontinued and records for only four were available. A total of 45 records were thus available during the first year. An unusual feature of these stations, which was due to the fact that topographic maps covered nearly the entire State, was that the zero of the gage for every station in the Ohio Valley section was referred to sea level datum. Prof. Sherman's strong interest in topographic mapping probably inspired this action. The available funds would permit the establishment of only a few

additional stations in 1922, but with the increase in State funds for the fiscal year 1924,[209] Lee established 17 additional stations and began

[209] p. 29.

an intensive program of constructing concrete shelters for recorders -- a program which continued through June 30, 1928.[210] As the increase in

[210] p. 67.

State funds continued a few additional stations were established each year, with the result that by 1928 there were 98 gaging stations, of which 38 were equipped with recorders.

Beginning in 1922 the stream-gaging program of the Miami Conservancy District was carried on under the Survey's direction, the District furnishing the gage heights and most of the current-meter measurements.[211]

[211] News Letter Mar. 10, 1922.

During the later years of the period, Survey engineers made an increasing number of measurements at those stations and installed recorders at several.

One result of the close contact with the University, through Prof. Sherman, and the location of the district office in University quarters, was the interest in stream gaging created among the civil engineering students. Lee and his assistants utilized the various bridges in the vicinity of Columbus to instruct students in the science and art of current meter measurements.[212]

[212] News Letter Apr. 10, 1923.

A number of stations were located at navigation dams where the leakage through the lock gates was a large percentage of the total flow of the river at low stages. Lee made use of the volumetric method of measuring that leakage as devised by Peterson and Morgan in 1924 for use in West Virginia. The field measurements required by this method, as used in Ohio were made in 15 minutes and the computations in 45 minutes.[213]

[213] News Letter Jan. 10, 1926.

Of the many odd requests received by different Survey offices for information, perhaps the oddest was one received by the Ohio district. A man jumped into the Olentangy River to save another man from drowning, and the friends of the former, in connection with a recommendation to the Carnegie Hero Commission, desired to know the depth and velocity of the water at the point where the rescue was made.[214]

[214] News Letter Dec. 10, 1924.

A considerable portion of the energies of the district personnel was directed to developing and revising plans for gaging-station structures. The great part which the Ohio district had in developing and producing stream-gaging equipment began about 1928. It reached its full growth during the next period of this history and will there be described.

The district personnel during 1921-28 was:

Lasley Lee	July	11, 1921	to	June	30, 1928
V. B. Lamoureux	Aug.	15	to	Dec.	31, 1921
E. E. R. Dornbach	Jan.	1, 1922	to	Dec.	31, 1923
	June	1, 1924	to	Mar.	18, 1927
E. R. Morgan	July	16, 1923	to	Apr.	12, 1924
W. W. Perrin	June	25, 1923	to	Apr.	12, 1924
F. A. English	May	6, 1924	to	Sept.	2, 1925
W. A. Werner	Feb.	11, 1924	to	Nov.	18, 1925
R. G. Kasel	July	20, 1925	to	Apr.	17, 1928
W. S. Frame	Dec.	2, 1925	to	Dec.	31, 1926
E. H. Markel	July	1, 1926	to	July	13, 1927
J. I. Perrey	July	1, 1927	to	June	30, 1928
C. V. Youngquist	Mar.	2	to	June	30, 1928

Wisconsin - Minnesota.-In July 1919 the Upper Mississippi River (Designation changed from Upper Mississippi River in 1925) district comprised the States of Wisconsin, Minnesota, Iowa, and Illinois. At that time Michigan was a "no-man's land" and a few records of Michigan streams, computed by private power companies, were sent to the Upper Mississippi district for publication. Eighty-six stations were being maintained, chiefly in Wisconsin and Illinois. Iowa and Illinois were sub-districts with headquarters in Ames and Chicago, respectively. The former became a separate district on July 15, 1920, and the latter on Nov. 1, 1919. These changes reduced the Upper Mississippi River district to the States of Wisconsin and Minnesota.

The chief use of stream-flow records in Wisconsin continued to relate to water-power development and the recording of winter discharge was an important item in the stream-gaging program. Mindful of an unfortunate experience in the district, Soulé at the beginning of each winter period contributed an article to the News Letter and its successor the Water Resources Bulletin calling attention to the danger attending ice measurements. The 1926 warning was as follows:215/

215/ Water Resources Bulletin Nov. 10, 1926.

> Before the appearance of the next bulletin the work of making discharge measurements through the ice will be well under way in the northern states. For the benefit of the new men, we wish to call attention to the fact that the strength of ice, especially over flowing water is very uncertain.
>
> Even though a greater part of the streams may have ice of ample strength there is always a chance that spots are so thin as to be unsafe. An inch of sound ice will support a man, but the only way to know that you have that inch on an untried section is to test it every step. The writer makes a practice of giving it a hard stab with the ice chisel every few feet in all cases where the water is not known to be shallow underneath.

The construction of new water-power plants made it increasingly difficult to find sites for stations above the backwater caused by such developments; some established stations had to be abandoned; others had their accuracy considerably impaired. The station on Red Cedar River

near Colfax, Wisc., gave excellent records until a power plant was built some distance downstream. Subsequent discharge measurements indicated that the station was influenced by the power plant, although there were quite pronounced rapids between the power plant and the gaging station.216/

216/ Statement by S. B. Soulé to the author.

One opportunity at least to compare the results of current-meter measurements with those obtained by the salt-velocity method, originated by Prof. C. M. Allen of the Worcester Polytechnical Institute was afforded by the installation of new power plants. This method consists in determining the velocity of flow through a penstock by means of the reduced resistance of the water to an electric current produced by the injection of a solution of salt. In December 1924 the salt-velocity method was used at the Ford power plant on the Mississippi River at St. Paul to determine the discharge at 17 different gate openings. This installation was under Federal Power Commission license, and to check the results of the penstock discharge, Soulé and Christopherson made four current-meter measurements from a boat in the tailrace about 1,200 feet below the power plant. The gate-opening, discharge curve developed from the measurements crossed a similar curve developed from Prof. Allen's tests and at no point were the two curves more than two per cent apart.217/

217/ News Letter Feb. 10, 1925.

An unusual use, which is worthy of note, was made of streamflow records in one instance. In 1924 the State of Michigan sued the State of Wisconsin in the United States Supreme Court for the purpose of changing the existing State boundary, which was the East Branch of Montreal River. Michigan contended that the flow of the West Branch was larger than that of the East Branch and hence, as it would be the main stream it was the proper boundary. The cooperating Wisconsin officials called upon the district to make measurements of both branches as no station had been maintained on either. During the hearings before the "Master" the results of the measurements were introduced as evidence, and as they showed the flow of the East Branch to be larger than that of the West Branch the Court later decided that Michigan had no cause for action and the boundary remained unchanged.

Deficiency tables were prepared each two years for practically every Wisconsin station as many of the users of the records were interested chiefly in water power and preferred the records in that form to the daily discharge tables. Instead of segregating the number of days with discharge between selected rates of discharge, the segregation was by percentage of time for the period of record, such percentages being 95, 90, 80, 70, 60, 50, 40, 30, 15, and 10 percent.

Cooperative funds in Wisconsin were practically constant during the period, and although a few stations were established and discontinued each year, the total number was gradually decreased from 45 to 38, of which nine were equipped with recorders. An average of ten stations was maintained with the assistance of private interests.

State cooperation with Minnesota, which had been discontinued in 1917, was resumed in 1919. Some old stations were reopened and a few new ones established, chiefly in cooperation with Federal Power Commission permittees. An average of 12 stations, of which two were

equipped with recorders, were maintained during the period.

W. G. Hoyt was transferred to the Washington office July 15, 1920. On Apr. 1, 1921, S. B. Soulé, his principal assistant, succeeded him as district engineer.

Other personnel of the district were:

E. E. Foster	Aug.	2, 1922	to	Mar.	23, 1924
F. C. Christopherson	Feb.	5, 1924	to	Apr.	6, 1926
W. J. Parsons, Jr.	July	14, 1926	to	Apr.	18, 1928
Arthur Olson	Feb.	1	to	July	31, 1922

E. F. Chandler, who had held a per diem appointment since 1903 maintained several stations in the northwestern part of Minnesota.

Missouri. - The Missouri district was created on June 1, 1921, with E. L. Williams as district engineer and Reginald Waldo as assistant. Headquarters were established at Rolla in quarters furnished by the State geologist. At first the district comprised the States of Missouri and Kansas, but in July 1923 Kansas was made a separate district. Cooperation with Arkansas in September 1927 added that State to the district.

The only stream gaging in Missouri carried on previously by the Survey had been the operation for about three years of seven stations that were discontinued in 1906. Prof. T. J. Rodhouse of the University of Missouri, had maintained since 1912 two gaging stations at which the gage heights were obtained by measuring with a tape from reference point to water surface and discharge measurements made by current meter. Prof. E. G. Harris of the School of Mines had been making some miscellaneous measurements in the Ozarks in the interest of the water power. These records with the exception of those from the few stations operated by the Survey between 1903 and 1906, represented the sum total of available stream-flow data in Missouri when the new district was organized.

The first year was a busy one for Williams and by June 1922 he had established 45 stations. At first he concentrated on the principal water-power streams and established at least one station on each. Later he established stations on streams subject to severe floods, particularly in the St. Francis River Basin. Several large springs in the State were of great interest. The State had taken the position that these should be State property and had purchased them and turned them into State parks. A station was established on each of these, as by so doing the new stream-gaging program was given some degree of the desired publicity. The maintenance of the stations established during the first year was nearly as great a burden as the available funds would carry. However, during the next few years additional private contributions were received which brought about the establishment of 13 additional stations, bringing the total to 58 in 1928. Two were equipped with recorders, two with staff gages, and the others with chain gages. In addition 12 stations were maintained in Arkansas.

High-water measurements were particularly desired and an arrangement was made with the Weather Bureau whereby the Survey, in connection with its regular work, installed about ten rain gages and received in return telegraphic notices of 24-hour rainfalls of 2 inches or greater. These telegrams enabled the Survey to obtain high-water measurements which might otherwise have been missed.

Some cooperation was in effect with Federal Power Commission permittees, which resulted in the erection of a cable of 800-foot span on the Current River near Eminence in 1922, the installation of a recorder at the station on the Sac River near Collins, and the establishment of two stations in Arkansas, at one of which a recorder and cable were installed. Two stations were established on the Missouri River. High-water measurements at these stations required such heavy weights that a reel with boom was devised.[218]

218/ p. 64.

With the beginning of State cooperation in September 1927,[219]

219/ p. 34.

W. S. Frame was detailed to Arkansas. Ten new stations were established during the next few months.

As stream gaging was a novelty in Missouri during the early years of the district, two human-interest incidents deserve mention. A forgetful engineer left several torpedo weights in his hotel in a small town which were discovered by the town marshall who, in his bewilderment, believed the statement of the usual by-stander that they were probably bombs used in aerial warfare. Thereupon the marshall decided that they should straightway be destroyed and taking one to a vacant lot he destroyed it by means of a dynamite cap. The only explosion was that of the cap itself, but the weight was thoroughly wrecked.

The other incident was, as usual, concerned with a gage observer. To stimulate interest Williams sent a copy of the recently-published State report to each observer. One of them replied by asking if the report, which was about half as large as an elementary geography, was the complete instructions for reading the gage. This side light on the observer's mentality led to the conclusion that he was unable to read the gage correctly, and his successor was appointed.

Williams resigned on May 31, 1923, and was succeeded by H. C. Beckman, who had been reinstated in the Survey. In addition to carrying on and expanding the regular work Beckman compiled the records for all Missouri stations to 1926, inclusive, which compilation was published by the Missouri Bureau of Geology and Mines,[220] together with long-time

220/ Water resources of Missouri, 1857-1926.

precipitation records.

Other personnel in the district during 1921-28 was:

Reginald Waldo	June 1, 1921	to	June 30, 1922
W. L. Austin	Jan. 1, 1922	to	June 30, 1928
W. R. Denison	June 1922	to	March 1923
W. S. Frame	Oct. 3, 1923	to	Nov. 30, 1925
W. A. Werner	Nov. 19, 1925	to	May 2, 1927

Illinois.- Illinois was actually a separate district during the entire period, with headquarters in Chicago in the offices of the State Division of Waterways -- the cooperating State agency. From an

administrative standpoint, however, it was attached to the Upper Mississippi River district until Nov. 1, 1919, when H. C. Beckman resigned and was succeeded by H. J. Dean. With the gradual increase in cooperative funds the number of stations was increased from 24 to 34, of which four were equipped with recorders.

Illinois streams are subject to severe floods which cause heavy damage, and unusual efforts were made to obtain flood measurements, especially as the State Highway Commission submitted to the cooperating State agency for report as to adequacy, all plans for bridge openings. The latter called on the Survey for the necessary and available flood records. At first it was the practice to have observers telegraph when certain flood stages were reached, but in 1924 this was discontinued. As it had been shown that practically all storms causing the most severe floods came from the southwest, it became the practice to visit the stations in the southern part of the State when the weather reports indicated the approach of such storms and to follow the storms to the stations in the eastern part of the State. By so doing it was possible to obtain crest measurements at most of the stations.221/

221/ News Letter Feb. 11, 1924.

The good-roads movement was just getting started in the early years of the period, so during the winter break-up (the "season of mud") the engineer had his tribulations. Travel was by train and by livery, if needed, hired at the point nearest the gaging station. As owners were not always willing to rent their teams when the roads were in bad condition, on one occasion when Grosbach arrived in a good-sized town in a farming community he spent several hours interviewing all owners or reported owners of teams without success. Finally after calling on several farmers he succeeded in obtaining a team to drive to the station 5 miles distant.222/

222/ News Letter June 10, 1924.

The differences in discharge at a given stage, due to rising or falling stages, was observed by Murray Blanchard, an engineer of the Division of Waterways who devised the unit-slope method for making adjustments for such changing stages. To make use of the method at the gaging station on the Illinois River at Beardstown Grosbach obtained daily gage heights from two gages 8 miles apart which had been installed by the Army Engineers.

Not only were the records in Illinois of value for flood protection measures, but some, at least, were of use in connection with an intensive study made by the Army Engineers to determine the effect of a proposed additional diversion through the Chicago Drainage Canal. During this investigation the Army Engineers made a number of measurements which did not agree with those made by the Chicago Sanitary District engineers and the State officials requested Grosbach to make check measurements. The results which he obtained were between those obtained by the other agencies, indicating his ability and innate diplomacy.

Dean remained in charge of the district only a few months as he became ill and the office was left in charge of a clerk until H. E. Grosbach was appointed district engineer Dec. 1, 1920. He continued in

that position. Illinois was a one-man district with part-time assistance in office work.

Montana-- North Dakota.- (Designation changed from Upper Missouri River in 1925). Until 1925, when all work ceased in North Dakota, the Upper Missouri River district area consisted of the States of Montana (except the small area in Yellowstone Park) and North Dakota. The period at first was one of expansion followed by contraction in Montana due to a substantial increase in State cooperation followed after several years by a decrease.[223] The decrease in stations was due

223/ p. 36.

also in part to a decrease in the number of Reclamation Service stations upon the completion of the Indian Service projects which were constructed by the Reclamation Service.

During the period the division between the United States and Canada of the waters of the St. Mary and Milk Rivers was placed upon a workable basis. This division was not only an important part of the district operations, but also a unique experience. The stations, not only on the St. Mary and Milk Rivers, but also on all the important tributaries in both the United States and Canada, were increased to 24 in 1927, of which 18 were equipped with recorders. They were operated jointly by the Survey and the Dominion Water and Power Bureau. Each organization made current-meter measurements and inspected the gages, and the records were computed jointly. The treaty provided that the expense was to be shared equally and at the end of the year the books were balanced to determine the cost to each organization. It was generally found that the expense to each was within a few hundred dollars of that of the other, and such differences were offset in the following year.

The terms of the treaty provided that a division of the natural flow of the St. Mary River at the international boundary should be made. The Bureau of Reclamation operates Sherburne Reservoir on 75,000 acre-feet capacity on a tributary of the St. Mary River, and diverts water by a canal from the St. Mary to the Milk River. To determine the natural flow at the boundary, it was necessary to correct the observed flow at that point for water stored in, or released from, Sherburne Reservoir, and for the diversion through the St. Mary Canal. The necessary records were worked up currently and at about 10-day intervals the natural flow was determined. When the natural flow of the St. Mary River was less than 666 second-feet Canada was entitled to three-fourths of such flow, and the United States to one-fourth. Above 666 second-feet Canada was entitled to 500 second-feet plus one-half the increase over 666 second-feet, and the United States to the remainder. The fulfillment of the treaty obligation required the regulation of the storage in Sherburne Reservoir and of the diversions from the St. Mary River, and orders for such regulation were issued to the Bureau of Reclamation by Lamb when necessary. Although theoretically the diversion of the flow of all tributary streams was also required, the diversions from them was so small that little was done beyond keeping records of the discharges at the mouth of each, and of the diversions above.

As an aid to the irrigators a joint snow survey of the St. Mary River Basin, a region of glaciers and heavy snowfall in Glacier National Park, was started in 1922. The percentage method by means of snow courses

as developed by Dr. J. E. Church of the University of Nevada was adopted, and six courses located in characteristic parts of the basin were used. These courses were visited early in May of each year and the water-content of the snow determined at fixed points on the courses. A comparison of the average of these water-content values each year with the ensuing run-off at regular gaging stations gradually established a rule-of-thumb relationship whereby the discharge could be forecast with reasonable accuracy from the results of the snow survey each year. For this work a snow sampler, snow-weighing balance, and camera were carried. As much of the travel was on snowshoes, the equipment was kept as light as practicable.

The stations in the St. Mary River Basin were generally not operated during the winter and the difficulty in finding them in the spring is shown by the following statement:[224]

224/ News Letter June 10, 1922.

> In visiting some of the gaging stations at the opening of the present season, it was found that our ordinary station description did not give sufficient data to enable us to locate readily the stations under all conditions. This was found especially true of one station in Glacier National Park. From the description it is an easy matter to get within 30 or 40 feet of the gage, but the last 30 or 40 feet was found to be pretty hard going. It was necessary to dig straight down 20 feet through the snow to the river bed and then tunnel to the gage.

To avoid the difficulty of thawing out intakes when the stations were reopened in the spring, intakes were eliminated and open trenches were maintained from the channel to the recorder well.

Even though most of the international stations were not operated during the winter months, winter comes early and lingers late in northern Montana and there are late fall and early spring blizzards which create a real hazard to field work in that sparsely-settled region. In the late fall of 1922 Lamb started out with a team and buggy to drive the 55 miles from Browning to Babb. He had not gone very far when sleet began to fall and this turned into a blizzard. He could only keep the road by following the telephone poles, not losing sight of one until he saw the next. Lamb wore a coon-skin coat and this was so covered with ice and snow that when he finally reached Babb, he was unable to move and had to be lifted from the buggy. When his coat was removed it was so frozen that it stood upright on the floor.[225]

225/ Statement of A. H. Tuttle to the author.

Lamb, who had first used the single-wire meter suspension in 1907, continued to be a strong advocate of that method and made it the standard method for the Montana district. Referring to the difficulties in obtaining a satisfactory cable for the standard return-current method,[226]

226/ p. 60 et seq.

he stated:[227]

227/ News Letter Oct. 10, 1923.

This question is not a very vital one in this district for the reason that we have been using a single wire and ground circuit for the past few years, and have found it to be entirely satisfactory in deep and swift streams.

The number of gaging stations increased from 98 in 1920 to 125 in 1922 and gradually declined to 81 by 1928. Of these, 38 were equipped with recorders.

