A HISTORY

OF THE

Water Resources Branch

OF THE

United States Geological Survey

VOLUME 3
YEARS OF 50-50 COOPERATION

JULY 1, 1928 TO JUNE 30, 1939

BY

ROBERT FOLLANSBEE

WATER RESOURCES DIVISION
REPORTS SECTION

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It has appeared fitting that just as the first volume was dedicated to the founder of the Branch, Frederick H. Newell, so the present volume should be dedicated to the head of the Branch from 1913 to 1939, covering the period of its great expansion, Mr. Grover. It further appeared fitting that the dedicatory notice be prepared by Mr. Grover's successor, C. G. Paulsen.

Denver, Colorado
March 22, 1944

YEARS OF 50-50 COOPERATION (1928-1939)

The 11-year period from July 1, 1928, to June 30, 1939, was one of violent contrasts, both natural and man-made; great floods and severe droughts occurred, and great industrial activity was succeeded by deep and persistent depression which droughts made even more devastating. It spans the time from the first year of 50-50 cooperation with the States, to the last year that Nathan C. Grover was Chief of the Branch.

The 50-50 cooperation with States increased both the Survey funds available for cooperation, and the State funds provided for water-resources investigations, and brought every State but three into the various cooperative programs. In addition, other Federal funds became available to the Survey in large amounts. At the end of the previous period, the Army Engineers had begun their "308" investigations which required many additional gaging stations, and a major part of those additional stations were established and maintained by the Survey by means of Army Engineer funds. However, many of this group of stations were abandoned within a few years when the "308" reports had been completed. Thereafter, Army Engineer cooperation continued on a reduced scale until 1937, when the passage of the first Flood Control Act resulted in another increase in cooperation which continued during the remainder of the period.

The most important additions to the Federal funds resulted from the efforts of the Franklin D. Roosevelt Administration to furnish employment during the years of depression. Soon after that Administration came into office, on March 4, 1933, Congress passed the National Industrial Recovery Act, which created the Public Works Administration and provided it with funds to carry out the purposes of the Act. The natural resources were studied and allotments of Federal funds were made which enabled the Survey to rehabilitate many of its gaging stations and establish additional stations. Cooperation with the newly-created Tennessee Valley Authority which took over much of the work of the Army Engineers in the Tennessee River Basin, expanded materially the stream-gaging program in that basin. The Department of State allotted very considerable amounts for the operation of gaging stations on the Rio Grande and of international gaging stations along the Canadian border. Other Federal agencies cooperated to a lesser extent. The average amount allotted annually during the period by the various Federal agencies was about $500,000.

Branch funds from all sources increased from $1,044,000 in 1929, to $3,063,000 in 1939. Branch personnel increased from 154 to 513. During this period President Hoover drafted Director Smith to be chairman of the reorganized Federal Power Commission, and W. C. Mendenhall, chief of the Geologic Branch, succeeded him as Acting Director, and later, on December 22, 1930, as Director.

For the Division of Surface Water, the period was one of great activity, and the stream-gaging program was expanded to cover more intensively all sections of the country. Practically every State cooperated in that expanded program and the number of gaging stations was increased from 1,830 to 4,164, of which 3,000 were equipped with water-stage recorders. The establishment of gaging stations on large rivers brought about the development of heavy equipment needed for their measurement.

The Division of Ground Water experienced a greater relative expansion than any other division, due chiefly to greatly increased State cooperation brought about largely by the drought years which emphasized the

importance of knowledge of ground-water supplies. At the beginning of the period 8 States and counties were cooperating with the Survey in ground-water work, and by 1939 the number had increased to 26. The nation-wide program of observation wells was started, the records from which were of great assistance in determining the perennial yield from ground-water basins. The technical personnel of the division increased from 14 to 49.

GENERAL ORGANIZATION

The general organization of the Branch continued the same as in the previous period and included the Division of Surface Water, Division of Ground Water, Division of Quality of Water, and Division of Power Resources. In addition, the Division of Water Utilization, which had passed out of the picture in the spring of 1917, 1/ reappeared about

1/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 445.

March 1, 1931, and was formally recognized in August 1931 when the Director requested the Secretary's office to include it in the authorized divisions of the Branch. 2/

2/ Letter to author from Acting Director, Aug. 7, 1931.

Nathan C. Grover was chief of the Branch until his retirement January 31, 1939, at which time C. G. Paulsen became acting chief. The great expansion of the Branch made necessary an increase in the administrative personnel, and Henry F. Hill, Jr. became administrative assistant on August 15, 1930. J. C. Hoyt became technical adviser to the Branch on December 18, 1931, and C. H. Pierce was reinstated in the Survey on May 1, 1931, for the purpose of preparing or revising various technical reports. Miss Marian J. Dickman was chief clerk until her resignation on December 31, 1929. She was succeeded by Miss Helen Kiesel whose assignment in that position was effective on January 17, 1930.

J. C. Hoyt was chief of the Division of Surface Water until December 17, 1930. C. G. Paulsen succeeded him on March 16, 1931. O. E. Meinzer was chief of the Division of Ground Water, W. D. Collins chief of the Division of Quality of Water, A. H. Horton chief of the Division of Power Resources, and R. W. Davenport chief of the Division of Water Utilization.

APPROPRIATIONS

During the period Congress recognized for the first time the principle of 50-50 cooperation with States and municipalities, although during a considerable part of the time the recognition was in principle only, as the funds appropriated were insufficient to meet cooperative offerings fully on that basis. During the middle years of the period this failure was due very largely to the severe depression when the Bureau of the Budget and the committees of Congress did not believe that the States and municipalities would offer as great an aggregate amount as was estimated by the Branch. Another reason for the failure to provide fully for cooperation, particularly during the later years, was the rapid increase in State cooperation offered, an increase so rapid that the State funds actually available during the fiscal year were greater than the

amounts that had been estimated by State officials when the Budget and Committee hearings on the appropriation for each year were in progress. It was no longer necessary to educate Congress as to the value of the records of water because that value was now recognized by everyone, but the difficulty related to the obtaining of sufficient funds to meet fully the State offerings. During the previous period the failure to obtain increased appropriations had apparently been due to the failure of the Budget Bureau to evaluate accurately the probable offerings and especially the attitude of Congress with respect to 50-50 cooperation. But during the present period, following the recognition by Congress of the 50-50 principle, the Budget Bureau estimated amounts annually which were substantially in accord with that principle, and with Congressional policy and actions.

The Director's recommendation in his annual report for 1927 that the Government should recognize the 50-50 principle, 3/ doubtless had

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3/ p. 7, 1919-1928.

Secretarial sanction, and the appropriation bill for 1929, hearings on which were held a few months later, showed the effect of such recommendation, backed up by the representations of cooperating State officials and engineering organizations. Coolidge was still in office, and the Bureau of the Budget reflecting his views on economy recommended the same amount as for the previous fiscal year ($147,000) with a supplemental item of $12,000 for the Colorado River stations. Congress, however, giving heed to the representations made, recognized the justice of 50-50 cooperation on the part of the Federal Government. This change of heart may have been influenced in part by the fact that Coolidge was nearing the end of his term of office and would not be a candidate for reelection, and therefore the need for adhering strictly to the economy plan which had been followed for several years was less impelling, particularly as the country was then nearing the peak of a prosperity era. The first result of the influencing factors was an increase in the item for the maintenance of the Colorado River stations from $12,000 as recommended, to $50,000. The increase in the item for the Colorado River stations was due largely to the influence of Senator Carl Hayden of Arizona. J. C. Hoyt met him at Flagstaff, Arizona, a few months before Congress considered the Survey item in the annual appropriation bill, and convinced him of the need for a very substantial appropriation to maintain the Colorado River stations the records for which would be required to furnish complete information needed in the operation of the Colorado River Compact then pending in Congress. The $50,000 for the Colorado River stations was specified

> for operation and maintenance of the Lees Ferry, Arizona, gauging station and other base gauging stations in the Colorado River drainage.