Lamb was district engineer during the period and had as his assistants:

A. H. Tuttle	July 1, 1919 to June 30, 1928
L. H. Hershner	July 1, 1919 to June 15, 1923
R. F. Edwards	July 1, 1919 to May 31, 1920
H. S. Price	June 5 - 30, 1920

C. S. Heidel, a State employee, also had a per-diem appointment and devoted his time to the cooperative work except during the period Mar. 1, 1920 to July 1927 when he was State engineer.

In North Dakota an average of eight stations was maintained under E. F. Chandler's immediate supervision until 1925, when the stations were discontinued as State cooperation had ceased.

Kansas - Iowa.-Kansas and Iowa were in turn sub-districts, separate districts, and a consolidated district at some time during the period, and their operations are described together. Operations in both States were originally started chiefly for the purpose of obtaining flood records, but as floods were few and far between during the period, cooperative interest waned and with it the stream-gaging activities in these States declined and fell. The available funds were so limited that Thomas Gray's reference to the "short and simple annals of the poor"228/

228/ Elegy written in a country churchyard.

applies to the brief description of the operations in these States.

The Kansas district continued under R. C. Rice's direction until he was transferred to Arizona in April 1921. At that time E. L. Williams was detailed to Kansas as Rice's successor, but with the creation of the Missouri district in June, Williams was made district engineer in Missouri, and Kansas was made a part of that district. H. B. Kinnison was placed in charge of the sub-office in May under Williams' supervision. On July 1, 1923, Kansas again became a separate district and remained so until December 1925, when Kinnison was transferred to the New England district as district engineer. The Iowa district was then combined with Kansas, and J. B. Spiegel moved his headquarters from Ames, Iowa, to Topeka. Spiegel continued as district engineer until the lack of cooperative funds made it necessary on June 30, 1927, to close the district. He then became a State employee and maintained a limited number of stations in Kansas during the remainder of the period.

In 1919 eleven stations were being maintained and during the next two years six additional stations were established. When Kinnison took charge he received private assistance chiefly from sand and gravel

companies operating in the river channels and increased the number of stations to 30 the first year. During the last two years of the district when the only support came from private sources,229/ the number of sta-

229/ p. 34.

tions was reduced to 24, of which, eight were equipped with recorders. The funds were so limited that only routine work was carried on.

In 1920 Rice compiled all records for Kansas streams from 1895 to 1919, which were published by the Kansas Water Commission.230/

230/ Surface Waters of Kansas, 1895-1919.

Kinnison continued the compilation through 1924, which was also published by the Commission.231/

231/ Surface Waters of Kansas, 1919-24.

Until State cooperation ceased in 1925 attempts were made to keep an assistant, but the attraction of outside employment was strong and of the four assistants attached to the district successively, three resigned and the other was transferred. Those assistants were:

E. L. Grant	July 1	to Dec. 31, 1919
A. K. Gowans	Dec. 21, 1919	to Apr. 12, 1921
W. R. Denison	May 1, 1922	to Mar. 10, 1923
Reginald Waldo	July 1	to Aug. 5, 1922
G. H. Barger	Oct. 1, 1922	to Mar. 15, 1924
J. H. Hofmann	June 25, 1924	to July 18, 1925

In 1924 permittees of the Federal Power Commission were required to establish and maintain four stations in Oklahoma. As Topeka was the nearest Survey office, the supervision of that work, which continued for one year, was delegated to the Kansas district.

The Iowa sub-district under the Upper Mississippi River district was created in April 1919 with E. D. Burchard in charge and 24 Iowa stations previously operated from the Madison office were turned over to it. The supervision by the Madison office was nominal and consisted chiefly in one inspection of the stations made by the district engineer in company with Burchard. When W. G. Hoyt left the Upper Mississippi River district on July 15, 1920, Iowa became a separate district. Burchard was made district engineer of Hawaii in March 1922 and was succeeded in Iowa by J. B. Spiegel. The funds were so limited that only four additional stations were established, making a maximum of 28 stations in 1922, of which, three were equipped with recorders.

By the end of 1925 the available funds not only for Iowa, but also for Kansas, were so limited that the two districts were combined with headquarters at Topeka. Karl Jetter, a junior engineer, was left in charge of the Iowa work and remained until cooperation ceased in June 1927. The stations were maintained until the end of the water year.

Texas.-This period was one of rapid expansion for the Texas district. This expansion occurred chiefly in two successive years,

during which 99 stations were established and was accompanied by a corresponding expansion in personnel.

Until the large increase in State funds in 1923[232] only 11

232/ p. 36.

additional stations were established, bringing the total to 50, and the operations were chiefly routine in connection with their maintenance. The increase in State funds from $14,000 to $63,000, effective July 1, 1923, however, caused a radical departure from the routine character of work. Texas is so large that the existing stations did not cover the State even thinly, and there were large areas, particularly in the eastern part, which Ellsworth had never visited. Few topographic maps were available in that section and it was necessary to make a personal reconnaissance not only to select sites for the new stations to be established but to learn the characteristics of the streams themselves, as these characteristics would have an important bearing on the operation of the new stations. Ellsworth spent the first 2½ months of the new fiscal year in extended reconnaissance of the State, during which time he travelled 8,000 miles by car, accompanied during part of the time by the chairman of the Board of Water Engineers. Although a few of the sites were favorable, he concluded that most of them would be extremely difficult to rate on account of flood plains. Sites for 99 stations were selected, of which 74 were established during the next few months and 25 during the following fiscal year. Practically all were equipped with staff gages.

When the enlarged program became effective field headquarters were established at seven points throughout the State. Many of the streams were subject to floods of short duration and it was only by having engineers stationed in the vicinity - in the Texas sense - that flood measurements could occasionally be obtained. Also, the shifting character of the beds of some of the streams at least, made it necessary to obtain frequent measurements. A condition that has not been noted elsewhere in this history was reported by the observer in the Prairie Dog Town Fork of the Red River (a name that succinctly describes the character of that part of the state) who wrote:[233]

233/ News Letter Apr. 10, 1924.

> Sometimes sand will be under the gage in the morning and in the afternoon the sand will not be there. Wind changes the gage height very much. The river can be flowing at a good rate - a strong wind or sand storm comes up and the river will not flow. The sand will cover up the water; when the wind stops the river starts to flow again.

In commenting on that letter Ellsworth stated that the engineer in charge of that sub-district had his headquarters within an hour's drive of the station and that he had only four stations to maintain. Fortunately for the accuracy of the records for the two worst stations, they were dry for several months each year.

During the busy period of rapid expansion the American member of the International Boundary Commission requested the Texas district to

reopen some of the Rio Grande stations,[234] and as a result the Survey

234/ p. 55.

reopened the stations at Langtry, Del Rio, and Eagle Pass, and that on the Devils River near Del Rio. One of the seven field headquarters established was at Del Rio. At one station the gage was on the Mexican side of the river, but the American observer read it from his own side by means of a telescope. The stations at El Paso and below old Fort Quitman, formerly maintained by the American section, were not taken over as the former was being maintained by the Bureau of Reclamation and the latter by the State engineer of Colorado, who was investigating the water supply of the Rio Grande.

After two years of prosperity the State appropriations were cut in half or less during the remainder of the period, and the number of stations was reduced to 105 from a maximum of 148. The necessity for expanding the work so greatly during the two prosperous years had not made it possible to install recorders generally, nor would the available funds permit. Thirty-six stations were equipped with recorders and the remainder with chain or staff gages. Seven stations were equipped with cables, two of which had 850-foot spans.

The series of seepage measurements on certain streams, which was started soon after the district was created, were resumed in 1925. At that time funds were available to make these measurements which answered many of the inquiries received from water users and others interested in the Texas streams. In all, 29 series, principally on the Rio Grande, Nueces, and Devils Rivers were made, during the period 1925 to June 1928, covering a total of 2,165 miles.

Some of the Texas streams are subject to severe floods, when stages of 40 feet or more are reached. When the reconnaissance for the enlarged program was made in 1923 all available high-water marks were noted, and an analysis of these high stages for 70 stations showed the following maximum stages: [235]

235/ News Letter May 10, 1923.

Number of stages	Range of stage
7	less than 15 feet
5	-- 15 to 20 feet
24	-- 20 to 30 feet
17	-- 30 to 40 feet
17	greater than 40 feet

Ellsworth, confronted with such flood conditions, found early in the period that the available field equipment was insufficient. Not only did he experiment first with airplane wire and later with stranded cable to suspend the heavy weights required,[236] but he developed also a reel

236/ p. 63.

and boom for handling them. The first reel and boom consisted of a home-made reel fastened to a 2"x8" timber, 8 feet long, having a pulley at the outer end to guide the meter cable. This boom was leaned against a bridge rail, with the outer end over the stream. One measurement as described

below, made with this reel and boom on Trinity River at Dallas, conveys an idea of the size of Texas streams in flood. The city engineer's department gave C. E. McCashin two men to help with the measurement. They started out about 7 in the morning, but at 8 the men were recalled for emergency work elsewhere, leaving McCashin to make the measurement alone, using 90 pounds of lead. He worked all day, and as the viaduct was a thoroughfare, he had a continuous gallery. This was not altogether a drawback as someone was always ready to help him move the equipment from one measuring point to the next. About dark the measurement was supposedly finished and McCashin returned with the equipment. He then learned of two additional channels about a mile beyond the main channel, and thereupon chartered a taxi, placed the boom crosswise of the car, which had both doors open to permit this, and hastened back through traffic to the newly-discovered channels. Fortunately the traffic police were not on duty and so McCashin made the journey without interruption and measured the additional channels by aid of the lights on the viaduct.237/

237/ Letter from C. E. McCashin to the author.

In 1922 the Federal Power Commission issued a permit covering the development of power in Louisiana and the Texas district maintained three gaging stations for several years on the Louisiana streams involved.

The district personnel during 1919-28 was:

C. E. Ellsworth	July 1, 1919 to June 30, 1928
C. E. McCashin	July 1, 1919 to June 30, 1928
A. K. Gowans	July 1 to Dec. 20, 1919
H. B. Kinnison	July 1, 1919 to June 7, 1921
D. A. Dudley	July 8, 1919 to Mar. 1, 1921
Trigg Twichell	July 12, 1922 to June 30, 1928
W. E. Armstrong	Sept.15, 1923 to June 23, 1928
J. W. Bones	Sept.16, 1923 to Aug. 31, 1925
A. G. Fiedler	Sept.16, 1923 to July 4, 1925
E. H. Morgan	Oct. 23, 1923 to Apr. 10, 1925
H. C. Pritchett	July 1, 1923 to June 30, 1928
T. A. Slack	Sept. 1, 1922 to May 31, 1925
D. S. Wallace	July 9, 1923 to Apr. 10, 1925
J. L. Saunders	July 1, 1924 to June 30, 1928
R. G. West	Aug. 16, 1920 to January 1923, and Mar. 20, 1924 to Mar. 31, 1926
S. D. Breeding	May 1, 1924 to June 30, 1928

Colorado - Wyoming (Designation changed from Rocky Mountains in 1925).-With the discontinuance of two stations in Oklahoma in 1919 and one station in South Dakota in 1920, the activities of the Rocky Mountain district were limited to Colorado and Wyoming.

In Colorado, as a result of gradual reduction and final discontinuance of Forest Service Cooperation in 1925 and the reduction of State cooperation in 1925 to the furnishing of field data for a few stations,238/ the Survey operations were reduced by 1928 to the maintenance

238/ p. 37.

of six stations.

Cooperation with Wyoming continued. The cooperative and Federal funds fluctuated during the period and with them, the gaging

stations, which varied from 60 to 36 in number. Certain base stations on the principal streams were maintained uninterruptedly, but stations on the smaller streams were changed to meet the requirements of the successive State engineers whose major concern related to stations in the sections of the State with which they were most familiar. The Indian Service cooperated in the maintenance of five stations, and the Bureau of Reclamation furnished records for an average of seven stations. Fifteen stations were equipped with recorders, the remainder with staff or chain gages. During 1920 a series of seepage measurements was made on streams in the Big Horn River Basin and on streams in the northeastern part of the State. A total of 496 miles was covered.

In addition to the author, who was in charge of the district during the period, the personnel list was:

P. V. Hodges	July 1, 1919 to June 30, 1928
J. B. Spiegel	July 1, 1919 to Mar. 2, 1922
M. B. Arthur	Apr. 11, 1922 to April 1923
P. S. Parker	May 17 to August 1923
J. W. Mangan	Sept. 17, 1923 to Oct. 15, 1924

The Survey allotments to the district were:

1919	$7,000	1923	$7,500	1927	$4,700
1920	7,375	1924	7,000	1928	3,900
1921	8,000	1925	5,500		
1922	7,500	1926	5,000		

Idaho - Boise.-The creation of the Idaho Falls district in May 1919 divided the Idaho operations between two districts, Boise and Idaho Falls.

On June 20, 1919, C. G. Paulsen became district engineer of the old Idaho district with headquarters at Boise and including all stations except 25 stations in the upper Snake River Basin which were turned over to the Idaho Falls district. At that time about 50 stations were being maintained, including a few in Yellowstone Park.

The period was one of intensive irrigation activity in Idaho - an activity perhaps greater than that in any other western State. It was also one of activity in water-power development. Mindful of the lean years before 1919, when State cooperation was stopped, Paulsen devoted considerable time to familiarizing the public with the Survey's work and the need for it as the basis for intelligent design and operation of irrigation and power projects.239/ In this he was aided materi-

239/ News Letter Jan. 22, 1920.

ally by the influential Idaho Reclamation Association and the provisions of the recently enacted Federal Water Power Act.

The increasing interest in stream gaging, which led to a restoration of substantial State cooperation, resulted in a rapid expansion in the work. Many requests were made by irrigation districts, power companies, etc., for additional stations, many of which were established in response to such requests and some were installed without cost to the district except for supervision. Many of the 53 recorders installed in

the district during the period were placed at such stations, and the shelters were erected by cooperators, generally in accordance with more or less standard plans. By 1928 the number of stations had increased to 103 exclusive of stations installed in the spring of 1928 for a special investigation in the Kootenai River Basin. The 103 stations included five maintained in Yellowstone Park.[240] Cooperators

240/ p. 49.

installed artificial controls of various types at ten stations. For economy in operation, 12 stations in northern Idaho were operated by the Washington district for the Boise office and at the latter's expense.

A special investigation of Mud Lake was made jointly by the Surface Water and the Ground-Water Divisions in cooperation with the State. The necessary stream gaging and detailed surveys relating to the work were conducted by L. L. Bryan. This investigation was started in March 1921 and the stream gaging connected with it continued for many years.[241] The State Commissioner of Reclamation called upon the

241/ p. 167.

district for much special work in connection with investigations of Carey Act and other irrigation projects, the special work ranging from determination of carrying capacity of canals to complete reports on projects.[242]

242/ Statement of C. G. Paulsen to the author.

The intensive use of streams brought the inevitable disputes over water rights which sometimes ended in lawsuits. On one occasion Paulsen was subpoenaed to verify certain records published in water-supply papers which were to be introduced as evidence. He was not called upon, however, as the court ruled that all data contained in Survey publications were to be considered comparable to law books for ready reference.[243]

243/ News Letter May 22, 1920.

Two experiences with observers were unusual. At the beginning of the winter season Paulsen sent the usual notices to observers requesting, in addition to ice notes, sketches showing actual conditions. One observer replied by sending in carefully taken photographs with apologies that he was unable to draw accurate sketches. The other experience was with a totally different type of observer. A temporary staff gage was installed at a new station located a quarter of a mile from the observer's house. To save himself this walk, he moved the gage to a point directly back of his house and continued to send in the readings without mention of the change. He was evidently sharp enough to set the staff to read nearly the same as at the original location so the change was not detected until the station was again visited by an engineer. The gage was moved back and installed so securely that it could not be moved again.

During the last year of the period plans were made for an

intensive study of the Kootenai River, an international stream, to be financed by the State Department. The investigation was started at the end of the period.

Paulsen continued as district engineer during the period, and Miss E. Hazel Haugse, the district clerk, served in many ways as the office engineer.

Others in the district were:

A. G. Fiedler	July 1, 1919 to Apr. 30, 1920 and Oct. 1, 1920 to Sept. 14, 1923
L. L. Bryan	Mar. 1, 1920 to Apr. 30, 1923
Berkeley Johnson	Apr. 16, 1921 to June 30, 1928
K. N. Vaksvik	Apr. 29 to Nov. 14, 1924
C. L. Batchelder	Dec. 12, 1923 to June 30, 1928
F. M. Veatch	July 17, 1923 to June 30, 1928
R. G. Kasel	Apr. 19 to June 30, 1928
W. J. Parsons, Jr.	Apr. 20 to June 30, 1928
K. K. Hoyt	May 1 to June 30, 1928.

Idaho - Idaho Falls.-The duties of the new district under the cooperative agreement made at the end of the previous period[244] required

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244/ Follansbee, Robt., Hist. of WR Br. to June 30, 1919, p. 411.

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a very considerable organization to segregate the natural flow of the Snake River from the stored water released from Jackson Lake; to determine the transportation losses applicable to the latter; and to allocate the natural and stored water to the many canals in the upper Snake River Basin. Under the State law the expense of administering the water laws must be borne by the water users of which the Reclamation Service was one. In order to assist the water users in financing the project the State Commissioner of Reclamation proposed that a special deputy commissioner to administer the water rights be stationed at Idaho Falls. As an intensive stream-gaging program was the basis for such administration, he further proposed to divide both State and Survey cooperative stream-gaging funds between the existing Boise district and the proposed Idaho Falls district, such division to be proportionately to the number of general-interest gaging stations that each would operate. This proposal was accepted and G. C. Baldwin, formerly in charge of the Boise district, was appointed special deputy commissioner for the State. He was also the Survey's district engineer in charge of stream gaging.

The Idaho Falls office was opened on May 22, 1919, with T. R. Newell and E. C. Howard as assistants. In addition to operating the 25 stations in the Snake River Basin between the south boundary of Yellowstone Park in Wyoming and Milner dam, about 100 stations were established and operated on canals to show the diversions from the Snake River and its principal tributaries. After one season's operation, the need for additional stations was apparent, and four more were established on tributary streams in 1920.

During each irrigation season the amount of stored water released from Jackson Lake was reported daily to the Idaho Falls office, together with the daily stages at the river and tributary stream stations and the amounts diverted by each canal. From this information

daily "run sheets" were prepared showing the discharge at each river station, the estimated transmission losses, and the proportion of natural flow and storage flow available for diversion. On the basis of this information the various canals were regulated.

At the very beginning of its existence the new organization was called upon to function during the year of lowest flow known and had its hands more than full in administering the water rights under exceptionally adverse conditions. This test, which was successfully met, justified the new plan.

In the beginning of the administration by Baldwin, the transmission losses were based on those determined by the investigations made during 1916 and 1917, but the routine data collected during the first few years of operation indicated that these values should be modified, and special investigations for that purpose were conducted during 1922 and 1923. During the latter year R. I. Meeker, a former member of the Survey, was engaged to make a report on the methods used in determining the transmission losses, and, inter alia, he recommended the establishment of two additional gaging stations on the Snake River. These were installed in 1923, one of which required two recorders and three separate cables. No additional river stations were established during the period, as the existing stations were found sufficient.

In 1923, as an economy move, the positions of deputy commissioner of reclamation, and water master were combined in Baldwin and later other administrative duties were added. As a result his title became "deputy State commissioner of reclamation, special deputy in charge of Jackson Lake, Twin Lakes, Market Lake, and American Falls stored water delivery, and water master of District No. 36." Baldwin was extremely fortunate in having a strong physique that enabled him to bear such a long title. Each year in his report of operations he stressed the fact that the stream-flow records were collected in accordance with standard Survey practice and this assurance was sufficient to quiet any doubts regarding their accuracy. A small force of engineers was employed during the entire year, augmented by several hydrographers during the irrigation season.

The full-time personnel was:

C. G. Baldwin	May 22, 1919 to June 30, 1928
T. R. Newell	May 22, 1919 to June 6, 1923
E. C. Howard	May 22, 1919 to Mar. 31, 1921
L. L. Bryan	May 1, 1923 to Oct. 10, 1926
C. A. McClelland	Sept. 17, 1924 to June 30, 1928
M. H. Coffin, Jr.	Dec. 16, 1926 to Mar. 30, 1928

Baldwin's administrative decisions were sometimes questioned by disgruntled water users, who on several occasions brought suit against him. In each case he was upheld by the court, thus indicating the essential justice of his decisions. Another difficulty with which Baldwin had to contend was expressed by him, as follows:245/

245/ Trans. Am. Soc. C. E. vol. 94, p. 299.

It is often said that in an irrigated country an otherwise upright man will not hesitate in times of drought to steal water

and that the most peaceable citizen under ordinary circumstances may quickly become one of the most violent if he thinks his water rights are being attacked or infringed in any way.

The completion of a channel reservoir at American Falls about 1926 caused a new complication in the administration of the stored and natural flow waters of the Snake River. The area covered by the reservoir was one in which springs, having a flow of about 2,000 second-feet, entered Snake River, and the effect of the storage in the reservoir on the flow of these springs was problematical. To determine this, special investigations were made,246/ both by the Bureau of Reclamation engineers

246/ Statement of G. C. Baldwin to the author.

and by T. R. Newell, who was employed by the Water Users for that purpose. Another effect of the American Falls Reservoir was the growth of aquatic plants on the rocky stream bed below the dam, due to the clarification and warming of the river water during its passage through the reservoir.

The Snake River is rarely subject to sudden floods, so when the news was received in May 1927 that the failure of a natural dam on the Gros Ventre River, a tributary stream in Wyoming below Jackson Lake, had suddenly released a large quantity of stored water, the citizens along the lower Snake River were greatly alarmed and many of them camped on the hillsides all night. Inquiries poured into the district office so fast that Baldwin kept the office open all night and was on duty himself for thirty-six hours to answer the questions regarding the damage done and the probable height of the flood at the various points. One man wanted to know if he should move his bees, another if he should move a stock of pianos which he had stored in a basement in Idaho Falls. Fortunately for both, Baldwin's reports from upstream stations where engineers were stationed, enabled him to assure them that the flood would reach neither the bees nor the pianos. His assurance was proved valid.

Backwater caused by ice was an unknown phenomenon to one gage reader in the district, who reported that the river at his station was frozen and that the gage read 3.12 feet. This was so much higher than during open water that he added "but that can't be."

Utah - Nevada (Designation changed from Great Basin in 1925).- The area of the Great Basin district, comprising the States of Utah and Nevada, remained unchanged during 1919-28.

In Utah the special Sevier River investigations247/ were dis-

247/ Follansbee, Robt., Hist. of Water Res. Branch to June 30, 1919, p.336.

continued at the end of the water year 1919 and 47 stations, chiefly on canals, were closed. Thereafter, with no additional investigations, the district operations continued on what may be termed a stable basis -- the number of stations were decreased from 58 in 1920 to 49 in 1924 and increased to 56 at the end of the period with a few changes in stations each year. Of the 56 stations, 31 were equipped with recorders. The increasing interest in the Colorado River resulted in the reestablishment of one base station each on the Colorado, Green, and San Juan Rivers with

cooperation from several sources. The Utah Power and Light Co. continued its stream-gaging program and furnished the Survey with all or most of the field data for 11 stations, of which two were in the Bear River Basin in Idaho.

An unusual case of interest on the part of a former observer occurred at the San Juan station near Bluff. Although this station had been discontinued in 1917, the former observer notified the district office five years later that the river was at the lowest stage in some 20 years, and the following year sent in a report of gage height for the greatest flood he had seen at that point.[248]

248/ News Letter Oct. 10, 1923.

The number of stations in Nevada increased from 22 to 29 in 1922 and 1923, then decreased to 15 in 1928, due to reduction in available funds. Seven stations were equipped with recorders. Private interests rendered assistance at about half these stations.

A. B. Purton continued as district engineer during the period. The remaining personnel were:

J. W. Bones	July 1, 1919 to Mar. 31, 1920
W. E. Dickinson	July 1, 1919 to Nov. 24, 1923
R. R. Rowe	Apr. 20, 1920 to June 30, 1923
B. A. Howell	Aug. 1 to Sept. 12, 1923
M. T. Wilson	Dec. 3, 1923 to June 30, 1928
D. M. Corbett	Oct. 16, 1924 to Jan. 27, 1928
J. W. Mangan	Oct. 10, 1924 to Feb. 26, 1926
J. J. Sanford (per-diem)	Jan. 1, 1922 to June 30, 1928.

Arizona.-Arizona was part of the California district until the spring of 1921. J. F. Kunesh, from headquarters at Tucson, (moved from Phoenix in 1918), carried on the field work under McGlashan's supervision. At the same time Prof. G. E. P. Smith, irrigation engineer of the State Agricultural Experiment Station, the cooperating State agency, was conducting the field work at 10 of the 23 stations that were being maintained. These 10 stations were situated chiefly in the southeastern part of the State, while those being maintained by the Survey were mainly in the upper Gila River valley and were continued from work previously carried on in cooperation with the Indian Service.[249] Kunesh resigned

249/ Follansbee, Robt., Hist. of Water Res. Br. to June 30, 1919, p. 346.

July 15, 1920, and as no experienced engineer was available at the time, the Survey discontinued its field work temporarily. The office equipment and records were stored with the cooperating State official pending resumption of work. The State continued its work and the Indian Service and private interests maintained several additional stations. The Survey had been maintaining the Topock station on the Colorado River. The local observer, who had been making frequent measurements, continued to operate that station.

Because interest in the utilization of the Colorado River was mounting rapidly the necessity for additional stations was so apparent that it was decided to establish a separate district in Arizona. Before

arrangements could be perfected it was felt that the Survey should have a representative in Arizona who could keep in touch with the various interests and, also, do a limited amount of field work. J. B. Spiegel, who had been connected with the Arizona work from 1914 to 1917, was detailed from the Denver district to Arizona, and remained there from early January to late March 1921. The separate district was created April 1, 1921, with R. C. Rice as district engineer. The utilization of the Colorado River was an interstate problem with which various government agencies and private organizations were concerned and those interests contributed to the support of the Colorado River work.250/

250/ p. 110.

During the first year Rice had but one assistant, J. H. Gardiner, who was a State employee until given a civil-service appointment on Oct. 1, 1921. Rice devoted a large part of his own time to the Colorado River, and the State and Indian Service continued to furnish the greater part of the field data for the stations in which they were particularly interested. In May 1921 the Southern California Edison Co. installed gages at the Lees Ferry station and began the collection of records under Survey supervision.251/ The following year it was

251/ p. 104.

found necessary to have a resident engineer at the Topock station and D. A. Dudley was transferred from the Chattanooga district in May 1922 for that purpose. During the fall of that year Dudley constructed an entirely new station at a site about 2 miles downstream. A site for a station was selected in the Grand Canyon and Ebert was borrowed from the California district to construct this station during the fall of 1922.

The State Water Commissioner became the cooperating official on July 1, 1921, and as he was chiefly concerned with the water rights of which an adjudication was to be made in the Gila River Basin, 11 additional stations, chiefly on canals, were established in that basin during 1921 and 1922. Many of these stations had been maintained in connection with the special Indian Service investigations during the previous period.252/ Beginning in 1921 the work was all carried on

252/ Follansbee, Robt., Hist. of Water Res. Br. to June 30, 1919, p. 346.

under Survey supervision except for a few stations near Tucson, which Prof. Smith continued to maintain.

The large increase in State appropriations, beginning with the fiscal year 1924, made it possible for the Survey to install additional stations, re-equip existing stations, and pay a larger share of the cost of maintaining resident engineers at each Colorado River station. At the end of the period, 43 stations were being maintained, of which 16 were equipped with recorders.

Like other western streams, those in Arizona were subject to cloudburst floods, the type of flood that often cannot be reached in time to be measured by current meter. However, Gardiner obtained one measurement of that type of flood on the Gila River at Kelvin. He was in that vicinity when a flood occurred in the night and by the illumination afforded by the spotlight on his Ford, he was able to make a current-meter measurement.253/

253/ News Letter Sept. 11, 1922.

The isolated locations of many stations afforded vandals an opportunity to vent their spite against the existing order. A particularly aggravated case occurred at the station at the San Carlos dam site. Shortly after that station was completed some person unknown threw into the river every item of equipment which could be pried loose. Float, counterweight, and clockweight cables had been cut loose at each end, tied together and stretched along the trail leading to the station. The gage-height book was removed from the locked house, slashed with a knife, and thrown down on the trail. For some unknown reason the recorder itself was not molested.254/

254/ News Letter Oct. 10, 1924.

Dr. Newell's spelling of "gage" without the "u"255/ had a

255/ Follansbee, Robt., Hist. of .-- p. 68

repercussion, reported from Arizona, some thirty-odd years later. An itinerant printer was given some copy in which the word "gage" occurred. Thinking to correct the misspelled word, he inserted the "u", and the proof was returned to him with his addition deleted. Two minutes later he rushed into the editorial room after a conference with the proofreader and waved the offending proof in front of the copy reader. "Such a bunch of bums I never seen," he wailed. "Taking a man's education away from him! I've spent fifteen years in printing shops, trying to learn on which side of the "u" to put the "a" and now, dern you, you mark it out on me."256/

256/ News Letter Feb. 10, 1923.

Rice resigned on Dec. 31, 1923, and was succeeded by W. E. Dickinson, who came to the district Nov. 23, 1923, and continued as district engineer during the remainder of the period. Others in the district were:

J. H. Gardiner	Oct. 1, 1921	to June 30, 1928
D. A. Dudley	May 15, 1922	to Feb. 6, 1928
B. S. Barnes	Apr. 10, 1924	to Dec. 31, 1926
R. G. Kasel	Apr. 10, 1924	to July 16, 1925
J. A. Baumgartner	Oct. 23, 1924	to June 30, 1928
W. E. Code	June 16, 1926	to June 1, 1928
K. C. McCarter	June 17, 1926	to June 30, 1928
A. H. Williams	Apr. 14, 1927	to June 30, 1928
H. S. Leak	Apr. 2,	to June 30, 1928

Washington.- Water power continued to create the dominant interest in the water resources of Washington, which was accentuated by the nation-wide interest in water power during the period. An average of 40 stations was maintained west of the Cascade Mountains, of which all of the records were of primary value for power. East of the Cascades an average of 23 stations was maintained, of which the primary value was about equally divided between power and irrigation.[257]

257/ Letter from G. L. Parker to author.

These latter stations did not include an average of 13 stations maintained by the Bureau of Reclamation, the records for which were furnished for publication. Thus, 80 percent or more of the stations maintained by the district were primarily in the interest of water power. Water-power interests, both municipal and private, assisted in the maintenance of many of the stations and furnished not only gage-height records, but also discharge measurements. Much of this assistance was related to the Spokane River and its tributaries in Washington and northern Idaho, where the Washington Water Power Co. operated. The Company installed the recorder stations and detailed an engineer to the field work, who furnished most of the field data.

Many of the stations in the State were at isolated sites in the mountains and their installations were not only difficult, but resulted in unusual experiences. Perhaps the outstanding experience was that of Lasley Lee in the installation of the station on the Suiattle River near Darrington. This site was in the most isolated section of the State and materials and supplies could only be transported by means of pack horses from the nearest town, 28 miles away. During the period of construction rain or snow fell almost continuously. Shortly after the excavation was started Lee fractured a rib and the two helpers, who were brothers, were called home by serious illness in the family leaving Lee alone for three days while he nursed his fracture, rustled wood and water, and cooked his own meals. Upon the return of the helpers, he completed the installation and made three measurements of discharge before returning to civilization.[258]

258/ News Letter Jan. 25, 1921.

One of the most expensive stations constructed by any district during the period was that on the Skagit River near Concrete, where the 49-foot concrete well[259] and the cable of 820-foot span,

259/ p. 68.

anchored to reinforced concrete deadmen cost about $3,500, part of which was for the purchase of about 3 acres of right-of-way by Skagit County, which furnished the funds for the station. Another notable installation was that of the cable of 1,538-foot span across the Columbia River at Kettle Falls,[260] the longest span constructed by the

260/ p. 73.

Survey up to that time. Construction was active during the period and

25 recorder installations were made, of which 18 were concrete structures. Twenty-three cables were erected and one artificial control was built.261/

261/ p. 77.

Unusual conditions pertained to three stations situated on streams having great fall. The river banks, where the recorders were installed, were sealed off from the river channel with the result that when the intake became clogged (as intakes have a habit of doing) the water in the well drained into the soil.

The recently-devised Gibson method of measuring the flow through a penstock with a high degree of accuracy afforded a means of checking the accuracy of Survey records. In 1926 Parker made comparisons at two stations where there were favorable measuring conditions. At one station the Survey records for one month were 3.1 percent higher than those obtained by the Gibson method and at the other, 4.9 percent higher.262/ Later tests showed agreement within about 3 percent.

262/ News Letter Jan. 10, 1927.

Of the seven projected reports covering water power in the Cascade Range, three had been published during the previous period and a fourth was published early in the present period.263/ These reports

263/ Water-Supply Paper 486.

had of necessity been predicated on meager base data and additional data had rendered them obsolete. It therefore appeared advisable to Parker to discontinue the series and to expend the district's funds in obtaining more complete base data.264/

264/ Statement of G. L. Parker to the author.

Although no additional water-power reports were prepared, Parker compiled all records of Washington streams, not only to make those records more readily available for reference, but also to prevent so far as possible the use of earlier records which had subsequently been revised. At the same time he warned that some of the records in that compilation might themselves be revised at a later date.265/ This compilation, which contained all available records to

265/ Water-Supply Paper 492, p. 1.

1919 inclusive, was published in 1923 as Water-Supply Paper 492.

Although water power was the chief interest in Washington, investigations of the vast Columbia Basin irrigation project were being carried on during the period. Preliminary steps were taken in 1919 when the Governor called upon the State geologist to assemble all available data, and as much of the information was in the Tacoma office,

Parker was not only called upon to furnish it, but also to search for other information. A special State commission made an investigation in 1919 and 1920, and published a report. During 1923 and 1924 a special Reclamation Service Board made further investigations and Parker was detailed to that board for seven months for the purpose of making water-supply and storage studies.[266] Interest in the project

266/ p. 48.

continued to grow and in 1927 the State entered into negotiations with Montana and Idaho for the allocation of the waters of the Clark Fork and Pend Oreille Rivers and Parker was called upon to make storage studies of Flathead, Priest, and Pend Oreille reservoirs.[267]

267/ Letter from G. L. Parker to author.

The ubiquitous bystander appears in the annals of the Washington district. An old rancher was watching an engineer make a long and tiresome measurement from a highway bridge at one of the largest power sites in the State, and asked the usual questions regarding the reason for the work and its value. Having received courteous and complete answers, the bystander started away with the remark, "There are a lot of ways of making a living without working."[268]

268/ News Letter, Apr. 27, 1921.

At the end of the period 66 stations were being operated, of which 48 were equipped with recorders. Four stations in southwestern Washington were maintained by the Oregon district at the expense of the Washington district. Not included in the above figures were 12 stations in northern Idaho maintained by the Washington district at the expense of the Boise district.

G. L. Parker continued as district engineer during the period and had the following assistants:

Lasley Lee	July 1, 1919 to July 10, 1921
D. J. F. Calkins	July 1, 1919 to June 30, 1928
R. B. Kilgore	Apr. 5, 1920 to June 30, 1928
John McCombs	Jan. 23, 1920 to July 19, 1922
H. W. Newton	June 22, to Nov. 15, 1920
J. E. Stewart	July 25, 1922 to Mar. 17, 1923
J. S. Gatewood	Mar. 1, 1923 to May 26, 1928
C. C. Osborne	May 1, 1923 to Nov. 29, 1924
K. N. Vaksvik	Nov. 16, 1924 to June 30, 1925

Oregon.- The division of work between the Survey and State engineer of Oregon which occurred in 1924[269] reduced the number of

269/ p. 42.

stations actually operated by the Survey by slightly more than half. However, the Survey continued to make occasional measurements at the State-operated stations and during the winter months detailed an

experienced engineer to the State engineer's office to supervise and assist in the computation of the records.[270]

270/ Letter from G. H. Canfield to the author.

A considerable number of stations both on the natural streams and on canals were required for the administration of the water rights in the Rogue River Valley in Jackson County, one of the most important irrigated regions in Oregon. The stations on the Klamath Indian Reservation were readily accessible to Medford, the County seat of Jackson County, as were also stations required under Federal Power Commission permits. It therefore appeared advisable to have a sub-office in Medford, and beginning May 10, 1923, Jackson County, together with the Talent and Medford irrigation districts, and the Rogue River Valley Canal, contributed toward the maintenance of that office about $2,000 annually.[271]

271/ Letter from G. H. Canfield to the author.

K. N. Phillips was detailed to the Medford office during the remainder of the period, and maintained an average of 30 stations. The County funds contributed were not included in State cooperation.

The much-used records of the Columbia River at The Dalles were subject to further study during these years. The special Reclamation Service Board investigating the Columbia River,[272] made a study

272/ p. 48.

of power possibilities at Umatilla Rapids, for which the only stream-flow records were those at The Dalles. The low flow was of especial importance and the existing rating curve was based on current-meter and float measurements made by the Army Engineers in 1903, two current-meter measurements by J. C. Stevens in 1907-1908,[273] and three current-

273/ Follansbee, Robt., Hist. of -- pp. 282-3.

meter measurements made above the mouth of the Snake River in 1913.[274]

274/ op. cit. p. 421 (Hist. of --).

The Board desired a further check on the lower part of the curve and requested Henshaw to make another current-meter measurement at The Dalles. Accordingly, in November 1923, Canfield and Dawson made a measurement with the aid of a boat held in place by a quarter-inch cable. The single-wire suspension was used, and as the velocity was only a little greater than 1 foot per second, a 30-pound weight was sufficient to hold the meter in place. The meter and weight were attached to a 1/16-inch aeroplane strand and handled by what was described as "a simple wood lift reel." This reel was marked U.S.G.S. No. 1 and was used in measuring the Willamette River in January 1912

and the Columbia River in 1913.[275] The width of the river was 1,020

275/ News Letter Feb. 11, 1924.

feet and the maximum depth 76 feet. Six vertical velocity curves were obtained from observations made 1 foot below the surface, 1 foot above the bottom, and at intervals of one-tenth the depth. Those curves indicated a coefficient of 0.94 for velocity 1 foot below the surface, the point at which the meter was held except when making the vertical velocity curves.[276] Six hours were required for the measurement. A

276/ Letter from G. H. Canfield to the author.

second measurement, using the .2 and .8 method, was made at a slightly lower stage in January 1923. This measurement required only $2\frac{1}{2}$ hours. As a result of these measurements and of one made somewhat later the rating curve below 100,000 second-feet was revised but the revision was so small that the long-time record beginning in 1878 was not changed.[277]

277/ op. cit.

A gaging station situated below a power plant made it possible to compare the Survey records with those computed from the electrical output of the plants. During the low-water months of 1924 this comparison showed monthly deviations of $-.4$, $-.2$, and -1.4 percent.[278]

278/ News Letter, Mar. 10, 1926.

Some of the station installations for Federal Power Commission permittees in Oregon were at isolated sites, as they were in Washington and California. A noteworthy installation of that type was made by Canfield in 1927 at a site in a rugged and heavily timbered region, reached by traveling 14 miles over a forest trail. The recorder well was a 12-inch pipe 10 feet long, set in a protected niche in the bank. The shelter was constructed of cedar "shakes" on a platform supported in trees along the bank. A tree was felled across the 70-foot channel to serve as a footwalk for making measurements. A log cabin, 10'x14', was constructed for use by the field man, and was stocked with blankets, stove, and provisions.[279] Whether the pro-

279/ Water Resources Bulletin, Nov. 10, 1927.

visions were always there when needed has not been reported.