An item for the Colorado River stations was continued in varying amounts in subsequent appropriations. The total amount in the Federal appropriation for 1929 was raised to $247,000 and the 50-50 principle recognized by the addition of the following language:

> Provided, That no part of this appropriation shall be expended in cooperation with States or municipalities except upon the basis of the State or municipality bearing all of the expense incident thereto in excess of such an amount as is necessary for the Geological Survey to perform its share of general water resources investigations, such share of the Geological Survey in no case exceeding 50 per centum: Provided further, That $125,000 of this amount shall be available only for such cooperation with States or municipalities.

This language was similar to that used in the item for topographic surveys in which the 50-50 principle had been recognized since 1925. That 50-50 cooperation was recognized in principle only, is shown by the fact that the amount of State and municipal funds offered in that year amounted to about $368,000. To meet this situation, the Washington office made the allotments for 1929 on the basis of $1 Federal funds to $2 State funds, up to $10,000 of State funds, except that no Federal allotment should be less than that for the preceding year. 4/ The enactment of

4/ Letter from Chief Hydraulic Engineer, Jan. 30, 1929, to author.

the Welch act 5/ providing for salary increases, resulted in adding

5/ p. 12, 1919-1928.

$23,500 Federal funds, making a total of $270,500.

The recognition by Congress of the 50-50 principle was naturally gratifying, but the lack of funds to meet State cooperation fully was a cause of dissatisfaction on the part of State officials. Referring to this, the Chief Hydraulic Engineer in a letter to the district engineers, dated December 23, 1930, stated:

> During the year that has passed, we have had many tribulations. We had been looking forward with the pleasantest anticipation to the time when there would be Federal funds in sufficient amount to meet the State cooperative funds on a fair basis. In anticipation, we could see nothing but satisfaction in the arrival of that time. However, when the funds were available they were restricted by certain conditions that were new, unexpected and untried. They were not wholly satisfactory to the cooperating State officials and they involved new procedures that were troublesome. As a result, the past year has been one of the most trying in my experience. There have been dissatisfaction and misunderstandings that have been extremely difficult to overcome.
>
> I am glad to say that in general the clouds now seem to be lifting. The cooperating State officials have come to appreciate the limitations that have been placed on the Geological Survey and are now, I believe, trying in the best of spirit to work out our problems with us. I believe we have at last been able to write a standard form of cooperative agreement which is acceptable for general use among the States and which the State officials can and will sign with confidence that their interests and rights are fully protected.

The action of Congress in recognizing the 50-50 principle had its effect on the Bureau of the Budget to the extent that the latter recommended a total of $250,000 for 1930. Congress increased this to $275,000 of which $157,500 was for cooperation only. This amount was little more than the amount appropriated for 1929 plus the amount for increase of salaries under the Welch Act. The State offerings had been increased to about $398,000. Under that appropriation, the funds available for the Washington office were so inadequate that the plan of retaining 12½ per cent of Federal funds allotted for cooperation was adopted. This plan had been adopted previously by the Topographic Branch in its 50-50 cooperation. 6/

6/ Letter from Chief Hydraulic Engineer, Jan. 26, 1929, to author.

Herbert Hoover, an engineer, became President in 1929 and when the Bureau of the Budget prepared its estimates for 1931, the prosperity era was at its peak. Hoover was not particularly committed to economy, and having been in fairly close touch with engineering organizations, was influenced by the strong pleas of those organizations and of State officials for increased appropriations. Accordingly the Bureau of the Budget not only met the Congressional raise of the previous year, but went it one better by recommending $300,000 for 1931. When Congress considered the bill the House Committee was advised of the serious arrearage in the publication of the annual reports, an arrearage which was becoming steadily more serious because of insufficient printing funds. In that connection, Chairman Cramton of the sub-committee of the House Appropriations Committee stated: 7/

7/ Hearings on Interior Department Appropriation Bill 1931, p. 936.

> Now, it appeals to me that if we were to change the policy a little and say to these States, yes, we will meet you any amount of money you put up on any regular way; we can not have an up and down policy, a big amount one year and a small the next, but any regular course you follow we will meet you up to 50 per cent on topographic surveys, on water supply and surveys, including the work of compiling, publishing and printing the data and maps. In other words * * * in this matter of water supply where we have not been anywhere near matching them, we are ready to go along with you on that and match with you provided that you share on the whole proposition, the compiling of the data and its publication.

Congress adopted that suggestion and included the cost of preparing and publishing the annual reports as an item in the 50-50 cooperation. In so doing Congress increased the cooperative funds to $390,000, and the total appropriation to $510,000, believing that the funds so appropriated would match State offerings. These offerings, however, proved to be about $462,000 and with the full recognition by Congress of 50-50 cooperation, the Survey asked for a deficiency appropriation which was made in the second deficiency Act in the amount of $55,000, making a total cooperative appropriation of $445,000 and a total Branch appropriation of $565,000.

The recognition by Congress of 50-50 cooperation was, of course, accepted by the Budget, and for 1932, on a Survey showing of expected State cooperation, the Budget recommended $700,000 in the gaging streams

item. A part of this increase was due to the cost of maintaining, subsequent to September 30, 1931, when Army Engineer cooperation under HD 308 - 69th Cong., 1st Sess. would virtually cease, 120 important "308" stations which could not be absorbed into the State cooperative programs, in part in States where such cooperation was not in effect. Congress appropriated $720,000 on the basis chiefly of an increase in the amount of State cooperation expected, of which $552,000 was available only for cooperation. The total was subsequently reduced to $711,000 by the elimination of $9,000 estimated for salary increases which were prohibited by law during that year. 8/ In the wording of the Act for 1932, the super-

8/ p. 12..

fluous "u" in "gauging" which had previously been used by Congress, but omitted by the Survey since 1894, was omitted and "gauging streams" became legally the familiar "gaging streams;" this economy in letters was perhaps an augury of the forthcoming economy wave.

For the fiscal year 1933 the Budget estimate was $719,500, practically the same as the amount appropriated for 1932. However, the depression years were on, and members of Congressional committees stated frankly, but "off the record," that they did not believe the States would provide funds in the amounts estimated and so reduced the appropriation to $600,000, of which $450,000 was available only for cooperation. In reducing the latter item, the House Committee gave definite expression to its belief that the economy wave in the States would reduce the State appropriations to such an amount that $450,000 Federal funds would be sufficient. This did not prove to be true, however, and under the Economy Act of June 30, 1932, and subsequent acts which allowed a switching from one appropriation to another up to an amount of 12 per cent of the appropriation, $75,000 or 12 per cent was added to the Survey's appropriated funds making the total Federal funds available in 1933, $506,250 for cooperation only, and $675,000 for the Branch. The proviso that the cost of preparing and publishing the annual reports should be included in the cooperative Federal funds, which had been shown to be unworkable, was eliminated.

Influenced by Congressional action in reducing the appropriation for 1933, the Bureau of the Budget recommended $621,400 for 1934. When Congress met, Franklin D. Roosevelt had been elected President on a platform of economy, and Congress was in the "lame-duck" class during its short session which expired on March 4, 1933. The House, however, had been Democratic since 1931, and that body obeyed the people's mandate for economy, in which the Republican Senate concurred, and Congress appropriated $540,000 for the Branch, of which $400,000 was for cooperation only. This, however, was not the full measure of the reduction for 1934. By Executive Order of July 5, 1933, the amount of funds that could be withdrawn from the Treasury during the fiscal year 1934 on account of the stream-gaging appropriation was limited to $340,000, of which $240,000 was for cooperation. These amounts included not only the items chargeable to the 1934 appropriation, but also those items of expense incurred during 1933 which were actually paid subsequent to June 30, 1933, from the 1933 Federal appropriation. As a result of this drastic reduction only about 50 per cent of the appropriated funds were available although all were needed to meet State offerings on the 50-50 basis.