Oregon may well lay claim to having had the prize observer. He was an old German with characteristic Teutonic thoroughness. During one flood the recorder was not in operation and he watched for the peak of the flood and referred it to the gage datum by means of a level. He would also make a float measurement on his own initiative whenever he thought a change in the stage-discharge relation had occurred. As Henshaw observed,[280]

280/ News Letter, Oct. 24, 1919.

He was once a German, but is now 101 percent an American observer.

The total number of gaging stations remained fairly constant at about 90 during the period. Of these about 50 were operated by the State engineer. Fifty-one stations were equipped with recorders by 1928, of which 29 were installed during the years 1919 to 1928.

F. F. Henshaw continued as district engineer until May 1, 1928, when he was transferred to the reorganized Federal Power Commission. G. H. Canfield, who had been in the district since August 1921, succeeded him. Other district personnel was:

R. C. Briggs	July 1, 1919 to Dec. 31, 1920
J. J. Dirzulaitis	July 1, 1919 to May 11, 1920
J. W. Bones	Jan. 1, to June 30, 1921
K. N. Phillips	June 23, 1920 to June 30, 1928
W. Dawson	June 20, 1922 to Mar. 10, 1925 and Dec. 27, 1926 to June 30, 1928
E. O. Hokanson	July 7, 1924 to Aug. 20, 1927

California.- Until April 1921 the California district comprised the States of California and Arizona, but with the creation of a separate district in Arizona, the district activities were confined to the State of California. It was in general a period of intense activity, due not only to the Statewide development program which increased the already widespread interest in California's water resources and resulted in a substantial increase in available State funds,281/

281/ p. 43.

but to a much greater extent to the passage of the Federal Water Power Act which resulted in the expenditure of about $100,000 annually by Federal Power Commission permittees or licensees under the supervision of the district office. Additional cooperation with municipalities increased the available funds by several thousand dollars annually.282/

282/ p. 44.

During the first two years the number of stations was reduced slightly with a reduction in funds, but beginning in 1921 the increasing demand for records and the larger amount of funds available from all sources resulted in an increase in the number of stations from 153 to 193 followed thereafter a gradual increase to 225 in 1928. The Federal-Power Commission work accounted for the greater part of the increase. Much of this work was required by permits issued to the larger power companies who had their own engineers experienced in stream gaging. Therefore, the Survey's participation was confined chiefly to selecting the gaging station sites where the permittees constructed the stations and maintained them, and to supervising their operation.

Ebert selected the sites for several stations on the headwaters of the San Joaquin River, where natural solid granite controls formed pools in which the recorders were to be placed. The company engineers who were to install the stations trustingly turned over to their foremen the construction work. These foremen, knowing little of the purpose of the structure, decided that the work could be done more easily if the pools were drained, and dynamited a trench through each control. Fortunately the controls could be repaired by means of a small amount of concrete.[283]

283/ Letter from R. C. Briggs to the author.

The Survey usually inspected the stations at yearly intervals. Some of these stations were in isolated regions where the materials had to be packed by burros and mules over mountain trails. Perhaps the most inaccessible location was that of the station on the South Fork of the San Joaquin River near Hoffman Meadow. The materials for the concrete shelters were hoisted by tram from Big Creek to Huntington Lake, a rise in elevation of about 1,000 feet, then packed 30 miles over Kaiser Pass, rising from 6,000 to 10,000 feet in elevation then descending to 4,000 feet, again rising to 7,000 feet and descending to the site at an elevation of 5,000 feet.

The Southern California Edison, one of the permittees, not only maintained resident hydrographers throughout the year, but being concerned about the winter flow of the streams in the high Sierras, maintained during the first winter two hydrographers at each of several stations, who made a number of discharge measurements each week. The winter flow was found to represent so small a proportion of the annual flow that in succeeding years the winter program was considerably reduced. Life in the remote areas of the high Sierras was conducive to unusual experiences for the hydrographers. As R. C. Briggs writes:[284]

284/ op. cit.

> They saw great extremes of temperature, and came into contact with many wild residents of the Sierras, including bears, mountain lions, wolverines, coyotes, lynxes, wildcats, martens, deer, skunks, and rattlesnakes. Bears caused a great deal of trouble by breaking into cabins to get food.

In a few instances the Survey not only installed the required stations, but also operated them at the permittee's expense. In 1922 Leidl installed a group of 10 stations in the basin of the South Fork of the American River and maintained them for a year from headquarters at Placerville. So great was the interest in power that the larger power companies maintained gaging stations by means of their own engineering organizations. In addition a few irrigation districts maintained stations of value for irrigation, and the City of Los Angeles maintained five stations in Owens Valley in connection with its water supply. For some of these stations the base data were furnished, and for about 40 the complete records were furnished. Construction work

constituted an important part of the district activities, and 73 recorders were installed, of which 50 were in concrete shelters. In addition, 66 recorders were installed by cooperating interests. The stations in the Hetch Hetchy Basin, maintained in cooperation with the City of San Francisco, were continued by C. J. Emerson with headquarters at Groveland.

At the beginning of the period the cooperative work with Los Angeles County was performed under Ebert's supervision by C. W. Sopp who had been transferred to the Forest Service for that purpose. On July 1, 1920, the Forest Service withdrew from active participation and the Survey assumed complete charge of the investigations.285/

285/ News Letter June 24, 1920.

Sopp was retransferred to the Survey and continued to operate the stations until December 1920 when he was detailed to assist LaRue in utilization studies. The Forest Service then detailed H. J. Tompkins to the Survey to operate the Los Angeles county stations. Cooperation with San Bernardino, Riverside, and Orange counties, effective in February 1919,286/ required the installation not only of 15 permanent

286/ Follansbee, Hist. of -- p. 340.

stations on streams at the base of the mountains to determine the recharge of the gravels from which water was pumped for irrigation, but also of three stations on canals. In addition records from three existing canal stations were utilized. This work was started in 1919, and J. Oliver was detailed to it with headquarters at San Bernardino. There were no unusual features connected with this work which continued during the period. These two investigations were conducted from the sub-office in Los Angeles.

Toward the end of the period cooperation between the Survey and the East Bay Municipal Utilities District required both surface and ground-water investigations in the Mokelumne River Basin.287/ The

287/ p. 170.

former involved the establishment and maintenance of 11 gaging stations, in addition to the maintenance of three existing stations. This work was started in March 1926 when B. S. Barnes was detailed to it with headquarters at Lodi. He collected records also of some 50 pumping plants located along the river.

As the publication of the annual reports were several years in arrears, McGlashan, in order to meet the numerous calls for records, prepared blue-print summaries for about 75 stations for which records were in greatest demand and distributed them as requests were received. He also published as contributions to hydrology288/ monthly

288/ Water-Supply Papers 597, 636, 637.

summaries of the California records, together with the maximum and minimum discharges at each station.

H. D. McGlashan continued as district engineer throughout the period with F. C. Ebert in charge of the Los Angeles sub-office.

Other personnel of the San Francisco office was:

Charles Leidl	July 1,	to Dec. 31, 1919 and
	July 11, 1922	to June 30, 1928
Wm. Kessler	July 1, 1919	to June 30, 1928
T. G. Bedford	July 1, 1919	to Mar. 15, 1920
C. J. Emerson	July 1, 1919	to June 30, 1928
K. M. Kelley	May 10, 1920	to Dec. 31, 1925
R. C. Briggs	Jan. 3, 1921	to June 30, 1928
J. Arnold	July 27, 1921	to June 30, 1928
B. S. Barnes	Jan. 1, 1926	to June 30, 1928
A. C. Swanson	July 15, 1926	to June 30, 1928
G. H. Taylor	Sept. 8, 1926	to June 30, 1928

That of the Los Angeles office was:

C. W. Sopp	July 1,	to Dec. 1, 1920 289/
J. Oliver	Sept. 15,1919	to June 30, 1928
H. C. Troxell	Apr. 1, 1921	to Aug. 12, 1925

289/ Forest Service employee prior to July 1, 1920.

Hawaii.- Prior to 1919 stream gaging in Hawaii had been confined to the islands of Kauai, Oahu, Maui, and Hawaii, but at the beginning of the period it was extended to Molokai. In his annual report the Governor of Hawaii stated that at that time the Territory had under consideration an enlarged homesteading program on Molokai, the success of which depended upon the water supply of the streams on the windward side of the island. Referring to the stations which were established, the report went on to state:290/

290/ Rept. Gov. of Hawaii, 1922, pp. 36-37.

> few people realize the inaccessibility of most of the stations and the personal hardship and hazard engineers encounter in maintaining this work.

Like the other islands in the Hawaiian group, Molokai has extremely rugged topography, particularly on the north or windward side. Referring to this side of the island, Stewart states:291/

291/ News Letter July 24, 1919.

> We would enjoy taking some of the mainland engineers along (this) coast, as some of the best, wildest, and most picturesque scenery in the islands is to be found there; waterfalls 500 to 2000 feet high, palis (cliffs) 2,500 to 4,000 feet high, caves and arches at the base of sea cliffs, etc.

Reconnaissance for the proposed stations was made during July and August 1919. The trip in August was made by a Japanese motorboat, known as a sampan. The reconnaissance itself, made by three engineers, required four days, during which five proposed sites for gaging stations were visited. The rains had begun and one night was spent with no blankets or food on a 50-degree slope at an elevation of 2,700 feet in the rain with the temperature reported to be near freezing, although Hawaii is in the tropics.[292] Construction

292/ News Letter Oct. 24, 1919.

work was started soon afterward and as few whites live in that section the construction crew consisted of eleven Hawaiians, one Chinese, and one Japanese, only one of whom could speak English readily. The lack of English-speaking laborers was due to the isolation of this region, in which few whites lived, and in which there were no schools to teach English to the natives. The installation of stations on Molokai was completed with the construction of two stations in Pelekunu Valley. Supplies and equipment for the work were brought to the mouth of the valley by sampan, which departed after delivering its cargo. When the construction was completed, B. F. Rush, in charge, could not return until his crew spent 3 weeks building a trail out of the valley to connect with another trail leading to the side of the island where there were settlements and where there were means of transportation from the island.

It must not be inferred from the foregoing account of the work on Molokai that all Hawaiian field work was strenuous, as some stations were accessible by automobile. The greater number, however, could be reached only by trails. Some of these trails were used by the natives, but others were cut by the Survey engineers before materials could be carried to the station sites, and the only means of carrying the materials was by man-power. The trails used only by the Survey required clearing at least every third year. The expense of clearing trails was sufficiently great to warrant a separate item for that purpose in the Territorial appropriation.[293]

293/ News Letter Aug. 11, 1923.

The inaccessibility of the stations led to the installation of recorders at every station. Furthermore, to avoid the trouble experienced in having natives change the weekly charts, Stevens continuous recorders were installed not only at the stations established during the period, but, as rapidly as funds permitted, they also replaced the weekly recorders which had been installed originally. To expedite this procedure the Hawaiian district offered to exchange six 1918 Gurley 8-day recorders for two Stevens continuous recorders of 1918 model or later.[294] The success of this effort was not reported.

294/ News Letter May 22, 1920.

By the end of the period the recorders with but few exceptions were operated by Survey engineers, insuring much better results than formerly.

Rainfall at the higher elevations on thw windward side of the islands is almost unbelievably high during the rainy season, reaching in one instance during a construction job, 40 inches in three days. Such heavy rains cause sharp floods, generally of short duration, and as many trails crossed the streams by fords, travel was frequently hazardous during the rainy season. R. H. Remington, junior engineer, was drowned while attempting to ford a stream in flood, and several other engineers had narrow escapes. Not only did the heavy rains cause floods which sometimes destroyed gaging stations, but they also caused landslides in the precipitous valleys, and on one occasion, at least, a landslide destroyed a station. The station on East Wailuaiki Stream near Nahiku was particularly ill fated, as a new recorder and shelter were destroyed by a flood in January, and another recorder placed in a shelter built at a more protected spot was destroyed by a landslide in the following May. On the smaller streams the flood flows were of such short duration that it was almost impossible to rate the gaging stations by meter measurements. At three stations established in 1926 weirs were installed for measuring flood flows. An orifice a foot long and six inches high was placed in the weir below the crest for measuring the low flow.

Although the rainfall stations had been turned over to the Weather Bureau in 1919, some of them were at such isolated sites that it was necessary for the Survey to resume their operation. In 1920 a station was installed on Mt. Waialeala at an elevation of 5,080 feet. This mountain is situated on Kauai, the most northwesterly island in the Hawaiian group and receives the full force of the trade winds with their accompanying rainfall, which is very heavy at that elevation. As the Weather Bureau had no means of installing this rain gage, it fell to the Survey's lot to do it. The station was to be visited only once a year, and as the rainfall was known to be very heavy, the rain gage was designed to hold 900 inches. It was undoubtedly the largest rain gage in the world.295/

295/ News Letter Feb. 24, 1920.

The supervision of artesian well operation on the island of Oahu, which had been given to the Territorial Division of Hydrography, practically the Survey's Hawaiian district, was greatly reduced during the years 1919 to 1921 and discontinued altogether from 1921 to 1923, as funds for that purpose were not available.296/ In 1923 the legis-

296/ Dept. of (Hawaiian) Public Lands; Geol. and ground-water res. of the island of Oahu, Hawaii, 1935.

lature made a special appropriation for the supervision of the artesian water supply of Honolulu, and John McCombs was appointed artesian well engineer. He continued the use of a current meter in detecting leaks in pipes, a use which had been started in 1918, and devised a method of repairing leaks in such wells.297/ Following a suggestion made by

297/ Water-Supply Paper 596, pp. 4-24.

Meinzer, a water-stage recorder was placed on a well in Honolulu in

March 1925. The chart from this recorder indicated that the head on the well reflected rainfall, pumping draft, barometric pressure, and tidal stages.298/ During the remainder of the period six additional

298/ News Letter May 11, 1925.

recorders were placed on artesian wells. McCombs resigned in March 1926 and was succeeded by Penn P. Livingston, who in turn was succeeded by K. N. Vaksvik in May 1927.

The number of gaging stations was very nearly constant during the period, increasing from 76 in 1920 to 83 in 1928, except during the fiscal year 1921, when a reduction in available funds made it necessary to reduce the number of stations to 64. Private assistance continued to play an important part in the district's operations as a third of the stations were maintained with some degree of such assistance.

J. E. Stewart continued as district engineer for the Survey and chief of the division of hydrography for the Territory until Mar. 21, 1922, when he returned to the mainland and was succeeded by E. D. Burchard. The latter remained in charge until June 18, 1924, when he likewise returned to the mainland. At that time M. H. Carson became district engineer and chief of the division of hydrography, and continued in those capacities throughout the remainder of the period.

The district personnel were:

J. E. Stewart	Aug.	1,	1918	to Mar.	15,	1922
E. D. Burchard	Mar.	21,	1922	to June	18,	1924
M. H. Carson	Sept.	21,	1919	to June	30,	1928
H. A. R. Austin	Apr.	1,	1914	to July	15,	1916 and
	May	21,		to Sept.	9,	1919
John Kaheaku	Sept.	1,	1919	to Nov.	3,	1923
John McCombs	July	19,	1922	to June	30,	1925
B. L. Bigwood	Feb.	23,	1924	to July	6,	1926
Karl Jetter	Dec.	14,	1921	to Nov.	5,	1924
Penn. P. Livingston	July	30,	1924	to May	21,	1927
K. N. Vaksvik	July	15,	1925	to June	30,	1928
J. H. Hofmann	June	30,	1926	to June	30,	1928
J. L. Lamson	Aug.	20,	1926	to June	30,	1928
K. M. Kelley	Oct.	1,	1927	to June	30,	1928
J. F. Kunesh	Sept.	1,	1927	to June	30,	1928
Reid Jerman	Dec.	16,	1919	to Aug.	21,	1920
E. M. Pickop	Jan.	18,	1921	to Aug.	21,	1922
M. H. Merry	June	21,		to Aug.	31,	1920
F. K. Walker	July	1,		to Oct.	31,	1924
W. C. Renshaw	Dec.	20,	1920	to Dec.	17,	1921
S. B. Hall	Dec.	7,	1921	to Sept.	28,	1922

In addition there were a number of territorial employees.

DIVISION OF GROUND WATER

The period 1919-1928 may be termed one of expansion and development for the Division of Ground Water, chiefly through increase in State cooperation. As contrasted with the previous period, when cash cooperation was effective with California and Connecticut only, and cooperation of service with Montana and New Mexico, cash cooperation with ten States or subdivisions and one territory was effective during some years of the present period. This cooperation was as follows:

State cooperation

Year	Conn.	N. J.	Penn.	N. D.	Ida.	N. M.	Ariz.	Calif.	Tenn.	Hawaii	Total
1920	1005										$1,005
1921	365				625					7500	8,490
1922	200				1710						1,910
1923					1601		2600				4,201
1924		5084		800	923		850				7,657
1925		6560									6,560
1926		7383	400			5515 1/		1950 2/			15,248
1927		7878	1684			2963 1/		3423 2/			15,948
1928		1585	433			5956 1/		9169 2/	538		17,681

1/ Including allotments by Chaves and Eddy Counties.
2/ East Bay Municipal Utilities District.

Note.- The cooperative funds for Idaho are not complete as the Surface Water Division furnished a now unknown amount from cooperative State funds.

It was possible to increase very materially the use of the quantitative methods of measuring ground water developed previously[299] and to

299/ Follansbee, Robt., Hist. of - - - p. 432.

develop a new method by using types of desert plants as indicators of ground water and as measurers of recharge. The use of quantitative methods brought about the installation of water-stage recorders on wells, which 26 were used during the period, and the development of a current meter to detect leaks in artesian wells. A hydrologic laboratory was established to determine the permeability and specific yield of various types of water-bearing materials that were being investigated in the field.

The increasing stress laid on quantitative methods which required the application of hydraulic principles is shown by the change in the character of the personnel. In 1919 the personnel consisted of seven geologists but by 1928 the seven geologists had been augmented by four hydraulic engineers. Close contact was maintained with the water-well drilling industry through cooperation with recently organized state and national well-drillers

associations. Areal surveys were continued and many brief investigations were made for other government organizations to help them in the development of water supplies from wells. The necessity for geologic examinations of dam sites by geologists familiar with the occurrence and movement of ground water was recognized, and considerable work of this character was performed by the Division.

Quantitative investigations.- Investigations by quantitative methods were conducted on a more extensive scale than during the preceding years; extensive not only as to character but also as to the number. They are described herein in chronological order.

Idaho.- In the spring of 1921 the State of Idaho, through the Bureau of Mines and Geology and the State Department of Reclamation, entered into cooperation with the Ground-Water Division to make an investigation of the Mud Lake area. Between 1908 and 1914 the lake level had risen 5 feet and during the heyday of irrigation expansion water filings on Mud Lake for the irrigation of more than 150,000 acres had been made. No thorough investigation of that region had been made and, one as a protection to the prospective settlers and investors, was necessary to show the annual water supply available and the amount of land that could be irrigated. As two Carey Act projects were included in the filings the General Land Office was interested in the investigations and cooperated to the extent of paying the salary and expenses of H. T. Stearns. The investigation included both ground- and surface-water studies. The former, conducted by Stearns, were supervised by O. E. Meinzer, Chief of the Ground Water Division; the latter, carried on by L. L. Bryan, were supervised by C. G. Paulsen, then Surface Water district engineer for Idaho.