The Bureau of the Budget for 1935 followed closely the amount of funds made available by Congress in 1934 and estimated $337,650, although

how that odd figure was determined is not now known. The wording of the stream-gaging item was simplified by leaving out specific reference to the Colorado River stations. Resenting the apparent abandonment of the 50-50 principle in 1934, cooperating State officials made a vigorous protest. Also, the contemplated projects of the Public Works Administration required more stream-gaging records. The Survey was therefore able to make a strong plea for additional funds and Congress appropriated not only the amount estimated by the Budget, but added to it the unexpended balance caused by the cash withdrawal limitation put into effect by the President during 1934. The resulting total amount was $516,234 of which $375,890 was for cooperation only.

For 1936 the Budget Bureau raised the estimate to $630,000 and in spite of strong representations by State officials as to the insufficiency of this amount, Congress appropriated only $650,000 of which $458,000 was for cooperation only. This amount fell short of meeting 50-50 cooperation by $100,000 or more.

The failure of Congress to appropriate sufficient funds for full 50-50 cooperation was interpreted by the Budget Bureau as a partial repudiation of that principle, and for 1937 the Budget Bureau estimate was $660,000. Again the State officials protested vigorously, and at the Senate hearings Senator Hayden of Arizona stated: 9/

9/ Interior Department Appropriation Bill 1937, hearings by Senate Committee, p. 33.

> I want to say for the record that it was understood in the beginning, and Congress has never had any other idea, that we would match the States in this very important work.

As a result of representations made by the Survey and by State officials, Congress appropriated $791,317, of which $589,317 was available for cooperation only.

The action of Congress in meeting State cooperation substantially on a 50-50 basis, together with Senator Hayden's declaration, convinced the Budget Bureau that the 50-50 principle was still in force, and for 1938 it estimated $800,000, a slight increase over the appropriation for the previous year. Congress, on the basis of the showing made at the hearings, and as a result of many letters sent to members of Congress by cooperating State officials, appropriated $900,000 of which $700,000 was available for cooperation only.

The Department of the Interior bill carrying the Survey appropriations did not become effective until August 9, 1937, and on July 1 no funds had legally been made available. From a strictly legal standpoint all work should have ceased, as unauthorized expenditures and performance of work for the Government without compensation are forbidden by statute. However, that point was disregarded and operations continued. Within a few days Congress passed a resolution making available for July 1-15, one twenty-fourth of the previous year's appropriation, and similar continuing resolutions for the periods July 16-31, and August 1-9, as is the general practice in such situations.

For 1939 the Budget Bureau accepted fully the 50-50 principle and estimated $1,050,000 of which $850,000 was for cooperation only on the

full estimated cooperative basis. Congress appropriated that amount with the result that for the first time since 1933 State cooperation was matched dollar-for-dollar.

The amounts actually available annually for cooperation with States and municipalities were not limited by law to the amounts which could be used only for such cooperation, as there was nothing in the various appropriation acts to prevent the difference between the amounts so specified and the total amounts appropriated being so used. However, the noncooperative needs of the Branch were so great that only in a few instances were such funds used for cooperation and then only in small amounts. The annual appropriations for the Branch were:

1929	$270,500	1935	$516,234
1930	275,000	1936	650,000
1931	565,000	1937	791,317
1932	711,000	1938	900,000
1933	675,000 1/	1939	1,050,000
1934	540,000		

1/ $340,000 actually available.

The limitation on salaries paid for services in the District of Columbia which was started in the fiscal year 1926 was continued, with annual limitations, as follows:

1929	$ 70,000	1933	$150,000	1937	$100,000
1930	90,000	1934	125,000	1938	130,000
1931	125,000	1935	124,540	1939	130,000
1932	160,000	1936	130,000		

The cut in 1934 reflected the general retrenchment policy in the total appropriation. Although increases in such appropriations after 1934 carried the totals to greater amounts than previously, the specter of centralization in Washington made Congress reluctant to grant corresponding increases in the limitation on District of Columbia salaries.

Throughout the years and with all of the vicissitudes with respect to the amounts of funds to be appropriated for investigating the availability and utility of water, the language of the water item has remained practically unchanged with respect to purposes. The wording of the item in the Act of August 18, 1894 10/ 11/ was

10/ 28 Stat., L. 398.
11/ Follansbee, Robert, History of the Water Resources Branch to June 30, 1919, p. 70.

> For gauging the streams and determining the water supply of the United States, including the investigation of underground currents and artesian wells in arid and semiarid sections, twelve thousand five hundred dollars;

Forty-four years later, the wording of this item in the Act of May 9, 1938 12/ was

12/ 52 Stat., L. 325.

> For gaging streams and determining the water supply of the United States, the investigation of underground currents and artesian wells, and the preparation of reports upon the best methods of utilizing the water resources, $1,050,000, of which amount not to exceed $130,000 may be expended for personal services in the District of Columbia; Provided, That no part of this appropriation shall be expended in cooperation with States and municipalities except upon the basis of the State or municipality bearing all of the expense incident thereto in excess of such an amount as is necessary for the Geological Survey to perform its share of general water resources investigations, such share of the Geological Survey in no case exceeding 50 per centum of the cost of the investigation; Provided further, That $850,000 of this amount shall be available only for such cooperation with States or municipalities;

The spelling of "gauging" had been modernized; the limitation to "arid and semiarid sections" had been removed; the "preparation of reports upon the best methods of utilizing the water resources" had been added; and limitations had been placed on the use of the funds for payment of salaries in the District of Columbia and for cooperation with States and municipalities. It is probably safe to say that there are few appropriation items in the United States statutes that have been as little changed in those years in the wording related to purpose as this one. Its age has inevitably led to familiarity; it has, for convenience, been given a short title, and is always referred to by the committees of the Bureau of the Budget and the Congress as the "gaging streams" item, even though everyone recognizes that it includes ground water, quality of water and utilization of water as well as surface water.

Colorado River stations

The key gaging station in the Colorado River Compact is on the Colorado River at Lees Ferry, Arizona, where, because of inaccessibility of site and instability of bed, one, and at times of high water, two resident engineers are required. This requirement involves a very considerable expense which, during 1928, was borne by contributions from some of the Colorado River Basin States. [13] Such financing

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[13] p. 110, 1919-1928.

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was adopted as a temporary expedient and was utilized only until other funds could be obtained.

Because of the interstate and international character of the Colorado River, involving not only the seven States in the basin but also the Republic of Mexico, the Conference of the Colorado Basin States held in Denver on September 24, 1927, requested the senators and representatives from those States to obtain an appropriation for the Geological Survey to maintain the Lees Ferry station at Federal expense. When this request was called to its attention, the Survey with Secretarial approval proposed to enlarge the States' request and include nine existing base stations in the Colorado River Basin and three new base stations needed in the lower basin. The Bureau of the Budget, however, would consider only the States' request and in a supplemental item for 1929, estimated $12,000 for the Lees Ferry station of which

$6,000 was for operation and $6,000 for equipment. The House Committee, at its hearings, was sympathetic toward the larger program and adopted the Survey's estimate of $50,000. That amount was appropriated, and was used for operating the following base stations in the Colorado River Basin: 1/

1/ Letter from Chief Hydraulic Engineer dated Mar. 1, 1928, to author.

Colorado River at Cisco, Utah
Colorado River at Lees Ferry, Ariz.
Colorado River at Grand Canyon, Ariz.
Colorado River at Topock, Ariz.
Colorado River at Yuma, Ariz.
Green River near Linwood, Utah
Green River at Green River, Utah
San Juan River at Goodridge, Utah
Little Colorado River at Grand Falls, Ariz.
Virgin River near Littlefield, Ariz.
Williams River at Planet, Ariz.
Gila River near Dome, Ariz.

Later in the period, the following stations were added: Colorado River at Glenwood Springs, Colo., Gila River below Gillespie Dam, Ariz., Colorado River at Willow Beach, Ariz., Paria River at Lees Ferry, Ariz. (the flow of that stream plus that of the Colorado River at Lees Ferry represented the Lees Ferry discharge specified in the Colorado River Compact), Colorado River near Picachio, Calif., Moenkopi Wash near Tuba, Ariz., two stations on the All-American Canal, and two on the Yuma Main Canal. As a result of cooperation with the Metropolitan Water District of Southern California, started in the fiscal year 1936, the stations on the Colorado River at Topock and the Williams River at Planet were no longer maintained from the funds restricted for the Colorado River. With these additions and subtractions, 20 stations were maintained by means of the funds appropriated for the Colorado River stations.

Each succeeding appropriation act carried a similar item until the Act for 1936, in which the Budget simplified the stream-gaging items by eliminating specific reference to the Colorado River stations, but including a specific amount for that purpose in the non-cooperative funds.

The amount appropriated each year was:

1929	$50,000	1933	$45,000	1937	$52,000
1930	50,000	1934	40,000 1/	1938	50,000
1931	50,000	1935	36,520	1939	50,000
1932	48,000	1936	50,000		

1/ $30,000 available under the limitation on cash withdrawals.

Federal-type stations

When the Army Engineers started their "308" investigations, it was contemplated that the gaging stations established in connection with those investigations in cooperation with the Survey would be maintained for several years, after which Army Engineer funds would not be available for their operation. The "308" report recommended that after the completion of the surveys by the Army Engineers, the important gaging

stations be continued by the Survey and that its annual appropriations be increased sufficiently to accomplish that purpose. 15/ The Survey was

15/ p. 59.

notified some time in advance that, in general, Army Engineer cooperation on account of the "308" work would cease on September 30, 1931. When the House Committee held hearings on the appropriation bill for 1932, the Survey called attention to this situation and was requested to furnish a full statement regarding the Army-Engineer stations. The statement 16/

16/ House Committee hearings on the appropriation bill for 1932, pp. 373-4.

furnished showed that 720 stations were being operated by the Survey for and at the expense of the Army Engineers; that 66 could be discontinued when the Army cooperation ceased; that 534 stations were of the type that could be included in State cooperation; and that 120 were chiefly of Federal interest, generally in connection with navigation, and would not have been established in a State cooperative program. The estimate for maintaining the 120 stations, which were designated as Federal-type stations, was $45,000 for the last nine months of the fiscal year 1932. Congress accepted this estimate and included $45,000 in the appropriation for 1932, but did not set up a separate item as had been done for the Colorado River stations.

The number of Federal-type stations remained substantially the same until the fiscal year 1936. During 1934 and 1935 Public Works funds had been used to finance the construction, maintenance and operation of 40 stations in the Mississippi River Basin, records from which were needed by many Federal agencies in national-planning studies. This program of work had the strong endorsement of the Mississippi Valley Committee and its successor, the National Resources Committee. Public Works funds were not available subsequent to June 30, 1935, and as the need for those stations continued, as well as the need by the Army Engineers for 6 additional stations in the Columbia River Basin, the 46 stations were included in the Federal-type-station list and additional funds were provided by Congress for their maintenance and operation. By the end of the period there were 163 Federal-type stations.

Specific amounts for the Federal-type stations were contained in succeeding appropriations, the amounts during the period being:

1932	$45,000	1935	$30,000	1938	$88,000
1933	46,000	1936	78,000	1939	88,000
1934	42,000 1/	1937	88,000		

1/ $20,000 available under the limitation on cash withdrawals.

COOPERATION

The growth of the Branch is shown strikingly by the increase in cooperation, State, Municipal and Federal. As funds furnished by other Federal agencies are not matched by the Survey, the increase of such funds indicates the growing importance of water in the National Life, and the increasing recognition of the Survey as the Government's fact-finding agency in the field of water.

Annual expenditures from funds furnished by Federal agencies, states and municipalities were:

Year	State & Municipal	Federal	Private 1/	Total
1929	$354,869	$389,809	$29,128	$ 773,806
1930	412,885	420,369	38,603	871,857
1931	459,564	357,591	50,419	867,574
1932	556,767	196,527	33,355	786,649
1933	532,653	109,441	31,508	673,602
1934	447,547	762,330	25,549	1,235,426
1935	481,422	843,845	22,372	1,347,639
1936	587,705	362,917	25,002	975,624
1937	626,441	423,450	22,922	1,072,813
1938	757,182	351,098	24,996	1,133,276
1939	829,123	1,156,625	27,199	2,012,947

1/ Funds of F.P.C. permittees and licensees deposited with Survey for operation of required gaging stations.

Not included in the foregoing tabulation are funds totalling about $675,000, contributed during the years 1934-1939, by the CWA-FERA-WPA for work projects, including field and office, conducted under Survey supervision, which are described on pages 722-730.

ECONOMY LEGISLATION AFFECTING GOVERNMENT SALARIES

The depression years caused reductions not only in governmental appropriations generally but also in salaries. The first salary reduction was made in the fiscal year 1933, when employees were furloughed for one month without pay. 17/ This was a practical reduction of 8-1/3

17/ 47 Stat., L. 399.

per cent. Some members of the Survey regarded it as such, and did not actually take a vacation during the furlough period.

Before the appropriations were made for the next fiscal year the Roosevelt Administration had come into office and the platform of economy on which it had been elected was reflected in the Act to maintain the credit of the United States, approved March 20, 1933. 18/ Sec-

18/ 48 Stat., L. 13

tion 3 of that Act provided that the President was authorized to investigate the cost of living during the six months ending June 30, 1928, taken as the base period, and to make a similar investigation for the six months ending December 31, 1932, and each six-month period thereafter. The percentage by which the cost of living for any six months' period was below the base period as announced by Executive Order was the percentage of reduction in all salaries paid during the succeeding six months' period up to a maximum of 15 per cent. The maximum reduction of 15 per cent was put into effect April 1, 1933. The percentage reduction was designed to be controlled by the change in the cost of living and presumably required no further legislative action. However, in the

winter of 1934, when the Executive Offices Appropriation Act for the fiscal year 1935 [19] was being considered, Congress included in it the

[19] 48 Stat., L. 521.

proviso that from February 1 to June 30, 1934, the maximum reduction should be 10 per cent, and during the fiscal year 1935 it should be 5 per cent. President Roosevelt vetoed this bill but Congress passed it over his veto. By Act of February 13, 1935, [20] the reduction of 5 per

[20] 49 Stat., L. 24.

cent was discontinued, beginning April 1, 1935.

Along with the reductions in salary, the so-called economy act of 1932 [21] provided that administrative promotions which were those within

[21] 47 Stat., L. 403.

the same grade, should be suspended during the fiscal year 1933. This proviso was continued during 1934, [22] and relaxed slightly during 1935. [23]

[22] 47 Stat., L. 1515.
[23] 48 Stat., L. 523.

Thereafter there was no legislative bar to administrative promotions but such promotions were made sparingly by the Interior Department, the total number allowed in the entire Survey being very small.

Annual leave which for many years had been 30 days per annum but not cumulative, was reduced to 15 days by the Act of 1933, and remained at 15 days until the Act of March 14, 1936 [24] increased annual leave to

[24] 49 Stat., L. 1161.

26 days and made it cumulative for 3 years. This increase was effective January 1, 1936.

Rio Grande Joint Investigation

The Rio Grande Joint Investigation covering the Rio Grande Valley from the headwaters in Colorado to Fort Quitman, Texas, was started in March 1936 and the field work was planned to be completed in January 1937, but at the request of the State Engineer of New Mexico, the investigation in that state was continued until June 1938. It was participated in by the Divisions of Surface Water, Ground Water, and Quality of Water. As it was sponsored by the National Resources Committee which furnished a large part of the cost, an account of the investigation is given under cooperation with the National Resources Committee, pp. 684-687.