Records of precipitation, temperature, wind movement, transpiration and evaporation from land and lake pans, stream flow, seepage losses and gains, pumpages from the lakes, and water levels of Mud Lake and several smaller lakes in the vicinity and about 400 wells, were obtained. Plane-table traverses were made of Mud Lake and adjoining lakes and swampy areas, from which contour maps of the land and the water table were constructed. By means of this information the source, movement, and disposal of the ground water were determined and an inventory was made of the total water supply of the basin. Field work was started in March 1921 and was actively continued through the summer of 1922. Additional investigation was made and meteorological records and records of stream flow and lake levels, and water levels of wells and pumpage were obtained during later years. A preliminary report of the investigations was released in mimeographed form in June 1922, another was published as Water-Supply Paper 560d in 1925. Reports embodying later data were released in typewritten form in 1930 and 1934. The final report was published as Water-Supply Paper 818 in 1939.

Three minor investigations were made in cooperation with the Idaho Bureau of Mines and Geology. The results of these investigations were published in three State bulletins.[300]

300/ Piper, A. M., "Geology and water resources of the Goose Creek basin, Cassia County, Idaho:" Idaho Bur. Mines and Geology Bull. No. 6, 1923.

300/ Meinzer, O. E., "Ground water in Pahsimeroi Valley, Idaho:" Idaho Bur. Mines and Geology Pamphlet No. 9, 1924.

300/ Piper, A. M., "Geology and water resources of the Bruneau River basin, Owyhee County, Idaho: Idaho Bur. Mines and Geology Pamphlet No. 11.

Connecticut.- The quantitative study of the Pomperaug River Basin, which had been started by A. J. Ellis,301/ was interrupted by the war and later by his death in 1920 and was continued in 1922 by Norah E. Dowell, who spent a few weeks in that area and made an exhaustive study of the data in collaboration with Meinzer. The next year H. T. Stearns completed the geologic map. The resulting report, which contains a monthly inventory of the water supply of the basin for a period of a little over three years, was published as Water-Supply Paper 597.

301/ Follansbee, Robt., History of the - - - p 434.

Arizona.- In 1921 the Survey started a cooperative project with the University of Arizona, whereby G. E. P. Smith and Kirk Bryan were to make a quantitative study of ground water in the San Pedro Valley, using among other methods the method devised by Smith for determining the rate at which water is withdrawn from the zone of saturation by vegetation. Both devoted considerable time to the project during several years, but the investigation was not completed. A by-product of the investigation was the discovery of many mammalian fossils, one of which is on exhibit in the National Museum.

New Jersey.- The increase in population in densely populated sections of New Jersey, which relied upon ground-water supplies for domestic and industrial uses, made necessary a knowledge of the additional safe yields of these supplies. In the spring of 1923 Dr. H. B. Kummel, State geologist, entered into cooperation with the Survey for an investigation of the ground-water supplies, and David G. Thompson was assigned to the work July 1, 1923, with headquarters at Trenton.

Emphasis was placed on observing the fluctuations of the water levels in wells and on a study of their relation to the fluctuations in the rate of pumping. As an aid to the determination of the rate of flow through the water-bearing formations, samples of sand obtained from the drilling of wells within the areas investigated were analyzed for porosity and permeability in the hydrologic laboratory of the Geological Survey in Washington. To obtain continuous records of water levels in observation wells, Stevens continuous recorders were operated on eight wells for varying lengths of time. This was the first use by the Survey of a water-stage recorder on a well. The investigations were carried on under the immediate supervision of O. E. Meinzer and H. T. Critchlow, chief of the Division of Waters of the State Department of Conservation and Development, of which the State geologist's office was a unit. The work was continued by the Survey until July 1927, when it was taken over by the State and H. C. Barksdale, Thompson's assistant, was given a State appointment. E. W. Downs, junior engineer, was Thompson's assistant from September 1924 to November 1926, when he resigned and was succeeded by H. C. Barksdale.

The investigations in the Camden area, started in 1923, and in the Atlantic City area, started in 1924, were the most intensive and were continued through 1928. A systematic program of obtaining records of pumpage and water levels in different parts of the State was continued

through the rest of this period. Reports on the various areas were prepared by Thompson and published by the Department of Conservation and Development.302/

302/ Bulletins 30, 35, 38, and 39, New Jersey Dept. of Cons. and Develop.

Utah.- An investigation based on the transpiration by plants and evaporation from soils in determining the annual yield of ground water was made in Escalante Valley near Milford from 1925 to 1927. This was the only quantitative investigation made without State cooperation. During the summer of 1923 Depue Falck and Walter N. White of the Land Classification Branch made a ground-water and soil survey of Escalante Valley for the purpose of classifying the public lands. They discovered that in a part of that desert valley alfalfa seed was being produced without artificial irrigation by means of sub-irrigation from ground water. Meinzer recognized the possibility of obtaining an estimate of the annual yield of ground water from daily water-table fluctuations and measured transpiration of alfalfa. When Herman Stabler detailed White to the Division in 1925 Escalante Valley was chosen as the site of a new type of quantitative study, suitable for a closed basin from which little or no water, either surface or underground, could escape. Here the ground-water recharge is from mountain streams, and is about balanced by the average annual loss by evaporation and transpiration from the areas of shallow ground water. Therefore a measurement of these losses is a close approximation of the water entering the aquifer. G. E. P. Smith had suggested the idea in 1922303/ and Meinzer had devised

303/ Jour. Wash. Ac. Science, vol. 14, p. 160.

the methods to be used.

The work was started in July 1925, when four wells were dug to the water table near Milford in areas covered by various types of vegetation obtaining water from the shallow aquifer. Later, additional wells 8½ inches in diameter were bored with hand augers, bringing the total number of observation wells to 90, all being less than 25 feet deep. Most of these wells were equipped with water-stage recorders for varying lengths of time, six Friez instruments being in use. A few wells were also bored in valleys of a similar character in Utah and Nevada. The well records showed marked daily fluctuations of the water table in the area of growing plants, a fluctuation which ceased when plant growth ceased. In order to make practical use of the field data it was necessary to interpret the fluctuations in terms of the amount of water used by the plants, and for that purpose an experiment station was established. Cylinders were driven near observation wells, enclosing columns of undisturbed soil in which the rise and fall of the water table was noted after adding or subtracting measured quantities of water. Ground-water plants were raised in four tanks provided with measured water supply. Two tanks were filled with bare soil to determine the evaporation loss alone. Surface evaporation pans and meteorological instruments were also installed. The investigation was continued until the end of the growing season in 1927, and the results were published in Water-Supply Paper 659a.

California.- The only investigation in California was carried on in cooperation with the East Bay Municipal Utilities District and the

California district of the Surface Water Division. In the fall of 1924 the East Bay Municipal Utilities District, comprising chiefly the cities of Oakland, Berkeley, and Alameda, in a quest for an additional water supply, proposed to construct a 325-foot dam on Mokelumne River above the alluvial cone where the ground-water reservoir, is replenished, in part, by the river. The ground water in this area was pumped for the irrigation of about 40,000 acres of land. As water was to be diverted from the river an application for such diversion was made to the State engineer's office. It was certain that there was a surplus of unappropriated water in the river, but it was not certain what effect this diversion would have upon the ground water in the valley below the dam. Therefore, as it appeared reasonable that the Utilities District should provide whatever data were necessary to show the effect of the proposed diversion upon the ground-water supply[304] the following clause was

[304] Letter from Deputy State engineer to the author.

inserted in the permit authorizing the diversion:[305]

[305] U. S. Geol. Survey Water-Supply Paper 619, p. 4.

> In order to determine the extent of prior vested rights to the use of Mokelumne River water which percolates into or supplies underground basins, permittee shall conduct a study of the replenishment and draft upon underground storage supply from Mokelumne River as to determine with reasonable certainty the effect of the proposed diversion and storage upon the underground supplies and shall file such information as a matter of public record with the division of water rights from time to time and at any time upon demand by the said division.

At that time A. P. Davis, who had left the Reclamation Service in 1924, was chief engineer and manager of the District. He came to see McGlashan and explained the kind of investigation which he considered necessary. As this investigation included both surface- and ground-water studies, cooperation was arranged with both surface- and ground-water divisions of the Survey, the District paying most of the cost. The surface-water investigation consisted in the establishment and maintenance of gaging stations at short intervals along the river from the point where it leaves the mountains downstream to the point where it is affected by the tide. Three stations were being operated in this area and eleven more were established for the investigation. All were equipped with recorders. The construction work was performed by the Utilities District, under McGlashan's supervision. Work was started in March 1926 and has been continued until the present time (1939).

The ground-water investigations were started in April 1926, with H. T. Stearns, geologist-in-charge. He had as an assistant T. W. Robinson, engineer, and in September 1926 G. H. Taylor, engineer, was employed also as assistant. During the first year records of water elevations in nearly 500 wells were measured monthly after which the number was reduced to 125. Recorders were placed on 8 representative wells. The amount of rainfall reaching the water table was studied by means of recorders on those wells that showed the effect of rainfall upon the water table in areas of shallow ground water. Tests were also

made to determine the recharge from irrigation and the specific yield of the material in the belt of annual fluctuation of the water table. Nine rainfall stations were established. A canvass of well owners in the area irrigated was also made to determine the quantity of water that was pumped from wells. This investigation continued after 1928 and the results obtained during this period were published in Water-Supply Paper 619.

New Mexico.- Ground Water is an important source of water supply in New Mexico. The State legislature made various appropriations to enable the State engineer to make ground-water investigation. These appropriations were made from the Water Reservoirs Revenue fund derived from the proceeds of a special federal land grant.

In planning for the ground-water investigations, the State engineer stated:306/

306/ Seventh Bien. Rept. 1925-26, p. 19.

> It has been the policy of the State engineer's office to solicit and to extend cooperation in all possible cases where it can be done under a strict interpretation of the laws governing those cases.****
>
> In conformity to this policy the government departments have been invited to participate in the special investigations that have been provided for. As a result, there have been secured *** the expert services of men long trained in their particular line of endeavor, ****.

An investigation was proposed in Estancia Valley, but a reconnaissance by Charles H. Gee proved that a detailed investigation was not warranted. The quantitative investigation in New Mexico was confined to the Roswell artesian basin, where an areal survey had been made in 1904-5 by C. A. Fisher.307/ About 60,000 acres were being irrigated by some 1,400 wells

307/ Follansbee, Hist. of --- p. 175.

and the artesian flow had declined so alarmingly that very considerable additional areas of land once irrigated had to be abandoned. This situation affected the entire community and the Roswell Chamber of Commerce urged the legislature, at the 1925 session, to make a specific appropriation to investigate the cause of the decline and to determine the remedy. The legislature appropriated $5,000 to the State engineer and under the ensuing agreement, the Survey allotted a like amount. The work was started in July 1925 with headquarters at Roswell by A. G. Fiedler, engineer-in-charge, and B. C. Renick, geologist.

The object of the investigation was to determine (1) the underground leakage, (2) the quantity actually withdrawn for irrigation and the relation between draft and decline in head, (3) the safe annual yield, and (4) to recommend a program of conservation. The first step in the investigation was to inspect the wells to ascertain their condition with a view to controlling the artesian flow and also to determine whether the water was being used efficiently for irrigation and other purposes. In order to cooperate effectively in the investigation the County Commissioners appointed a well superintendent who inspected

about half the wells.

A deep-well meter[308] for measuring leakage from artesian wells was

308/ p.

especially designed for this investigation. It was used in 60 wells and attempts were made to use it in many others, but these latter were so seriously obstructed as to make use of the meter impossible. The discharge at the surface from the wells was measured by means of weirs and current meters except that from wells pumped by electric motors, which was generally estimated on the basis of electric power consumed. In order to obtain timely information on the status of the artesian head and to study the fluctuations in head due to various causes, four Au drum recorders were operated on representative wells in different parts of the area. These representative wells were abandoned ones, situated a considerable distance from wells in use. Twice a year more than 200 wells were measured to determine the position of the artesian pressure surface throughout the artesian area. The pressure surface thus defined was compared with the original pressure surface as indicated by Fisher's earlier work. On the flowing wells the artesian head was measured by use of pressure gages and on the nonflowing wells the distance to the water level in the wells was measured with a tape.

The intake area for the artesian basin, as defined during the course of the investigation, was determined to be a strip several miles wide paralleling the area of artesian flow and situated in the limestone upland to the west of the flowing area. Seepage runs made along the tributary streams crossing the intake area showed considerable loss of water in the section comprising that area and confirmed the geologic evidence with respect to its position.

At the end of the first year Chaves County contributed $3,000 from the county artesian-well fund to continue the investigation and Eddy County contributed $1,500, with the understanding that the Geological Survey would contribute equal amounts. Additional State funds became available in 1927 and $4,500 was allotted by the State for the fiscal year 1928,[309] which in turn was matched by nearly an equal amount

309/ Statement of A. G. Fiedler to the author.

provided by the Survey.

The investigation was continued until 1928 with Fiedler in general charge of the work. On Nov. 10, 1926, Renick resigned and was succeeded by S. S. Nye, also a geologist. When the cooperative agreement was renewed in 1927 it provided that at the end of the investigation the Survey was to leave with the State engineer three recorders, which were continued in operation on representative wells, and a deep-well current-meter outfit.

At the end of the first year of the investigation a preliminary report was published in the Seventh Biennial report of the New Mexico State engineer and recommendations were made for a conservation program. New legislation was recommended to prohibit further irrigation developments with artesian water except as it was shown that such development

would not injure existing irrigators. Such legislation was subsequently enacted and formed the basis for ultimately making the use of artesian water in the Roswell artesian basin subject to appropriation. The application of the doctrine of appropriation to the use of artesian water was one of the outstanding accomplishments of this investigation. The report on the Roswell studies was published as Water-Supply Paper 639.

Use of current meters in deep wells.- The necessity for detecting leaks above the artesian horizon in wells brought about the use of a current meter. The procedure is to lower the meter in the well and observe the velocity at various points between the bottom and top. The discharge at each point is obtained from the observed velocity and the diameter of the well casing. Comparisons between the results at each point indicate not only the presence of leaks, but the amount lost. This method was apparently first used in 1918 by R. D. Klise in studying the artesian wells of Honolulu. A standard Price meter was used, with a wire guard to protect the cups, and with the yoke fastened rigidly to a length of 3/8-inch pipe. In this position the meter rotated with its axis horizontal instead of vertical, as in stream gaging, and was therefore less sensitive, also on account of its size it could not be used in wells having a smaller diameter than 6 inches. The need for a meter smaller than the Price was recognized, and in 1920 Kirk Bryan conferred with the makers of the Price meter and learned that a screw meter having four curved blades inclosed in a brass cylinder 6 inches in diameter was being developed. It was decided, however, that the meter needed should not have a greater diameter than 4 inches, and no further steps were taken at that time.

The investigations of the Roswell area, started in 1925, required the use of a meter capable of being used in wells smaller in diameter than 6 inches and up to 1,000 feet deep. As no meter of that type existed, the task of making one was given C. H. Au. He devised the so-called Au deep-well meter, which is of the screw type having three curved aluminum blades revolving on a point bearing, the meter mounted in a cylindrical brass case suspended in a 3-inch pipe. An interchangeable commutator head similar to that on the Price meter is attached to the upper end of the brass cylinder. The sensitivity of the Au meter is such that at a velocity of 4 feet per second it rotates three times as fast as the cups of the standard Price meter.[310]

310/ U. S. Geol. Survey Water-Supply Paper 596, p. 26.

As used on the Roswell investigations the initial equipment consisted of a section of 3-inch pipe containing the meter, which was fastened to 1,400 feet of 3/16-inch, 6 x 7, wire cable wound on a reel mounted on the back of a Ford truck. To complete the electric circuit a separate insulated wire cable was attached to the meter and wound on a second reel on the same axis as the reel for the cable suspending the meter. The latter reel was belt-connected to the odometer on the rear wheel of the truck which was jacked up during the measurement, allowing the wheel to turn. A special cable containing an insulated core was later used in place of the separate insulated conductor, and this cable therefore made it possible to handle the equipment on one reel instead of the two formerly required. The distance the meter was lowered was determined from the odometer.[311] The accuracy of the current-meter method for

311/ Op. cit.

determining leaks in wells was proven when a well casing was removed and found to have corroded at the points where the meter had indicated leakage.[312]

312/ Water Resources Bull., March 1927.

The meter just described could not be used in a well having a smaller diameter than 4 inches, and for use in small wells, Au spent two months during the spring of 1926 in developing a similar meter which could be used in a well of $1\frac{1}{2}$ inches diameter. This latter meter was used in Hawaii, beginning in 1926, displacing the Price meter which had been used until that time. Beginning in 1928 a meter of the first Au type was also used. To determine the direction of flow, which, under certain conditions might be downward, the Hawaiian district in 1938 added a reversible dog to the small meter which allowed it to turn in only one direction. The engineers of the Hawaiian district, adapting methods used in measuring streams, suspend the meter by the regular meter cable and have a commutator on the reel, giving a continuous connection between the headphones and the meter.[313]

313/ Letter from M. H. Carson to the author.

Areal and other surveys.- Systematic surveys of the ground-water resources were continued during the period, chiefly in cooperation with Hawaii, Pennsylvania, Idaho, North Dakota, and Montana.

Salt Water Investigations.- Cooperation with the State Geological and National History Survey of Connecticut, started in 1911 and interrupted by the war, was resumed in 1919 and continued until 1922. During the summer of 1919 John S. Brown made an investigation of ground water in the New Haven area. Because of the difficulty experienced in obtaining water suitable for domestic and industrial uses from wells close to the ocean, he made a study of coastal ground water and investigated the reasons for and the causes of contamination of wells by salt water, and possible remedies. In this connection he made a search of foreign literature for data. This was the first intensive study made by the Ground Water Division of the relation of sea water to fresh ground water. It was the beginning of intensive researches of this kind of problem to which the Division has given much attention in recent years. It introduced the Ghyben-Herzberg principle into the ground water work of the Geological Survey. The results of these investigations were published as Water-Supply Papers 537 and 540.

Hawaii.- Although the Territory, through its Division of Hydrography, which was also the Survey's surface-water district of Hawaii, had been making investigations of ground water in the vicinity of Honolulu, chiefly through a study of the artesian wells, a project suggested by Mendenhall while chief of the Division of Ground Water, and it was not until 1920 that that Division entered into cooperation with Hawaii.

Prof. H. E. Gregory, who had cooperated with the Survey while State geologist of Connecticut and had also carried on a number of investigations for the Survey in the western States, became director

of the Bernice P. Bishop Museum in Honolulu. On a visit to the Island of Hawaii he saw in the Kau district an opportunity for a detailed geologic and hydrologic investigation in an area lying on the slope of Mauna Loa, an active volcano covered with recent lava. He interested public-spirited citizens in the project with the result that the governor, in August 1919, made a request of the Secretary of the Interior for a geologic survey of the Territory of Hawaii with especial reference to the ground-water resources. The Secretary referred the request to the Survey and it was accepted. Meinzer, with W. O. Clark of the Division, and L. F. Noble, Survey geologist assigned to the investigation, arrived in Hawaii in February 1920. They spent three weeks in making a reconnaissance of the Iau district. Noble spent six weeks in studying the geology, all the time he could spare from his work in the Geologic Branch, and Clark devoted his attention to a detailed study of high-level ground water until he resigned on Dec. 31, 1921. His resignation left the investigations at loose ends, as but little detailed work had been done on the geology, and it was not until May 1924 that the investigation was resumed, when H. T. Stearns, who had a background of three years' experience in ground-water work in lava rock in Idaho, was detailed to the investigation. He finished his field work in November of that year and returned to the United States via Japan, Chosen, the Philippines, Java, and Italy, visiting the volcanic regions of those countries to increase his knowledge of volcanic processes. Stearns completed his report in February 1926, and it was published as Water-Supply Paper 616. The Survey paid all expenses of the investigation when it was resumed in 1924.

In 1920 an investigation of the high level ground water in the Honolulu area was made by H. S. Palmer, under the direction of Meinzer and a report based on this investigation was transmitted to the City of Honolulu.