DIVISION OF SURFACE WATER [25]

[25] Early in the period, the s was dropped from Surface Waters, probably for the sake of uniformity with the divisions of ground-water and quality of water.

Washington Office

J. C. Hoyt was chief of the Surface Water Division until December 17, 1930, when he was made technical adviser to the Branch. C. G. Paulsen became chief on March 16, 1931, and continued in that position during the remainder of the period.

Section of Investigations: G. C. Stevens continued in charge of the Section of Investigations, the duties of which consisted largely in answering the many requests for stream-flow records and studies of water supply by members of Congress and Federal agencies. Some requests were for data very remotely connected with the flow of rivers. The great increase in the use of stream-flow records during the period brought a corresponding increase in the number and variety of inquiries received. Regarding these inquiries, Stevens writes: 26/

26/ Letter to author.

> Most of the inquiries relate, of course, to questions on water supply, and all of them relate to water or water features, such as lengths of rivers, areas and depths of lakes, and information for use in planning a boat or canoe trip. School children and also teachers, in grade and high schools make requests for information on water resources obviously for use in preparing essays on the popular subject of conservation. Owners of property fronting on lakes frequently ask for the normal, established, or "Government" elevation of the lake as they fear their property is going to be damaged by some water conservation or control scheme. Inquiries relating to navigation are referred to the War Department, if possible, and those needing elevation data are referred to the Topographic Branch if our Branch has no data of that kind in the vicinity.

To meet certain requests of cooperating agencies, such as the Army Engineers, Stevens in 1938 began the practice of plotting on base maps of 1:500,000 scale, all gaging stations and keeping these maps current by means of the lists of stations established and discontinued included in the monthly reports. Many inquiries, particularly those requiring considerable research, were referred to C. H. Pierce.

Section of Review: B. J. Peterson was chief of the Section of Review during the period. The reviewing of the stream-flow records and preparing them for publication, were the chief functions. Suggestions for changes in methods of presenting records for publication and their character were considered by the Section of Review, and usually referred to the district engineers. In addition to engineers from various districts detailed to the Section for several months, there were engineers assigned to the Section for longer periods. Engineers so assigned were:

J. G. Leckie	July 1, 1928 to Apr. 30, 1929
R. H. Brigham	Apr. 19, 1929 to June 30, 1930
P. R. Speer	Oct. 13, 1929 to Jan. 31, 1932
S. C. Moore	Oct. 1, 1929 to June 10, 1930
L. L. Harrold	July 1, 1930 to July 5, 1931
	Oct. 1, 1935 to Dec. 25, 1935

F. F. LeFever	Sept. 29, 1930	to July 28, 1931
F. L. LeMert	July 2, 1931	to Apr. 17, 1932
S. K. Jackson	Apr. 6, 1931	to Nov. 4, 1933
D. S. Jenkins	Jan. 4, 1932	to June 30, 1935
M. C. Boyer	Dec. 1, 1936	to June 30, 1939.

Section of Instrument Design: C. H. Au was in charge of the Section of Instrument Design until his resignation on May 9, 1931. During that period he devoted much time to reels and booms, including the first power boom used at Vicksburg, and to the metal stand-up cable car. After Au's resignation the Section was virtually abolished. The improvement of current meters had been transferred to R. L. Atkinson, chief of the Survey's Division of Field Equipment, about November 1, 1930. The heavier equipment needed was developed chiefly by the Columbus office, and beginning in 1934 the development of smaller items of equipment was assigned to A. H. Frazier who was transferred from St. Paul to the Washington office on January 8, 1935.

Field

Many changes occurred both in district-engineer personnel and in the number of districts. During the previous period changes in the former had been due chiefly to resignation, but of the changes which occurred from 1928 to 1939 only one was due to that cause--G. C. Baldwin, who resigned in 1930. C. G. Paulsen, district engineer at Boise, was appointed chief of the Surface Water Division in 1931. W. R. King died in 1934, Lasley Lee in 1937, W. A. Lamb in 1938, and C. L. Batchelder in 1939. H. E. Grosbach was transferred from Illinois to the newly created Indianapolis district in 1930, S. B. Soulé was retired in 1938, and W. E. Dickinson was transferred to the Water Utilization Division and detailed to a special study of the Colorado River in 1938. Of the 23 districts which comprised the field organization at the beginning of the period, 15 had the same district engineers during the entire period.

The boundaries of several districts were enlarged, due at first to the "308" work of the Army Engineers and later to increased State cooperation. The creation of 16 new districts contracted the boundaries of other districts. District offices were established at Augusta, Me., Topeka, Kans., Tuscaloosa, Ala., Thief River Falls, Minn., and Fort Smith, Ark. in 1928; Hartford, Conn. and Charleston, W. Va. in 1929; Columbia, S. C., Ocala, Fla., Lansing, Mich., and Indianapolis, Ind. in 1930; Harrisburg, Pa. and Santa Fe, N. Mex. in 1931; Iowa City, Ia. in 1932; Atlanta, Ga. in 1937; and Louisville, Ky. in 1938. Of these district offices all, except Lansing which was discontinued within a year, were continued to the end of the period. However, the Alabama district office was moved from Tuscaloosa to Montgomery in 1933, and the Minnesota district office from Thief River Falls to St. Paul in 1930. Thus there were 37 district offices on June 30, 1939. In addition, an office had been established in St. Louis in 1934 to function as a coordinator and clearing house for the many interrelated records collected at stations in the Missouri and lower Mississippi River basins. The marked increase in the number of gaging stations in most of the districts, caused by the expansion of cooperation with States and municipalities, the increase in Federal funds by transfer and repay, and the greater emphasis placed on flood records during the period, made advisable the

establishment of sub-offices in many districts, in order to obtain efficiency of operation, thereby extending a practice which had been followed to a limited extent previously. The number of such sub-offices varied, but about 60 were maintained during some part or parts of the period.

The creation of additional districts and sub-offices resulted in more responsible positions and therefore in higher allocations for many men of experience which extended through the associate, assistant and junior grades. Such higher allocations brought about an excellent spirit in the Branch that must have more than compensated the Washington office for the great amount of work thrown on it in selecting men for transfer to new assignments, recruiting of many new employees and coordinating the expanded field activities.

State cooperation

State and municipal cooperative offerings were more than doubled during the period, from $320,558 in 1928 to $655,267 in 1939. This increase resulted largely from the establishment by Congress of the 50-50 principle of cooperation. The greatest immediate effect of this improved situation was brought about by arrangements for cooperation with States that had previously carried on independent stream-gaging programs, thereby making possible an increase in size of program without additional cost to the State. Five States, Pennsylvania, Indiana, Nebraska, Kansas, and New Mexico, which had such independent programs entered into cooperative relations. A sixth State, Colorado, should be included with this group because, although it was cooperating with the Survey in a minor way in 1929, it was carrying on a much larger program of its own. A compact group of six States which entered into cooperation at this time consisted of South Carolina, Georgia, Florida, Alabama, Mississippi, and Louisiana. In some of these, the State geologists had cooperated at one time or another to the extent of a few hundred dollars annually, but none of them were cooperating at the beginning of the period. Kentucky, Michigan, Iowa, and Oklahoma, in other parts of the country, also entered into cooperation. A variety of other causes, besides the 50-50 principle, varying among the different States, induced action; interest in water resources aroused by the "308" investigations of the Army Engineers [27] brought

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27 p. 58.

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about State appropriations for continuing the gaging stations following these investigations. Realization of the importance of flood data by State highway departments; need for stream-flow records in connection with stream pollution problems; and industrial growth (particularly in the southeastern States) also contributed to the States' interest in their surface waters. At the end of the period every State except Rhode Island, Delaware, and South Dakota was included in the list of cooperating States,--an increase of 15 States since 1928. Many other States increased very substantially their cooperative offerings.

The following table shows the increase in State cooperative funds by sections of the United States:

Increase in expenditures from State cooperative funds by sections of the United States

Section	1928		1939		Increase	
	Amount	Per cent of total	Amount	Per cent of total	Amount	Per cent of 1928
Eastern and Southern States	$90,863	28	$240,446	37	$149,583	165
Central States	49,836	16	79,756	12	29,920	60
Western States and Hawaii	179,859	56	335,087	51	155,228	86
Total	$320,558	100	$655,289	100	$334,731	104

The greatest percentage increase was in the eastern and southern States where the total cooperation in 1939 was 37 per cent of that for the United States, as compared with 28 per cent in 1928. The increase was 165 per cent of the cooperation in those States during 1928.

Relatively few changes in cooperating agencies occurred as the widespread reorganization of State governments which took place during the previous period did not continue into the present period.

The annual expenditures from State and municipal cooperative funds were:

1929	$320,169	1933	$451,001	1937	$553,230
1930	362,104	1934	396,068	1938	627,232
1931	397,951	1935	436,163	1939	655,289
1932	478,794	1936	526,354		

The small decreases during 1933-35 were caused by the depression when many States reduced their offerings and a few omitted them entirely.

Maine.- Cooperation with the State Public Utilities Commission of Maine continued during the period with but little variation in the State funds available. The Survey group was an integral part of the Public Utilities Commission's organization, being its Water Resources Department.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1929	$5,266	$2,000	1935	$6,499	$5,213
1930	7,204	4,160	1936	6,478	5,090
1931	6,525	6,980	1937	6,530	5,927
1932	6,998	6,851	1938	6,908	6,115
1933	6,348	5,668	1939	7,000	7,016
1934	6,490	3,728			

New Hampshire.- Cooperation with New Hampshire continued during the period although there were several changes in the cooperating agency. The Public Service Commission was the cooperating agency through the

fiscal year 1935. In 1933, the National Resources Committee suggested that state-wide planning could be financed under Federal emergency-relief grants, and the State Planning and Development Commission was created. Like many other new organizations, before and since, the Commission was apparently searching for more work to sponsor, and as the Chairman of the Public Service Commission was not particularly interested in stream-gaging, the succeeding appropriation bills for cooperative stream-gaging were sponsored by the Planning and Development Commission which became the cooperating agency.

In 1938 the State Water Resources Board became the cooperating agency. It had been created in 1935, 28/ "to investigate and ascertain

28/ Laws of 1935, Chap. 121.

the facilities for storing surplus water, and conserving, controlling, and distributing the same." Stream-flow records were of prime importance to the Water Resources Board and in the fiscal year 1938, the Board financed the State's half of the cooperation from its own funds. In subsequent years, an item for stream gaging was included in the budget of the Water Resources Board. 29/

29/ Letter from H. B. Kinnison to author.

In addition to these agencies, the State Highway department cooperated in the amount of $1,000 annually during the fiscal years 1931 to 1935. This cooperation was effected as a result of the Army Engineers' request to State officials for an increase in State funds to carry on the cooperative stream-gaging program after the "308" reports by the Army Engineers had been completed. 30/

30/ Op. cit.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1929	$1,592	1/	1935	$4,558	$4,172
1930	1,999	$1,168	1936	4,627	2,978
1931	3,010	3,003	1937	4,791	4,475
1932	2,715	3,011	1938	7,584	6,625
1933	3,278	2,968	1939	8,104	8,075
1934	3,772	1,909			

1/ District Survey funds not segregated by States.

The increases during 1938 and 1939 reflected the effect of the severe flood of March 1936. Referring to that flood, the Water Resources Board stated: 31/

31/ First Bien. Rept., 1935-1936, Foreword.

> The widespread disastrous flood of 1936, coming only nine years after one more limited in area but equally disastrous, the flood of 1927, has emphasized the need for study to devise ways to prevent a repetition of these losses and to find means to conserve these flood waters and to make them serve useful purposes for power, stream purification and recreation, to the ultimate benefit of all.

Vermont.- The special flood-control committee created in Vermont after the disastrous floods of 1927 [32] had as its head the chairman of

32/ p. 18, 1919-1928.

the Public Service Commission, and cooperation was continued with that agency through the fiscal year 1929. By that time the work of the special flood committee was completed and the chairman was no longer actively concerned with the State's water resources. Anticipating the exhaustion of the special flood appropriation, and recognizing the State's flood hazards, the legislature at its 1929 session resumed its former practice, which had been discontinued in 1923, of making specific appropriations for cooperative stream gaging. With no State agency particularly involved in water matters, the Governor became the cooperating State official. The vividness of the flood hazard led to an appropriation five times larger than that made previously, but gradually, with the depression years, that vividness faded and the appropriations became smaller until the floods of March 1936 again focused attention on flood hazards and brought about an increase in the appropriations for 1938 and 1939.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1929	$8,004	$1,500	1935	$2,284	$1,725
1930	7,110	4,204	1936	2,030	1,494
1931	7,609	8,054	1937	1,284	1,244
1932	4,864	5,246	1938	4,784	4,135
1933	5,626	5,238	1939	5,447	5,668
1934	4,184	1,647			

Massachusetts.- The droughts and floods to which Massachusetts was subjected during the period caused an increase in appreciation of streamflow records and two State agencies entered the cooperative picture in addition to the State Department of Public Works which continued its cooperation. The latter agency allotted $4,000 annually until the fiscal year 1936, after which it allotted $5,000. The hurricane floods of September 1938 caused so much damage to the gaging-station equipment that the Department allotted from a special flood fund an additional $5,000 to aid in repairing damages and in preparing the report on that flood. [33]

33/ Water-Supply Paper 867.

The Metropolitan District Water Supply Commission which had started cooperation near the close of the previous period [34], continued coopera-

34/ p. 19, 1919-1928.

tion in the amount of about $1,000 annually. The severe drought of 1931, and diversions to the water supply of metropolitan Boston, caused the Charles River to become nearly dry from Dedham to Boston. The Metropolitan District Commission, a separate agency having charge of water supply, sewage disposal, and parks for that area, needed a gaging station on the Charles River at Waltham, and cooperated with the Survey in the amount of a few hundred dollars annually in operating such a station. During the fiscal year 1936 the State Department of Public

Health entered into cooperation and turned over to the Survey the operation of several gaging stations which had previously been maintained independently in connection with problems of pollution and water supply. Several additional stations were also established.

The annual allotments of the Metropolitan District Water Supply Commission, the Metropolitan District Commission, and the Department of Public Health were made to one account, that of the Metropolitan District Commission, and the amount contributed annually by each agency was not disclosed.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1929	$4,223	1/	1935	$6,892	$4,297
1930	7,624	$5,576	1936	13,158	9,422
1931	6,188	6,496	1937	13,298	14,023
1932	6,762	6,712	1938	13,755	11,562
1933	4,351	5,220	1939	20,831	21,670
1934	6,821	2,871			

1/ District funds not segregated by States.

Connecticut.- Cooperation with the State of Connecticut had been resumed in the fiscal year 1928 to meet an emergency which arose in the Connecticut River Basin 35/, and as no State agency had been author-

35/ p. 20, 1919-1928.

ized to carry on stream gaging the Governor, acting through the Attorney General's Office, was designated as the cooperating official. At the conclusion of the litigation with the Metropolitan Water District (Boston and environs) in 1929 concerning diversions from the Connecticut River basin to the Metropolitan district, the Attorney General was so impressed with the great value of stream-flow records that he proposed to continue cooperation on a State-wide basis. 36/

36/ Seventh Bien. Rept. State Water Com., 1936-1938, p. 16.

The State Water Commission was concerned chiefly with the pollution of streams and, as its duties were more closely related to a study of the State's water resources than were those of any other State agency, its functions were increased at the 1929 session of the legislature by the addition of Section 2561, one chapter of which reads: 37/

37/ Chap. 221, 1929.