North Dakota.- The North Dakota Geological Survey in 1911 had begun investigation of the occurrences of ground water, and H. E. Simpson devoted several weeks to the study during the summers of 1911, 1912, and 1913. During the next few years detailed investigations for various cities were made but the general study was not resumed. Ground water is the most important source of water supply in North Dakota as 90 percent of the population, both city and country, is dependent upon it. The hydrostatic pressure of the principal artesian aquifer in the southeastern part of the State, which had been observed since the late eighties, had declined so seriously that in 1921 the Legislature enacted a law directing the State geologist to effect the conservation of the artesian waters of the State. As a result, an inventory of all flowing wells and a general survey of six artesian basins in the State were made. The only cooperative feature of that investigation was the collection and analysis of 200 water samples in the Washington laboratory of the Survey. The results were published in Water-Supply Paper 598.

Pennsylvania.- The Pennsylvania Topographic and Geologic Survey entered into cooperation with the Geological Survey in 1925 for a survey of the ground-water resources of the State. This investigation consisted chiefly in collecting well data, interpreting the occurrence, head, quantity, and quality of the water with respect to the rock formations and structures, and studying the best method of constructing wells and recovering the water. The first work was done in southeastern Pennsylvania, including Philadelphia, and G. M. Hall spent the summer of 1925

in that region. Samples of water collected from wells and springs were analyzed in the quality of water laboratory of the Geological Survey in Washington, D. C. The information obtained was supplemented by additional observations during brief trips in August 1927 and June 1931.

The second unit of the investigation was assigned to A. M. Piper, who made a field study of southwestern Pennsylvania, including Pittsburgh, from August to November 1926. In addition to the geologic studies he collected water samples from 89 representative wells and, for purposes of comparison, three samples from surface streams.

The results of these two investigations were published by the State.314/

314/ Penn. Geol. Survey 4th Series Bull. W. 1, 1933, and W. 2, 1934.

New Mexico.- Cooperation with the State engineer of New Mexico included not only the quantitative study of the Roswell area, but also four areal surveys, the most extensive of which was that in western Sandoval County.

At the request of citizens of Albuquerque, B. C. Renick, in 1924, made a preliminary investigation of western Sandoval County, which showed favorable artesian conditions. As a result the legislature made an appropriation for a more complete investigation and Renick spent three months during the summer and fall studying the feasibility of obtaining water for irrigation from artesian wells in the San Jose and Rio Puerco Basins. So serious was the water shortage that settlers on the plateau west of Cuba found it necessary in some instances to haul water many miles for domestic use. A small amount of field work was performed during the summer of 1926 and in a preliminary report of the State engineer Renick recommended that the State drill three test wells. The final report was published as Water-Supply Paper 620.

On account of over expansion the water supply of Hope community, an agricultural settlement deriving its water supply for irrigation from the Penasco River, was very seriously deficient. The Bureau of Reclamation, in 1923, made an investigation of storage possibilities, but found that none existed where water could be stored economically. The only other possible source of an additional supply was the ground water, and in 1925 the legislature made an appropriation for an investigation to determine the possibility of increasing the water supply by means of artesian wells. Renick spent two periods, Aug. 4-20, and Dec. 4-12, 1925, studying the geology and ground-water conditions, and made a report which was published in the Seventh biennial report of the State engineer. S. S. Nye made a study of the geology of the Cactus Flats reservoir site near Hope and also prepared a report that was released in typewritten form.

Another appropriation for ground-water investigations, made by the legislature in 1925, was for the purpose of determining the feasibility of supplying water for irrigation from artesian wells or pumping plants on State lands in Socorro and Torrance Counties. Kirk Bryan spent the period June 26 to July 9, 1925, in making a reconnaissance to determine the nature of the study required in the large area designated. A report of this reconnaissance was made to the State engineer. In 1925, the

State Taxpayers Association brought suit to prevent the use of the land-grant funds for that purpose, claiming that such use was improper under the terms of the grant. Although the court later held that appropriations for ground-water investigations were proper, withdrawals from the fund for that purpose were suspended during the interim.[315] As the State

315/ Letter from a former State engineer to the author.

funds for the investigation in Socorro and Lorrance Counties were thus "tied up" the investigation itself was not made.

A reconnaissance investigation of the ground-water area of the Mimbres Valley, Luna County was made by Fiedler in August 1927, and the report thereon was published in the Seventh Biennial report of the State Engineer. This investigation actually represented the beginning of an intensive investigation that was subsequently conducted by Walter N. White beginning in the summer of 1928.

Still another appropriation for ground-water investigation was made in 1925 for work in DeBaca County. Bryan spent three days in making a reconnaissance, but as the funds for this examination were likewise "tied up" nothing more was done.

Tennessee.- In 1927 the Division of Geology of the Tennessee Department of Education desired a study of the principal ground-water resources of the State to meet the growing needs of city, rural, and industrial development. Cooperation was arranged with the Survey and A. M. Piper made the first unit investigation, covering 12 counties of the North-Central part of the State. The results were published as Water-Supply Paper 640. An investigation of 11 counties in the southwestern part of the State was started by Francis G. Wells but was not completed until the following year, which is covered by the next period of this history.

Montana.- The investigations of ground water in Montana, started in the previous period and discontinued in 1919,[316] were resumed in 1921

316/ Follansbee, Hist. of - - - - p. 435.

when G. M. Hall made a study of the ground water in Yellowstone, Treasure, and Big Horn counties, a part of which area had been covered by a reconnaissance by A. J. Ellis in 1915 and 1916. The report covering Yellowstone and Treasure Counties was published as Water-Supply Paper 599. As the Big Horn area contained also resources in coal, oil, and gas, these resources were studied by members of the Geologic Branch, and a combined report was published as Geological Survey Bulletin 856.

In 1922 and 1923, George M. Hall made a ground-water survey of Fergus County. The resulting report was released in typewritten form. B. C. Renick made a similar survey of the central and southern part of Rosebud County in 1923, the results of which were published in Water-Supply Paper 600.

In describing the Montana work, Meinzer stated:[317]

317/ Water-Supply Paper 599, p. vi.

Thus a considerable part of eastern and central Montana has been covered by ground-water surveys, the results of which should be of much practical value in solving the innumerable problems of water supply that will certainly arise in this region in future years. The large amount of fairly detailed work was made possible by the fact that the geology of most of the region had previously been mapped by the Geological Survey and that therefore the field work in these projects could be devoted largely to hydrologic interpretations of the stratigraphy and rock structure.

Idaho.- Cooperation with the Idaho Bureau of Mines and Geology was effective from 1922 to 1928. During 1922 and 1923 quantitative investigation of the Mud Lake Region was made,318/ and thereafter a number of

318/ p. 167.

smaller areal investigations were undertaken. Three of these were published in State bulletins.319/

319/ Piper, A. M., "Geology and water resources of the Goose Creek Basin, Cassia County, Idaho:" Idaho Bur. Mines and Geology Bull. No. 6, 1923.

Meinzer, O. E., "Ground water in Pahsimeroi Valley, Idaho:" Idaho Bur. Mines and Geology Pamphlet No. 9, 1924.

Piper, A. M., "Geology and water resources of the Bruneau River basin, Owyhee County, Idaho:" Idaho Bur. Mines and Geology Pamphlet No. 11.

A cooperative study of the geology and water supplies of the Craters of the Moon Natural Monument was made in which H. T. Stearns studied the geology. The report was transmitted to the National Park Service, and a report on the volcanic feature of the monument was transmitted to the Bureau of Mines and Geology.

Federal cooperation.- During the war years Federal cooperation was confined chiefly to that with the Army and Navy in connection with water supplies for various establishments, but during this period investigations were made not only for the War and Navy Departments but also for a number of other departments and bureaus, including the Bureau of Reclamation, Public Health Service, Veterans' Bureau, Department of Justice, Park Service, Forest Service, and Indian Service. Salaries and expenses of the Survey personnel making the investigations most of which were brief, were paid by the cooperating agencies.

War Department.- Meinzer, while in Hawaii, in 1920 investigated with G. K. Larrison, then civilian engineer for the War Department, water-supply problems of the Army and Navy on the island of Oahu.

Bureau of Reclamation.- In geologic examinations of dam and reservoir sites one of the chief considerations was the exclusion of ground water, which required a knowledge of ground-water movement. Therefore, when the Bureau of Reclamation requested the assistance of Survey

geologists in such examinations, this assistance was rendered by the Ground-Water Division. In 1923 Congress authorized an investigation of the Columbia River irrigation project, which contemplated the irrigation of 1,750,000 acres, and Kirk Bryan was assigned to that work as geologist. The work lasted from May 1923 to January 1924. During 1924 Bryan made an investigation of the proposed sites for a salt-water barrier on the lower reach of the Sacramento and San Joaquin Rivers in California. He also examined dam sites in Washington and Oregon at various times. In 1927 he investigated the Avalon reservoir site near Carlsbad, New Mex. The results of these examinations were transmitted to the Bureau of Reclamation. Bryan prepared a paper dealing with geologic examinations of dam and reservoir sites, as a guide to future examinations of that character, which was published as Water-Supply Paper 597a.

H. T. Stearns made an investigation of a dam site on the Dubois project, Idaho, in 1923, and Meinzer, Bryan, and Renick of a reservoir site on the Carlsbad project, New Mex. The results of the latter study were published in Water-Supply Paper 580a. The need for information regarding examinations of this type was felt not only in the United States, but in foreign countries and "Water and Water Engineering", a leading British journal on that subject, abstracted Water-Supply Paper 580a and published it as the leading article in the issue of Feb. 21, 1927.320/

320/ Water Resources Bulletin, Mar. 10, 1927.

Public Health Service.- Four investigations were made for the Public Health Service between the years 1920 and 1924. Three were brief examinations of a more or less routine character, but the fourth was more elaborate. This was an investigation at Fort Caswell, N. C., to determine how far typhoid bacilli could travel in ground water. The Public Health Service had been making a series of tests for that purpose and in April 1922 Meinzer was called upon to inspect work being done. He recommended further tests that should be made, and in May detailed Norah E. Dowell to make a geologic and hydrologic study of the area. Her report was published by the Public Health Service.321/

321/ Hygenic Lab. Bull. 147, U. S. Public Health Service.

Department of Justice - Two investigations were made to determine feasibility of additional water supply for prisons, one by Bryan, the other by Meinzer. Regarding the latter, the Water Resources Bulletin322/

322/ Mar. 10, 1927.

commented as follows:

> Mr. Meinzer recently had the thrill of a life time as a result of the uncanny demonstration of his skill as a hydroscope. For six months digging and drilling operations had been going on at the farm unit of the Federal Prison for Women at Alderson, W. Va., without producing more than an insignificant yield of water. At last the Superintendent telegraphed to Washington and the Department of Justice called upon the Geological Survey for advice. On Sunday

night, January 30, Mr. Meinzer took the train for Alderson, arriving there the next day. He spent a few hours on the ground and, in conjunction with the construction engineer he selected a site for a new well. He took the train Monday night and was back in his office Tuesday morning. On Wednesday drilling was begun at the spot designated; on Saturday a strong flowing well was brought in, and by the following Monday a plentiful supply of good water was being delivered.

One more service which was rendered the Department of Justice could hardly be termed an investigation. In the Chicago Drainage case being heard in 1927 before Charles Evans Hughes, special master for the U. S. Supreme Court, Meinzer was subpoenaed to testify as a friend of the court.

Other bureaus.- Four investigations for water supplies at Veterans' hospitals were made for the Veterans' Bureau, four for water supplies in national parks were made for the Park Service, one for the Indian Service, one for the Federal Land Bank of Berkeley, Calif., one for the Land Classification Branch, and one for the Federal Power Commission. The investigation for the Federal Power Commission was in the Deschutes River basin by H. T. Stearns. The results were published in Water-Supply Paper 637d. In addition an investigation of dam sites was made for the Division of Land Classification.[323]

323/ p.

Hydrologic laboratory.- With greater stress being placed on quantitative methods, the desirability was apparent for a hydrologic laboratory in which quantitative data, such as the permeability and specific yield of various types of soil and rock material, could be obtained. When the New Jersey investigations were started this became a necessity and a small laboratory was installed in Washington with Norah E. Dowell in charge. As space was at a premium no definite location could be assigned and the laboratory was made sufficiently small to be moved whenever necessary. Finally, in April 1925, a definite room was assigned to it. The methods for determining permeability were developed by Meinzer. Mrs. Norah Dowell Stearns resigned in March 1926. In March 1927 A. M. Piper was placed in charge of the laboratory.

A description of the apparatus and methods and results of tests on various water-bearing materials were published in Water-Supply Paper 596f.

Well drillers associations.- Meinzer, with his scientific mind, realized the need for better technizue in the drilling of wells in order to reduce the waste of ground water through leaky wells, and became much interested in the well drillers' associations as a means to that end.

Prof. H. E. Simpson of the University of North Dakota, who had begun a study of the ground water in North Dakota in 1911 for the State Geological Survey, had come into close touch with the well drillers who were actively drilling wells in that State and through his efforts the North Dakota Well Drillers Association was formed in 1915. Its object

was to improve well drilling through a better knowledge of the occurrence and character of the ground waters and through better methods of recovering them.[324] Annual conventions were held, at which lectures were

[324] U. S. Geol. Survey Water-Supply Paper 598, p. 3.

given to achieve this objective.

It was not until 1922 that the Ground-Water Division made direct contact with the Association, when the convention held in January was attended by Meinzer. It was a three-day session that was considered a school in which the members were instructed in the elements of geology, sanitation, and technical methods related to well drilling. Meinzer addressed the meeting and was elected an honorary member of the association. Apropos of this convention the News Letter[325] contained the

[325] May 10, 1922.

following:

> "If you want to succeed in your life work, young man" exclaimed the Chautauqua lecturer, "begin at the bottom and work up!"
>
> "I've tried it," shouted a man in the audience, "and didn't succeed."
>
> "What business are you in?" asked the lecturer.
>
> "Well drilling," replied the man.

So successful was the North Dakota association that associations were formed in Minnesota and Illinois, and Meinzer continued his policy of attending some of the annual conventions. In January 1924 he gave a series of three lectures at the second annual convention of the Minnesota Well Drillers Association and in January 1925, two lectures at the North Dakota convention, during which he supported Prof. Simpson's program of artesian water conservation as a feasible and hopeful solution of the artesian water problem in North Dakota.[326] In January 1928 he

[326] News Letter Jan. 10, 1925.

gave an illustrated lecture on "artesian well problems in different parts of the United States" before the Illinois meeting in Urbana and the Minnesota meeting in Minneapolis.

Special reports.- In addition to the publications containing the results of the several investigations, Meinzer prepared three reports of a general character. The first was "The occurrence of ground water in the United States with a discussion of principles," which was published as Water-Supply Paper 489, and embodied the material of his doctoral thesis at the University of Chicago. It was planned to be the first of a series of six papers dealing with (1) occurrence, (2) origin, discharge, and quantity, (3) movement and head, (4) quality, (5) recovery and use, and (6) ground-water provinces.

The second report dealt with large springs in the United States and was a by-product of the first. Since there is wide-spread interest in springs the report was designed to answer the popular questions: What are the largest springs in the United States, how much water do they discharge, and what geologic conditions produce them? Meinzer enlisted the cooperation of the district engineers and others in the Branch in obtaining data relative to large springs throughout the country. He classified large springs according to their discharge and called those having an average discharge of 100 second-feet or more, springs of the first magnitude. He found 65 such springs. The limestone rocks of Florida produce 16, and those in the Ozark region 10 springs of the first magnitude. The lava rocks in the Snake River Basin in Idaho produce 15 first magnitude springs, the Sacramento River Basin in California, and the Deschutes River Basin in Oregon, 8 each. A few large springs are found in other parts of the country. The report was published as Water-Supply Paper 557.

The third report, "Outline of ground-water geology" W.S.P. 494, mentioned in the history of the period prior to 1919 in connection with the glossary of ground-water terms.[327]

327/ Follansbee, Robt. Hist. of - - - p. 439.

Personnel.- Like the other divisions of the Branch, the Division of Ground Water was affected in its personnel by the lure of outside employment. Only three members, Meinzer, Thompson, and Bryan, continued during the entire period, but Bryan was given a per diem appointment Sept. 16, 1926, and thereafter devoted only a part of his time to the Division. The complete personnel list was:

O. E. Meinzer	July 1, 1919 to June 30, 1928
A. J. Ellis	July 1, 1919 to July 23, 1920 1/
D. G. Thompson	July 1, 1919 to June 30, 1928
W. O. Clark	July 1, 1919 to Dec. 31, 1921
Kirk Bryan	July 1, 1919 to Sept. 16, 1926 2/
J. S. Brown	July 1, 1919 to Aug. 31, 1920 3/
C. P. Ross	July 1 to Dec. 31, 1919
Miss Norah E. Dowell (Mrs. H. T. Stearns)	Oct. 1, 1920 to Mar. 2, 1926
H. T. Stearns	Apr. 1, 1923 to June 30, 1928
B. C. Renick	July 1, 1923 to Nov. 10, 1926
E. W. Downs	Sept. 2, 1924 to Nov. 30, 1926
G. M. Hall	June 21, 1921 to June 30, 1928

A. G. Fiedler	July 5, 1925 to June 30, 1928
W. N. White	June 16, 1925 to June 30, 1928
T. W. Robinson	Apr. 15, 1926 to June 30, 1928
A. M. Piper	July 20, 1926 to June 30, 1928
S. S. Nye	Nov. 1, 1926 to June 30, 1928
G. H. Taylor	Aug. 1, 1927 to June 30, 1928

1/ Deceased. 2/ Given per diem. 3/ Went to Haiti.

Allotments.- The annual expenditures from Survey funds, as shown by Division's ledger, were:

1920	$18,000	1923	$17,915	1926	$24,892
1921	20,539	1924	20,255	1927	23,440
1922	19,884	1925	19,700	1928	25,178

The $1,400 contribution to the coastal plains investigation, which is included in the expenditures for 1920, was discontinued thereafter as that investigation had been substantially completed.[328]

328/ Statement of O. E. Meinzer to the author.

Division of Quality of Water

With the completion of its laboratory in 1918,[329] the Division of

329/ Follansbee, Robt., Hist. of - - - p. 442.

Quality of Water resumed the analysis of the mineral content of water samples from both surface and underground sources, not only for the Division's own investigations, but also for the Division of Ground Water and for the Geologic Branch. The "field kit" developed during the days of the Hydro-Economics Division, the progenitor of the Quality of Water Division, was brought into play when Kidwell made field tests of water while on a trip to Mississippi in 1919. In connection with the analyses, studies of methods were made and changes introduced from time to time in the methods that had been used earlier in the studies of river waters.[330]

330/ U. S. Geol. Survey Water-Supply Papers 236, 237, 239, 273, 339, and 363.

The number of analyses made annually varied from 275 to 819, with an annual average of 477 for the period.

Shortly after Collins became chief in 1920 the many inquiries for information about the hardness of water led to the preparation of an article on "Hardness of surface waters of the United States" which was published in the Journal of Industrial and Engineering Chemistry, December 1920. This article was based largely on the analyses in the series of papers on the quality of surface waters, supplemented by other available analyses. It was necessarily very general in scope.

Persistent requests for more specific information as to the chemical character of the waters actually used in homes and factories throughout the States almost forced the preparation of a report on "The industrial utility of public water supplies in the United States" published in 1923.[331]

331/ U. S. Geol. Survey Water-Supply Paper 496.

This contained the results of 64 series of analyses, 190 single complete, and 74 single partial analyses made not only by the Survey but also by State or municipal waterworks and commercial laboratories. These analyses represented water supplies for 287 cities, each having a population in excess of 25,000. In order that each State might be represented by at least two cities, analyses for 20 smaller places were also given.