> Stream-gauging stations.- The State water commission is directed to establish, operate and maintain stream-gauging stations in connection with the investigations of the water resources of the State in cooperation with the United States Geological Survey.

With continuing cooperation assured, a district office was established in Hartford on June 16, 1929, with B. L. Bigwood as district engineer. Beginning in 1932 the city of New Britain has cooperated to the extent

of $100 annually, and in 1937 the City of Hartford entered into cooperation for the establishment and operation of three gaging stations in the Park River Basin in connection with municipal water supply.

Referring to the stream-gaging program, the Commission stated: 38/

38/ Seventh Bien. Rept., 1936-1938, p. 16.

> The value of the stream-flow data which are being accumulated would be difficult to over-estimate. They furnish absolutely essential information to every industry dependent on waters for power or industrial process water, to municipalities in developing or adding to domestic supplies, to hydro-electric power developments, and to a variety of other uses.

Annual expenditures from State, municipal, and Survey funds were:

Year	State	Municipal	Total	Survey
1929	$5,645		$5,645	1/
1930	7,000		7,000	$3,948
1931	7,000		7,000	6,999
1932	7,157	100	7,257	9,261
1933	7,791	100	7,891	5,495
1934	5,999	100	6,099	2,827
1935	6,000	100	6,100	4,649
1936	6,100	100	6,200	4,981
1937	5,765	2,600	8,365	7,169
1938	8,100	550	8,650	7,457
1939	7,050	550	7,600	6,609

1/ Not segregated from expenditures for Massachusetts and New Hampshire.

When cooperation was started it was expected that two additional stations would be established each year, but the depression years prevented the immediate carrying out of this program expansion. The increase in State funds during 1938 and 1939 largely represented the resumption of the expansion program.

New York.- As a result of a combination of circumstances, the cooperating State agency of New York shifted from the Department of Public Works to the Department of Conservation in 1929, back to the Department of Public Works during 1930 and 1931, and to the Water Power and Control Commission of the Conservation Department from 1932 to the end of the period. As the chief interest in stream flow continued to center about water power, the last named agency was the logical one to represent the State in the cooperation. The Conservation Department's interest in stream gaging was shown at its fiftieth anniversary in 1935, which was celebrated by placing historical markers along the highways. Near the gaging station on the Hudson River at North Creek it placed an iron sign reading,

Stream Gauging

One of the first stream gauging stations. Operated since 1907 by the Conservation Department in cooperation with the U. S. Geological Survey.

Serious floods during the period combined with the utilization of water power to create a widespread interest in flood control. The Hudson River Regulating District, and the Black River Regulating District, State agencies, also cooperated during the period.

A new interest in stream-flow records arose in 1932. The Conservation Department had started an extensive program of State-wide reforestation and had purchased about 200,000 acres of marginal farm land. Governor Franklin D. Roosevelt, while inspecting this land remarked that every little stream should have a gaging station to show the effect of reforestation on stream flow. Harrington took advantage of that lead and suggested to the Conservation Department the advisability of an investigation of the effects of reforestation on stream flow. This suggestion was accepted and a 20-year program was started.

Substantial cooperation with New York City's Board of Water Supply was started late in 1936. In its need for additional water supply, New York City sought to obtain water from the tributaries of the Delaware River, an interstate stream situated in New York, New Jersey, and Pennsylvania. New York State, on behalf of the City, attempted unsuccessfully to negotiate a compact with the other two States which would permit diversion of water from the basin to New York City. The State then brought suit in the United States Supreme Court, and in 1931 the Supreme Court decided that under certain conditions New York City might divert 440,000 million gallons per day from the floodwaters of the Upper Delaware and its tributaries. Although its right to divert water from the Delaware River Basin was thus established, the depression prevented the appropriation of funds therefor until 1936. At that time, as a stream-gaging program was necessary, cooperation with the Survey was arranged, and a sub-office for the conduct of the field work was established at Kingston on July 1, 1937, to which three, and later four, engineers were detailed to install and operate 28 stations.

In 1933 the Village of Ossining made application to the Water Power and Control Commission for a permit to install wells and a pumping plant near the Croton River below the Cornell Dam of New York City's water-supply system. This application was protested by another village having prior rights. The Commission withheld approval until the increase in flow in the stretch of river concerned could be determined. This increase was believed to be due to seepage under the dam. The Village of Ossining entered into cooperation with the Survey and three gaging stations were established and equipped with recorders and artificial controls.

As practically no surface-water work had previously been done on Long Island by the Geological Survey, and as the flow of Long Island streams has little in common with that of other streams in the State, Harrington arranged cooperation with Nassau County on August 13, 1936. This agreement provided for an allotment of $6,000 by the County for

the construction and operation of six gaging stations equipped with concrete controls and water-stage recorders during the fiscal year ending June 30, 1937. Subsequent agreements were for smaller amounts to provide for maintenance and operation only.

The annual allotments of State, municipal and county funds, and actual expenditures of Survey funds were:

Year	State	Municipal and county	Total	Survey
1929	$17,781	$ 438	$18,219	$5,000
1930	17,480	1,646	19,126	5,970
1931	20,010	356	20,366	20,076
1932	20,758	356	21,114	18,961
1933	16,489	3,446	19,935	21,016
1934	19,405	1,256	20,661	10,103
1935	21,233	3,274	24,507	19,213
1936	21,466	2,788	24,204	19,211
1937	23,812	8,738	32,550	29,719
1938	28,444	20,204	48,648	41,407
1939	29,626	16,910	46,536	46,108

New Jersey.- In July 1929 the New Jersey Water Policy Commission succeeded the Department of Conservation and Development as the co-operating State agency. The State desired to extend its control over the waters and water supplies of the State, and to coordinate the various items of such control under a single commission having no other duties. 39/ Accordingly, at its 1929 session, the legislature

39/ Letter from O. W. Hartwell to author.

created the Water Policy Commission, whose duties were described as follows: 40/

40/ Chap. 267, PL 1929, p. 631.

> An act to conserve, protect, control, and regulate the use, development and diversion of surface, sub-surface, and percolating waters of the State; to control and regulate the construction and maintenance of dams; to create a water policy commission and define its powers and duties and to transfer to such commission the jurisdiction, powers, rights, and duties of the Department of Conservation and Development over water supplies, dams, and flood control.

The change in State agency did not involve a change in cooperating personnel as the Division of Waters was transferred to the new agency. Cooperation with the Water Policy Commission continued during the period.

In 1934 cooperation was started with the North Jersey District Water Supply Commission. That agency had been created by the State to furnish additional water to some 30 municipalities in the northern part of the State. In 1928 the Commission constructed the Wanaque Reservoir of 3,476,000,000 cubic feet (79,800 acre-feet) capacity and sold to municipalities the additional water made available by storage of flood waters. To protect existing rights, the commission

was required to release from the reservoir specified quantities of water, and to insure compliance with this obligation a gaging station was needed on Wanaque River below the reservoir. The Commission entered into cooperation with the Survey for the purpose of establishing and operating that station and six additional stations on streams entering the reservoir. The Survey took over also a gaging station previously maintained by the Commission above the reservoir, which measured the water released by the Morris Canal. The North Jersey Commission allotted about $2,000 annually in this cooperation.

In 1936 cooperation was started with the Delaware River Joint Toll Bridge Commission which had been created by the States of New Jersey and Pennsylvania for the purpose of acquiring the existing toll bridges across the Delaware River, and maintaining them as free bridges. The Commission wished to collect at each of its 13 bridges records of stage for flood-warning purposes, and entered into cooperation with the Survey to that end. Wire-weight gages were installed and read twice daily by the bridge tenders, and hourly during high water. The hydrograph for the Trenton station was used as a base of reference and was kept current. During floods, hydrographs of upstream stations were superposed on it, as a means for predicting the magnitude and time of the peak at Trenton. The Toll Bridge Commission allotted $1,100 annually to the cooperation.