In an attempt to summarize and generalize the analytical results in Water-Supply Paper 496 a map was prepared based on the weighted average hardness, by States, of the water supplied to consumers in the cities included in the report. Four ranges of hardness were indicated by different shadings. This "hardness map" and a later revision have been widely used, generally with acknowledgment of the source, in magazine articles, in books, and in advertising literature relating to products whose distribution and use are affected by the hardness of water.

When F. H. Newell, who had left the Reclamation Service in 1915 and was engaged in private practice, was preparing a report on the power resources of Pennsylvania, he was interested in the temperature of the water in certain rivers on which sites for steam-power plants were available. The efficiency of a steam turbine is notably affected by the last inch of vacuum, which in turn is dependent on the temperature of the condensing water. As in plants of moderate efficiency 600 tons of water are pumped per ton of coal consumed, such plants must be located close to rivers for their water supply. Newell came to Collins for data and from waterworks officials the latter obtained records of temperatures of surface waters at 21 points. It is obvious that daily and hourly fluctuations of air temperature are not followed absolutely by equal changes of surface-water temperature. Mean monthly temperatures of air and water might be comparable, and Collins found reasonable agreement between them. He also compiled data on ground-water temperatures, many of which had been obtained in deep wells by C. E. Van Orstrand of the Geologic Branch. From a study of more than 3,000 records Van Orstrand concluded that under normal conditions the temperature of ground water obtained at a depth of 30 to 60 feet will generally exceed by 2° or 3° the mean annual air temperature. These data were published in 1925.[332]

332/ U. S. Geol. Survey Water-Supply Paper 520-F.

State and other agencies were also making mineral analyses of water, the results of which were scattered through various State publications and technical journals. A knowledge of these analyses might, as Collins writes,[333] save not only the expense of collection and analysis of a

333/ U. S. Geol. Survey Water-Supply Paper 560-C, p. 54.

sample, but also the time required to make an analysis, which might be a few days or a few weeks. With this thought in mind he compiled an index of analyses of natural waters in the United States, which was published in 1925.[334]

334/ Op. cit.

By 1928 there was very considerable demand for information relative to the analytical methods used. Collins described these methods in detail in a report entitled "Notes on practical water analysis," which was published in 1928.[335] The report was confined to the methods regularly

335/ U. S. Geol. Survey Water-Supply Paper 596-H.

used in the Water Resources Laboratory and did not include many methods that were used only occasionally.

Other reports published, usually as contributions to hydrology, were "Chemical character of ground waters of the Northern Great Plains,"[336]

336/ U. S. Geol. Survey Water-Supply Paper 560-B.

"Quality of water of Pecos River in Texas," "Quality of the surface waters of New Jersey," and "Chemical character of waters of Florida."[337]

337/ U. S. Geol. Survey Water-Supply Paper 596.

The latter was a revival and extension of work performed by Dole in connection with the preparation of Water-Supply Paper 319.[338]

338/ Letter from W. D. Collins to the author.

In addition to preparing reports for Survey publications, articles dealing with particular phases of the quality-of-water investigations were published in the technical press.

During these years increasing attention was being given to the study of the flow of the Colorado River and its utilization. Storage reservoirs were needed and the heavy sediment load carried by the lower Colorado River had an important bearing on the life of such reservoirs. In 1925 Herman Stabler suggested the desirability of starting a study of the sediment carried by the Colorado River and offered to finance from funds of the Land Classification Branch a trip to the lower Colorado River for that purpose. C. S. Howard made the trip in May 1925 and arranged with Dickinson to have the resident engineers at the Topock and Grand Canyon gaging stations obtain samples for determination of sediment load and dissolved mineral matter. He also arranged with the Reclamation Service to furnish samples from the Yuma station for analysis

of the dissolved mineral matter. Samples for analysis were collected daily in 4-ounce bottles at each station. For the Topock and Grand Canyon stations a sediment sampler was designed by Au to be attached to the meter cable and weight in place of the meter. It consisted of a metal frame holding a pint milk bottle. In operation the sampler was lowered to the desired depth and a small weight allowed to slide down the line until it struck the top part of the sampler arm, forcing knife edges to puncture the ordinary milk bottle cap, allowing the water to enter the bottle. The normal procedure was to take three samples at each of three points in the cross-section--at the bottom and at a point 1 foot below the surface, where the bottle was held until filled, and a so-called average sample, where the bottle was lowered to the bottom, the cap punched, and the bottle drawn up at such rate that it was filled when the surface was reached. All analyses, both for dissolved mineral content and sediment content, were made in the Washington laboratory. A total of 539 samples were analyzed for sediment, which, from the method of collection, disclosed only the sediment carried in suspension, there being no known method by which the bed load or material rolled along the bottom could be measured.[339] An attempt was

339/ U. S. Geol. Survey Water-Supply Paper 636-B, p. 26.

made to get a rough idea of the amount of the bed load, described by Howard as follows:[340]

340/ Op. cit.

> A few samples were collected at Grand Canyon by typing the pint milk bottles to the fins of the weights used with the sampler in such a manner that the bottles would be near the bottom with their mouths pointed upstream. At the same time a sample was collected in a bottle held in the sampler in an upright position. Care was taken to avoid stirring up mud when the weight hit the bottom of the river. The mean of 16 samples collected in bottles on the fins of the weight was about 35 percent higher than the mean of 10 samples collected in bottles held in an upright position in the sampler. The samples were in the water for about 30 seconds.

The results of the analyses of the dissolved mineral matter made during 1925 and 1926 were published in 1928[341] and the results of the

341/ U. S. Geol. Survey Water-Supply Paper 596-B.

sediment analyses for the years 1925-28 were also published in 1928.[342]

342/ U. S. Geol. Survey Water-Supply Paper 636-B.

Howard was in direct charge of these investigations.

During the early years of the period the lure of private employment was so strong that there was a rapid turnover in the Division personnel. A. A. Chambers, who was chief of the Division, resigned on July 31, 1919, and was succeeded by C. H.Kidwell, who in turn resigned on May 18, 1920. Stabler, as a former member of the predecessor Hydro-Economics Division, was acting chief until W. D. Collins was transferred from the Department of Agriculture, Bureau of Chemistry, and appointed chief July 10, 1920. Collins likewise had been a member of the Hydro-Economics Division, but had transferred to the Bureau of Chemistry in 1908 when the reduction in the appropriation had made necessary a drastic curtailment of the Division's activities.

The rapid turnover in personnel extended to the other positions in the Division, and it was found during those early years almost impossible to obtain suitable chemists even though the entrance salary was $600 greater than before the war.343/

343/ News Letter March 1920.

The following list of personnel shows the effect of the many resignations:

A. A. Chambers	July 1 - 31, 1919
C. H. Kidwell	July 1, 1919 to May 18, 1920
Miss Margaret D. Foster	July 1, 1919 to June 30, 1928
Miss Addie T. Geiger	July 1 to Oct. 9, 1919
Nathaniel Fuchs	Sept. 22 to Dec. 31, 1919
H. B. Riffenburg	May 29, 1920 to June 30, 1925
C. S. Howard	June 14, 1920 to June 30, 1928
W. D. Collins	July 10, 1920 to June 30, 1928
S. K. Love	June 22 - 30, 1928

The work of the Division was carried on almost entirely by means of the Survey allotments, which were:

1920	$ 7,850	1923	$13,000	1926	$11,350
1921	13,000	1924	13,500	1927	12,000
1922	14,000	1925	14,400	1928	12,600

The only state cooperation listed in the Director's Annual Reports was that with Florida in the amount of $1800 during 1924. Concerning this cooperation Collins writes:344/

344/ Letter to author.

> The cooperation * * * was entirely informal and involved no definite amount of funds. * * * Arrangements were made with the State Board of Health which collected the samples and paid for their transportation to Washington.

Division of Power Resources

The work of collecting and publishing monthly and annual reports of the production of electricity and consumption of fuel by public utility plants, started by the Survey in January 1919,345/ continued during the

345/ Follansbee, Robt., Hist. - - - p. 450.

period and was the chief activity of the Division of Power Resources. Classed as public utility plants were central stations, municipal plants, electric railway plants, plants operated by steam railroads generating electricity for traction, Bureau of Reclamation plants, and manufacturing plants which sold a portion of their power output for public use.

While the work was being carried on by the Fuel Administration during the World War weekly reports had been received from public utility power companies, but when the work was taken over by the Survey monthly reports only were requested. At that time reports of output were requested of all public utility companies irrespective of size of plants. The total number of plants of all sizes was about 5,600. It was soon discovered that many small plants were so slow in making reports that prompt publication of the monthly reports was impossible. An analysis of the output of plants having a capacity of 100 kilowatts or less showed that their total output was less than 0.25 percent of the total. A monthly output of 10,000 kilowatt-hours was considered equivalent to a capacity of 100 kilowatts and plants of lesser capacity were eliminated, reducing the list of reporting plants to about 4,300 at the beginning of the monthly publication of reports in 1920.346/ The absorption of

346/ U. S. Geol. Survey Water-Supply Paper 579, p. 121.

municipal plants by public utility companies, consolidation of companies and the abandonment of small and obsolete plants, replaced by larger and more efficient plants, gradually reduced the number of plants until in 1928 some 1,800 companies were operating about 3,700 plants.

The publication of the monthly reports of output began in 1919. Reports for that year were published for February, March, April, July, September, and October, and for each month beginning with January 1920. The relatively small output was estimated for those plants on the list whose reports were late, so the figures as published represented the output of all plants requested to report. The monthly reports included separately by States the kilowatt-hour output by the use of water power

and by the use of fuels, also the consumption of coal, fuel oil, and natural gas, expressed in the usual units.

Each monthly report contained the figures for three consecutive months. Therefore, the figures for each month were published three times, permitting revisions by the substitution of actual reports for the estimated figures for those plants whose reports were not at hand when the monthly figures were first published. For comparative purposes the total output each month was compared with that for the corresponding month of the previous year and brief comments were made as to the monthly trend in output and the relative output by the use of water power. Yearly summaries of the monthly figures were published as an annual report, which permitted a final revision of the monthly figures of output. The monthly reports were mimeographed and about 1,300 copies distributed to individuals, companies, and financial and other newspapers. The annual reports were sent to all companies which had furnished records of output and fuel consumption of their plants.

The publication of each annual report was advertised by a press bulletin distributed to newspapers. In these bulletins special attention was directed to the improvement in the efficiency in the use of fuels in generating electricity for public use. From 1919 to 1929 the average consumption of coal and the coal equivalent of oil and gas per kilowatt-hour decreased from 3.2 pounds to 1.69 pounds, a reduction of nearly 50 percent. It is considered that the marked increase each year following 1920 in the average fuel efficiency in generating electricity by public-utility power plants was to a considerable extent brought about by the publication and comment on the annual improvement in efficiency and resulted in substantial savings in fuel resources and in the reduction of millions of dollars in the cost of fuel for generating electricity.

The growth of the electric power industry during this period is shown by the 100 percent increase in total output from 43,600,000,000 kilowatt-hours in 1920 to 87,800,000,000 in 1928. During these years the development of water power by public utility companies kept pace with the total power development, as the output of electricity by the use of water power maintained its relative position during this period of rapid increase of power production.

Since the Survey's first census of developed water power in 1908 no attempt had been made to keep this information up to date. In 1921 the Division of Power Resources started the compilation of the amount of developed water power in the United States. The district engineers were requested to obtain information relative to each developed water-power plant of 100 horsepower capacity or greater in their districts on forms which had been prepared. States in which no stream gaging was being conducted were assigned to the nearest district office in order that the entire country would be covered. These lists were kept up to date and press notices giving the installed capacity by States were issued in November 1921 and yearly beginning with 1924. In 1924 the estimate of potential water power made in 1908 was revised on the basis of more adequate stream-flow data, additional topographic maps, river surveys, and special power investigations made by other Branches of the Survey. The figures represented 24-hour power available 90 percent and 50 percent of the time with an over-all efficiency of 70 percent at the sites.

In 1919 the preparation of maps by States on the Survey's base maps of 1:500,000 scale, showing the location of power plants and transmission lines used in public service, was started and continued to 1921, when this work was discontinued for lack of funds for that purpose. Maps were prepared and published as of the year indicated for the States of New York (1919), Pennsylvania (1920), Massachusetts-Rhode Island-Connecticut (1919), New Jersey (1920), Vermont-New Hampshire (1919), Maryland-Delaware-District of Columbia (1920), Virginia (1921), Indiana (1921), Maine (1919), West Virginia (1921), and Kentucky (1921).

A. H. Horton became chief of the Division July 1, 1919, and continued throughout the period. Other members of the Division were:

G. D. Thomas	July 1, 1919 to June 30, 1921
A. D. Morehouse	Sept. 2, 1920 to June 30, 1921
J. T. Moore, Jr.	January to June 30, 1921
Miss B. B. Borst	July 1, 1919 to June 30, 1928
Miss H. G. Broughton	July 1, 1919 to June 30, 1928
Mrs. M. M. Allen	Aug. 24, 1920 to June 30, 1921
Miss J. B. Harden	Aug. 18, 1919 to June 20, 1921
Miss E. M. Klemm	July 1, 1919 to Oct. 7, 1920
Miss M. S. Baker	June 21, 1920 to June 30, 1921
Miss H. L. C. Connolly	Apr. 1, 1920 to July 22, 1922
Mrs. L. F. Havell	May 24, 1920 to Sept. 16, 1923
Miss L. M. Wiltshire	July 1, 1919 to Oct. 7, 1920

The annual allotments to the Division were:

1920	$14,000	1923	$8,500	1926	$7,700
1921	25,000 1/	1924	7,000	1927	4,455
1922	10,000	1925	7,700	1928	4,500

1/ Allotment included in that for the Superpower Survey.

Division of Land-Classification Investigations

Field investigations required in the classification of the public lands for designation under the enlarged and stock-raising homestead acts, which had been started in 1917,[347] continued as the chief activity

347/ Follansbee, Robt., Hist. of - - - p. 445.

of the Division of Enlarged and Stock-Raising Homesteads with H. C. Cloudman as chief during the first year of the period. Beginning with the fiscal year 1921 a general appropriation for the classification of the public lands under the various acts (including those for the homestead entries) was made by Congress and, as the urgency for the examinations of lands for designation under the enlarged and stock-raising homesteads had been met in large measure, the chief activity of the Division became the examination of lands under the various water-power and irrigation acts. Private interest in water power was increasing rapidly as a result of the enactment of the water-power act, while interest in irrigation was decreasing. Consequently the chief work was concerned with water power. Less attention was paid to the homestead acts and the number of land classifiers employed was greatly reduced. Cloudman resigned on Jan. 30, 1922, and thereafter Nathan C. Grover took direct charge of the Division. He changed its name to that of land-classification investigations, as being more descriptive of its activities.

The functions of the Land Classification Branch (the name having been changed from Board to Branch Nov. 25, 1922),[348] were greatly en-

348/ The alleged reason for the change was that boards are often narrow and wooden, while branches are alive and growing.

larged by the addition of the Mineral-Leasing Division of the Bureau of Mines, which was transferred to the Survey by executive order of June 4, 1925, and on July 1, 1925, the name of the enlarged branch was changed to the Conservation Branch. Theretofore the Land Classification Branch had been strictly an office organization, as Director George Otis Smith had insisted that the necessary field work should be performed by other appropriate branches of the Survey. The new duties, however, required field work which could best be performed by the trained personnel of the Mineral-Leasing Division, and thereafter the Director was willing to have the Conservation Branch perform a part of its own field work. Major field investigations for classification purposes, however, were still performed by the appropriate branches. On June 1, 1925, homestead classifiers were transferred to the Land Classification Branch though their field work was performed under the auspices of the Water Resources Branch for about 6 months longer. Then all work of examining public land for uses other than water power and irrigation was taken over by the Conservation Branch. At that time the number of homestead classifiers had been reduced from 32 in 1919 to 9.

During these years a change was made in the chief of the Land Classification Branch. W. C. Mendenhall, who had been chief since Jan. 1, 1911, was made Chief Geologist of the Geologic Branch on Nov. 16, 1922. He was succeeded as Chief of the Land Classification Branch by

Herman Stabler, his principal assistant, and one-time acting chief of the Quality of Water Division (May - July 1920).

Field work of classifying the public lands for water power and irrigation and the preparation of the necessary reports, which had been performed by the old Water-Utilization Division, had been continued on a limited scale during the years when the classification of lands under the homestead acts was the chief activity. Field work in connection with water power and irrigation became the sole function of the Division after about Jan. 1, 1926. Heretofore, all field work, whether performed by members of the Water Resources Branch or of the Conservation Branch, had been under the direction of the chief of the Division and had all been here considered as members of the Division. During the remainder of the period, however, the members of the Conservation Branch were not detailed to the Division but operated under the supervision of the Conservation Branch although engaged in work similar to that continued by the Division. At that time E. C. LaRue, R. R. Woolley, E. E. Jones, W. N. White, and E. C. Murphy constituted the field personnel of the Division. LaRue resigned on July 25, 1927, and White was transferred to the Ground-Water Division on June 16, 1925. Murphy was retired Oct. 16, 1926, leaving Woolley and E. E. Jones the sole engineering representatives of the Division at the end of the period.

Funds for the Division were allotted by the Conservation Branch or its predecessor, the Land Classification Branch, as follows:

1920	$118,500	1923	$67,869[1]	1926	$55,918[1]
1921	106,000	1924	71,427[1]	1927	41,898[1]
1922	95,500	1925	75,233[1]	1928	22,633[1]

1/ Actual expenditures.

The only water-power work during the first year of the period was performed by E. C. LaRue, who devoted his entire time to it, and by R. R. Woolley and E. E. Jones, who had entered the Survey soon after the organization of the Division of Enlarged and Stock-Raising Homesteads, and they divided their time between water-power and enlarged-homestead work. LaRue was detailed to make a power-site examination of the Oregon and California Railroad grant lands and those granted to the Coos Bay Wagon Road, both of which had reverted to the United States and were located in the Coos Bay region of western Oregon. The General Land Office made $2,000 available for this examination. Woolley was engaged on the examination of homestead and power-site lands in Idaho, Utah, Nevada, and Arizona. E. E. Jones performed similar duties in Wyoming and Colorado.

As an aid to the field work in investigating water-power sites, the Land Classification Board, in July 1920, when the general appropriation became available, arranged with the Topographic Branch to finance river surveys. The Topographic Branch had been making, by means of its own funds, river surveys since 1911 when the work was started in the State of Washington. To bring out the necessary hydraulic features these surveys had been based on recommendations of the district

engineer in whose district the work was performed. Under the arrangements made by the Land Classification Board in 1920 the Topographic Branch furnished the services of a topographer and necessary equipment for each survey party, and the Land Classification Board made an allotment to pay all expenses. The Division of Enlarged and Stock-Raising Homesteads furnished a hydraulic engineer to designate the dam and reservoir sites to be surveyed in detail. The streams surveyed under this arrangement were sufficiently large to require transportation by boats, and each party, except that for the Colorado River during 1923, consisted of a topographer as chief of party, two or three boatmen and rodmen, and, in some respects the most important, a cook, in addition to the hydraulic engineer. Mapping was done by plane-table and stadia on a scale of 2 inches to the mile, with 5-foot contours on water and, in general, 20-foot contours on land, except on the Colorado River, where 50-foot land contours were used. Main-line levels were made by direct level readings for all turning points and checks for elevation were made wherever bench marks were available. Side traverses were made at all places which could not be covered from one setup on the main line. Allotments for these surveys were made through the fiscal year 1927, when the gradual reduction in the appropriation for the Conservation Branch became so great that it was necessary to discontinue them.

The first river survey under this arrangement was made during 1920. It covered the Snake River between Huntington, Oreg., and Lewiston, Ida., a distance of 188 miles, and W. G. Hoyt, who had recently been transferred from the Madison district, was hydraulic engineer. In 1921 a survey was made of the Colorado River from the mouth of the Green River to Lees Ferry (216 miles), one of the San Juan from Bluff, Utah, to its mouth (133 miles). These 1921 surveys were made in cooperation with the Southern California Edison Co., but as LaRue was attached to them as hydraulic engineer, it is considered an activity of the Division.

The years 1922 to 1924 constituted the most active period of these surveys. In 1922 a reconnaissance of the Colorado River from Halls Crossing to Lees Ferry, a distance of 120 miles, was made with LaRue responsible for the hydraulic features; of the Green River from Green River, Wyo., to Green River, Utah, 387 miles, and Blacks Fork in Wyoming for a distance of 23 miles above its mouth, with Woolley as hydraulic engineer; and of the Yampa River in Colorado from Morgan Gulch to its mouth, 111 miles, in cooperation with the Utah Power & Light Co., with Warren Oakey as hydraulic engineer. River surveys made during 1923 included the extension of the 1921 Colorado River survey to the mouth of the Grand Canyon, 24 miles above Pierce Ferry, 253 miles, with LaRue as hydraulic engineer; of the Rogue River and tributaries in Oregon, 341 miles, in cooperation with The California Oregon Power Co. with B. E. Jones and Warren Oakey as hydraulic engineers; of the Klamath River from the extension of a previous survey near Scott River to Keno, 88 miles, with G. F. Holbrook as hydraulic engineer; and of streams in the Uinta Basin, Utah, with Woolley as hydraulic engineer. These latter surveys were continued during 1924 and a total length of rivers surveyed in that year was 154 miles. Other surveys during 1924 were the Payette River and South Fork of Payette River in Idaho, a total distance of 125 miles, with W. H. Hoyt as hydraulic engineer; of the Clearwater River and tributaries in Idaho, about 400 miles, with Oakey as hydraulic engineer; and of the Umpqua

River in Oregon, 44 miles, with B. E. Jones as hydraulic engineer, and South Fork of Coquille River in Oregon, 46 miles, with W. G. Hoyt as hydraulic engineer. Supplementing the Colorado River survey, made in 1923, an examination and survey of promising dam sites, a 100-mile section of the Colorado from 10 miles above Pierce Ferry to the Eldorado dam site was made. As was usual with Colorado River surveys, LaRue was detailed to this survey.

The survey of the Colorado River during 1923 was made by a party considerably larger than the other river parties, owing to the length of the survey and the difficulties to be encountered as it would be through the most inaccessible region of the country. As it was the outstanding river survey a description of it is warranted. The interest in the development of the lower Colorado River, stimulated by the Colorado River Compact, made it advisable to make an actual survey of the canyon section from Lees Ferry to a point near the mouth of the Grand Canyon, a distance of 253 miles, and there connect with a survey made for the Reclamation Service in 1920. This was the only unsurveyed section of the river as well as the section having the greatest power possibilities. The great depth of the canyons and steepness of the walls made the river inaccessible except at a few points. The only means by which it could be surveyed was by boats and the heavy fall of the river concentrated in many rapids made the undertaking a hazardous one. Powell had made two reconnaissance trips through all or part of this section in 1869 and 1871-72,[349] but no real survey had ever been

[349] Follansbee, Robt., Hist. of - - - pp. 12, 13.

made.

It was therefore decided in 1923 to survey this section, and C. H. Birdseye, chief of the Topographic Branch, took personal charge of the project. LaRue, who more than anyone else had been concerned with surveys on Colorado River, was the hydraulic engineer. Birdseye organized a party consisting of R. W. Burchard, topographer, R. C. Moore of the University of Kansas, geologist, E. C. Kolb, head boatman, L. R. Freeman, Leigh Lint, and R. E. Blake, Jr., boatmen, F. B. Dodge, rodman, and Frank Word (Lees Ferry to Supai Creek) and Felix Koms (Supai Creek to Needles), cooks. Four Colorado River-type boats, decked over except for a cockpit in the center for the oarsman, were provided, one being constructed by the Survey. The party was equipped with a special radio receiving set and arrangements were made with the Los Angeles Times to broadcast items of special interest to the party which would otherwise be out of touch with the world for weeks at a time. Pack trains with supplies were to meet the party at the few accessible points. These pack trains and the furnishing of supplies were in charge of Roger Birdseye, a cousin of C. H. Birdseye. Herman Stabler, who as chief of the Land Classification Branch initiated the survey, prepared a guiding memorandum containing all known facts regarding various rapids and the distances between them.

The party left Lees Ferry August 1, 1923, picking up the 1921 survey which had been made from the mouth of Green River to that point. The survey was carried through the canyon sections without serious mishap, and reached the mouth of the Grand Canyon October 16, where it was connected with the survey brought to that point in 1920. The closing level error was 4 feet in 253 miles, which was remarkable considering the great difficulties under which the survey was made. At Bright Angel Trail the party was joined by Herman Stabler, who accompanied it to Needles, about 200 miles downstream from the mouth of the Grand Canyon, where the party disbanded October 20. The Survey's boat was shipped to Washington where it was placed on exhibition in front of the Interior Building, and later deposited with the Smithsonian Institution. Dam sites were surveyed and sufficient information was obtained to show the feasibility of a comprehensive plan of development of the entire canyon section by a series of dams and reservoirs which would also control the floods.

By means of the radio the party was kept informed of world events and received the news of President Harding's death 45 minutes after it occurred. One day's rest was observed out of respect to his memory. When the party reached the supply train at Hance Trail word of the safe arrival at that point was sent out, and later the party heard that message broadcast, as great interest in the survey had been shown throughout the country. Apprehension was felt when it was known that a severe flood, originating on the Colorado River, would overtake the party on the main river, and warnings were broadcast to it. These warnings were not received as the party's radio was temporarily out of commission, and the party was caught at one of the most precipitous rapids. The flood came in the evening, the first warning being the very rapid rise, which amounted to 21 feet in 24 hours. Fortunately, the party was able to drag its equipment far enough up the canyon sides to escape. The flood gave the party a three-day rest in what was termed the finest camping place in the canyon. The only spectators which the party had was at Grand Canyon, where a "gallery" composed of the guests at El Tovar watched them traverse Hermit Creek Rapid, the only large rapid in that section. A commercial news reel was prepared from moving pictures taken on the river in the vicinity of El Tovar.

Lewis R. Freeman, an author attached to the party as boatman, wrote an interesting account of the party's experiences, which was published in the National Geographic Magazine, May 1924.

Beginning in 1925 the practice of detailing hydraulic engineers to the topographic parties was discontinued as the large rivers had been surveyed and hydraulic engineers were not needed to work on the smaller streams. As later field work on some of the streams so surveyed was performed by members of the Division a list of these surveys follows. During the years 1925 to 1927 the following streams were surveyed: Clark Fork in Idaho, Crooked, McKenzie, Siletz, East Fork of Coquille, and Middle Fork of Willamette Rivers in Oregon, San Raphael River in Utah, and the North and South Forks of Stilaguamish River in Washington.

In addition to the surveys made by the Topographic Branch, which were chiefly of streams having sufficient size to require transportation by boat, reconnaissance surveys of smaller streams which in general did not require such transportation were made by the Division, generally with 2-man parties. In 1920 LaRue investigated streams in northwestern California, and E. E. Jones, streams in Colorado. These, however, were not surveys of continuous stretches of the streams, but only of those sections having the greatest power value.

In 1921 a survey requiring boat transportation on the Big Horn River was made by B. E. Jones and David J. Guy, the latter detailed by the Federal Power Commission. The Commission had received an application to develop power by means of a storage reservoir in the Big Horn Canyon in Wyoming and Montana. This canyon is inaccessible except by boats as the river fills the gorge which has precipitous sides from 1000 to 1500 feet high. Through this canyon the Big Horn River falls 450 feet in 50 miles. B. E. Jones had two flat boats built at Lovell, each boat sufficiently large to carry two persons and the necessary provisions and equipment. The boats were transported to the river by trucks and the party started their trip at Kane early in August, accompanied by two boatmen. The heavy fall through the canyon and the many large boulders in the channel made the trip a hazardous one. One boat was capsized and a portion of the provisions lost, but the factor of safety employed in purchasing provisions had been sufficiently large to provide for the remainder of the trip in spite of the loss. The trip lasted 10 days during which a reconnaissance of dam sites was made.

Beginning in 1921 E. E. Jones devoted most of his time to the reconnaissance surveys of continuous stretches of several streams and that year covered the Arkansas River in Colorado from its headwaters near Leadville to Canon City. The next year he surveyed the South Platte River in Colorado. In 1923 he made a short survey of Encampment River, Wyoming, and in 1924 surveyed the Taylor, Gunnison, Blue, Roaring Fork, Eagle, Dolores, and San Miguel Rivers in Colorado. From 1925 to 1928 he investigated the streams draining the Olympic Range in Washington and some other streams in that State. J. F. Deeds and W. N. White, in 1923, surveyed the upper Missouri River and principal tributaries in Montana for both power and irrigation and that same year W. G. Hoyt investigated various streams in Wyoming and Idaho for power and irrigation. In 1925 he investigated streams in Idaho. That same year LaRue and Holbrook made surveys of streams in the San Juan River Basin in Colorado, New Mexico, and Utah, paying particular attention to the possibilities of water-power development.

The first investigations were concerned with specific power-site withdrawals, but with the increasing interest in water power, the scope of the work was expanded to cover a plan of power development for the entire stretch studied of each river. Such a plan[350]

350/ U. S. Geol. Survey Water-Supply Paper 636f, p. 223.

> must be regarded as tentative in detail and subject to modification in the light of further and more intensive studies made as a preliminary to construction, such a tentative plan can be used with assurance as a basis for estimating the potential power of the river, for locating the principal concentrations of potential power, and for guiding further studies undertaken for the purposes of actual development.

In the later investigations in Oregon geologic examinations of the proposed dam and reservoir sites were made by H. T. Stearns of the Division of Ground Water.

Reports on the power resources of the streams investigated were prepared primarily for use of the Conservation Branch in classifying the public lands involved, but also to aid development. To make the information available to the public it was deemed advisable to publish many of them. This was done either by publishing them as water-supply papers, or by filing in the nearest district office a copy for public use. The reports generally contained data on geography, geology, physiography, water supply, river control, water-power sites, and market for power.[351]

351/ Op. cit.

The published reports were: Water utilization in the Snake River Basin, by W. G. Hoyt;[352] Water-power resources of Umpqua River, Oreg., by B. E.

352/ U. S. Geol. Survey Water-Supply Paper 657.

Jones and H. T. Stearns;[353] Water-power resources of the McKenzie River

353/ U. S. Geol. Survey Water-Supply Paper 636f.

and its tributaries, Oreg., by B. E. Jones and H. T. Stearns;[354] Water-

354/ U. S. Geol. Survey Water-Supply Paper 637c.

power resources of the Rogue River Drainage Basin, Oreg., by B. E. Jones, Warren Oakey, and H. T. Stearns;[355] Water power and irrigation in the

355/ U. S. Geol. Survey Water-Supply Paper 638b.

Madison River Basin, Mont.,[356] and Water power and irrigation in the

356/ U. S. Geol. Survey Water-Supply Paper 560a.

Jefferson River Basin, Mont.,[357] both by J. F. Deeds and W. N. White;

357/ U. S. Geol. Survey Water-Supply Paper 580b.

Water power of Great Salt Lake Basin, by R. R. Woolley;[358] The Green River

358/ U S. Geol. Survey Water-Supply Paper 517.

and its utilization by R. R. Woolley;[359] and lastly, Water power and flood control of Colorado River below Green River, by E. C. LaRue.[360]

359/ U. S. Geol. Survey Water-Supply Paper 618.

360/ U. S. Geol. Survey Water-Supply Paper 556.

This latter was by far the most comprehensive of all the reports and represented the culmination of LaRue's many years' study of the Colorado River and its problems. So important did the flood-control features appear that Secretary Work wrote a foreword to the report, stressing that phase of the problem.

LaRue's report covered the lower Colorado River and Woolley's report the Green River. To complete the studies in the Colorado River Basin, the writer was requested to prepare a report on the Upper Colorado River which included a precipitation map and was published as Water-Supply Paper 617. As practically no precipitation records except snow-scale readings were available for the higher elevations where the precipitation is highest, it was necessary to compute that precipitation by adding to the known runoff in depth in inches, 15 inches to represent the losses between precipitation and runoff. Each drainage area was analyzed by percentages between each 1000-foot contour and the mean computed precipitation for the area varied according to that analysis.

Another activity supervised by the Division of Land-Classification Investigations pertained to those Federal Power Commission investigations which were referred to the Conservation Branch. These in turn were referred for examination and report to the district engineer in whose district the prospective development was located.

Superpower Survey

Although the superpower survey was made by a special group of engineers organized for that purpose, and recruited largely outside the Survey, the work was administered as a unit of the Branch. The only Federal funds for the work were provided by an item in the Survey's appropriation. Grover was a member of the superpower survey's engineering staff.

The economic value of interconnecting power plants to form large systems, with resulting lower costs of operation through higher effieiency, had long been recognized by the electric power industry, but the popular fear that such interconnection would lead to power monopoly had tended to delay such procedure and to prevent it from becoming widespread. In order to meet the power shortage during the war, emergency interconnections were made in some instances which fully demonstrated the economies that could be obtained, and the public realized dimly that the economic value of interconnected power systems might outweigh the dangers of monopoly.[361]

361/ Letter from George Otis Smith to the author.

In December 1918 W. Spencer Murray, a consulting engineer of New York City, urged on Director Smith and Secretary Lane a survey of power sources in New England and along the Atlantic seaboard as far south as Washington, in order that what he called a superpower system for that region might be designed. In January 1919 the Secretary sent to Congress a recommendation for $200,000 to make this survey during the fiscal year 1920. As the Geological Survey, through the Division of Power Resources of the Water Resources Branch, was already making a statistical study of the country's power resources, it was the logical bureau of the Interior Department for administering such a study. Although the Appropriations Committee of the House held hearings on this item, during which considerable interest was shown, this interest was not sufficiently evident to immediate action.

During 1919 the subject was presented before engineering, trade, and commercial organizations, and American Engineering Council appointed a committee of eminent engineers, of which Murray was chairman, to advocate the project before the Appropriations Committees at the next session of Congress. The interest so aroused, brought about an appropriation of $125,000 to the Survey for use during the fiscal year 1921.362/

362/ Sundry civil act.

> For the survey of power production and distribution in the United States, including the study of methods for the further utilization of water power, and the special investigation of the possible economy of fuel, labor, and materials resulting from the use in the Boston-Washington industrial region of a comprehensive system for the generation and distribution of electricity to transportation lines and industries, and the preparation of reports thereon, $125,000. The Secretary of the Interior is authorized to receive any sums which may be contributed for this purpose. Such sums shall be deposited in the Treasury and credited to the appropriation herein made and be available for expenditure for the purposes thereof.

For the completion of the entire investigation, an additional $26,000 was needed and this was contributed by public utilities and manufacturers within the region of the study which contained 22 percent of the country's population and produced 24 percent of the electrical power that was generated by public utility plants.363/

363/ News Letter Sept. 24, 1920.

Murray was made director of the superpower study and he selected an engineering staff of assistants which had its headquarters in New York City. As the power market to be served would be furnished by the electric utilities, railroads, and various industrial establishments, three division engineers were appointed to head the divisions of power and transmission, railroads, and industries. Grover was detailed for advisory service on the engineering staff of which Director Smith was an active member. An advisory board of 13 members representing the several interests affected was also appointed. The division engineers

had eight assistants whose duties were, as Murray said,[364] so shifted

364/ Murray, W. S. and others, A superpower system for the region between Boston and Washington: U. S. Geol. Survey Prof. Paper 123, p. 27.

as to maintain the highest engineering load factor in the work. Among these assistants was B. J. Peterson, who was detailed from the Washington office. In addition there were 20 experts who, realizing the national importance of the problem, contributed their experience to the fullest practicable extent. The study required data from the leading prospective users of the superpower system, and Murray listed 149 engineers and business men who were contacted and furnished the desired information. Among these, A. H. Horton as chief of the Division of Power Resources, furnished a list of the public electrical power companies in the superpower zone. To carry out the survey of power production and distribution as specified in the appropriation, $25,000 was allotted to the Division of Power Resources.

The conclusion reached at the end of the survey, which was terminated June 30, 1921, was that by 1930 the proposed coordinated power system could supply electrical energy at an annual cost of $239,000,000 less than by the uncoordinated system in use at that time. The results of the study were published by the Geological Survey.[365] Although the

365/ Prof. Paper 123.

proposed superpower system did not materialize at once, it developed more rapidly than was anticipated. The economies of large systems demonstrated by the study undoubtedly promoted the movement toward consolidation of small systems into larger ones; many of its recommendations were adopted; superpower stations were constructed and interconnected; and the movement gained remarkable headway during the nineteen-twenties.

Evaluation of the Period
by
Nathan C. Grover

The years 1919 to 1928, called by Mr. Follansbee "years of increasing cooperation", constituted a period of great discouragement because of the progressive dwindling of Federal appropriations for the work of the Water Resources Branch, representing an apparent (but certainly not real) lack of appreciation of its value in both the Bureau of the Budget and the Houses of Congress. The progressive cutting of appropriations that was, of course, also taking place throughout the whole Federal service, was explainable on the grounds of an economy that was planned in a drastic program to reduce the public debt and so was not an attack on any one appropriation item. However, explanations, though valid and understandable, do not serve to offset the depressing effects of gradual reductions in appropriated funds.

Instead of stressing this discouraging phase of the period, Mr. Follansbee has properly selected the more encouraging aspect and has emphasized the gradual and encouraging increase in cooperation throughout Federal, State and municipal services, and contributions by individuals and private organizations that was truly representative of an appreciation of the value of the work among all water users. The increasing support received by cooperation and contribution served two very important purposes: (a) the increases in cooperative and contributed funds exceeded the decreases in the Federal appropriations and so served to keep the Branch growing not only in funds and activities but also in personnel, and (b) the group of experienced engineers was thereby generally held intact and its excellent morale maintained. These great values should not be overlooked, since they constitute, in my opinion, one of the conspicuous aspects of the period. In future years the Survey personnel should not forget the debt they owe to the cooperating State, municipal and Federal agencies, and contributing individuals and private organizations that carried the Branch through this period which, otherwise, would almost certainly have so curtailed and enfeebled the organization that it could not have carried with relative ease and success the greatly expanded program of subsequent years.

The increased cooperation had other values also. It brought new and important problems. It opened up the international contacts along both the Canadian and Mexican borders with the wide diversity in problems arising between the United States and its northern and southern neighbors. It led to consideration of the economics of agriculture by irrigation and of the industrial uses of power; to realization of the importance of water in the generation of steam power as well as of water power; to recognition of the problems of water pollution by industrial plants and municipalities and of the steps taken to control pollution in order that the essential purity of the surface and ground waters shall be preserved as a valued heritage of future generations; to consideration of the problems of flood and erosion control whether by vegetal cover, levees or reservoirs; and to the necessity of reliable and continuing records of water as it constantly moves, constantly varies in quantity and quality, and constantly controls the activities of man along all lines and in all parts of the country.

With the growth in cooperative efforts new problems have been solved. Of these, the development of successful methods for evaluating the recharge and perennial yield of ground-water sources and the improvement in instruments and equipment for measuring the discharge of large rivers are, perhaps, outstanding among many developments and improvements. I would place first, however, at all times and under all circumstances, the improvements in personnel, because, in the final analysis, it is the personnel that counts for most and is of the greatest significance in any organization. Improvements in instruments, equipment and methods, important though they always are, have no great or lasting value without a wide-awake, well-trained, mature and scientifically sound personnel.

To me, therefore, this period is chiefly notable for the maturing of a carefully-selected, well-organized, well-trained personnel whose guiding star was and is the unbiased collection and recording of facts related to the quantity, chemical quality and utility of surface and ground waters in relation to the many problems of their control and utilization.