Annual expenditures of State funds, including those of the North Jersey District and the Toll Bridge Commision, and of Survey funds, were:

Year	State	Survey	Year	State	Survey
1929	$12,000	$5,000	1935	$11,803	$10,565
1930	12,063	5,738	1936	14,345	12,865
1931	13,634	13,361	1937	14,078	13,715
1932	12,638	13,187	1938	14,253	13,772
1933	11,471	11,298	1939	15,126	14,913
1934	11,673	5,827			

Pennsylvania.- After the short-lived cooperation which was in effect from 1919 to 1921, [41] Pennsylvania resumed its independent stream-gaging

[41] p. 22, 1919-1928.

program. With Federal funds available, Grover in 1931 conferred with Governor Pinchot concerning the possibilities of cooperation on a 50-50 basis. This was a vastly different basis from that under which the previous cooperation had been effected, and Governor Pinchot being in favor of it, arranged for a conference between Grover and C. E. Ryder, the chief engineer, Department of Forests and Water, the State agency carrying on the State's program. At this conference it was decided that the cooperative program would be placed under a district engineer of the Survey who would become chief of the State Water Resources Service, that the personnel would consist of both State and Survey employees, and that the initial program would be the State's current program which included not only the operation of 97 gaging stations, but also the collection of other hydrologic data needed for the forecasting of floods. A district office was established at Harrisburg on June 1, 1931, with J. W. Mangan as district engineer. In 1935 the State's Water Resources Service became the Division of Hydrography, as it was decided that the latter name better described the activities of the service.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1931	$1,949	$1,664	1936	$18,848	$15,927
1932	21,120	20,008	1937	23,432	18,909
1933	19,465	23,619	1938	43,227	30,615
1934	21,497	9,773	1939	30,348	36,436
1935	18,563	15,453			

The increase in State funds during 1938 and 1939 was brought about by the floods of 1936, which had made the people flood-conscious, and this flood-consciousness was reflected in the legislative action which made available an increased amount of money, particularly in connection with the extension of hydrologic investigations needed by the flood-forecasting service. In addition, cooperation was in effect with the City of Harrisburg during 1938 and 1939 for the purpose of establishing and operating three gaging stations in connection with the city water supply. The city allotted $2,500 for 1938, and $600 for 1939, and the Survey half of those amounts. The expenditures from these allotments are included in the tabulation above.

Maryland.- Cooperation with the Maryland Geological Survey continued during the period. In 1929 at the suggestion of the State Board of Health which was concerned with the pollution of the Potomac River, the West Virginia Pulp and Paper Co., the Celenese Co., Potomac Edison Co., Kelly Springfield Tire Co., and City of Cumberland organized the Upper Potomac River Board. Records of stream flow were essential to the study of pollution and each of the five agencies contributed $200 annually to the State Geological Survey for stream gaging. The State's cooperative funds consisted, therefore, of direct appropriations by the legislature plus the contributions by these five agencies. The City of Salisbury cooperated to the extent of $200 annually for the operation of one station; Baltimore, $900 annually for four stations; and the Washington Suburban Sanitary District, about $600 annually for three stations.

Annual expenditures from State and municipal funds and Survey funds were:

Year	State and municipal	Survey	Year	State and municipal	Survey
1929	$ 923		1935	$7,575	$5,890
1930	6,068	$2,453	1936	5,861	5,049
1931	3,050	3,050	1937	7,888	6,000
1932	6,002	9,512	1938	6,958	6,812
1933	8,418	6,730	1939	6,737	7,736
1934	8,097	3,881			

Virginia.- The Virginia Conservation and Development Commission, shortened in name to State Conservation Commission in 1937, continued as the cooperating State agency during the period. So intimate was the cooperation that J. J. Dirzulaitis served in a dual capacity as the Survey's district engineer and as chief engineer of the Commission's Division of Water Resources and Power. Also, he was appointed a member of the State Planning Board when it was organized in 1934. Water power was an important element in the rapid industrial development which was taking place

during the early part of the period, and there was widespread interest in the flow of the State streams. This interest was actively fostered by the State Chamber of Commerce, which in 1930 obtained about 60 pictures of various phases of stream gaging that were published in the booklet "Virginia First in the Heart of the Nation" which was distributed throughout the State. The pictures were published also in the Richmond Times Dispatch. 42/ Publicity was also given to the

42/ Water-Resources Bulletin, Nov. 10, 1930.

water resources investigations by means of articles in the Virginia Quarterly Review (a University of Virginia publication) and by an exhibit at the Richmond State Fair in 1932 showing the work done in the State. Among the exhibits was a plate 20 by 30 inches listing the uses of stream-flow records. 43/ This exhibit attracted many visitors.

43/ Op. cit. July 11, 1932.

The result of these various activities was that the State appropriations were not only well sustained but were substantially increased during the depression.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1929	$16,645	$5,000	1935	$18,995	$14,856
1930	15,537	5,812	1936	18,657	15,223
1931	20,688	21,545	1937	20,108	20,280
1932	24,150	23,933	1938	20,874	19,548
1933	18,908	18,070	1939	22,931	23,289
1934	15,777	9,404			

North Carolina.- Cooperation with the Department of Conservation and Development of North Carolina continued during the period and the annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1929	$18,413	$5,000	1935	$6,777	$4,851
1930	12,000	5,000	1936	10,705	7,373
1931	9,673	10,438	1937	10,172	10,032
1932	11,822	11,142	1938	11,102	9,771
1933	9,858	9,530	1939	9,092	12,051
1934	3,240	3,325			

The appropriations for the years 1934 and 1935, which were made at the low point of the depression, reflected the strain on the State's finances.

South Carolina.- Until the present period, South Carolina had not cooperated in stream gaging. At the beginning of the period a few stations were being operated by the Survey chiefly in cooperation with the Army Engineers, and a few for Federal Power Commission licensees. Before the "308" work was terminated, E. D. Burchard, district engineer in the North Carolina district, under whose supervision the few South Carolina stations were being operated, attempted to arrange for continuing

those stations in cooperation with the State, in accordance with the arrangements made with the House Appropriations Committee. [44] The

[44] p.

State Highway Department was the only agency that had available funds and a possible interest. The attempt was at first unsuccessful as the chief engineer of the Highway Department could see no benefit to be obtained by his agency from stream gaging. However, not easily discouraged, Burchard interviewed that official a number of times before a lucky "break" gave him his opportunity in the following manner: [45]

[45] Letter from E. D. Burchard to author.

> By chance, a letter concerning a lawsuit arising from flood damage crossed his (chief engineer's) desk while I was being retold that he was not interested in cooperation. He requested that I investigate the facts of this case and my report won his cooperation.

The special investigation made by Burchard consisted of a slope-area study of a flood on a small drainage area where two box culverts on a recently-constructed State highway had become so choked with debris that the flood water was held back and flooded several buildings. The owner had sued the Highway Department for damages. As Burchard's investigation showed that the culverts had failed to operate properly, the matter was settled out of court. This incident convinced the chief engineer of the State Highway Department as to the value of, and need for, hydraulic data, and so changed his viewpoint that he wished not only to cooperate with the Survey, but also to have a Survey office in Columbia where Survey engineers' services would be available to the State at all times. As a result, the South Carolina district was created and an office established in Columbia on November 1, 1930, with A. E. Johnson as district engineer.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1930	$ 236	$ 0	1935	$3,353	$2,978
1931	2,697	2,726	1936	3,610	2,992
1932	5,340	3,910	1937	3,824	2,702
1933	4,312	2,644	1938	4,686	4,474
1934	1,596	4,052	1939	5,583	7,118

Included in the above State expenditures are a few hundred dollars allotted annually by the City of Spartansburg, cooperation with which had been started before the creation of the South Carolina district.

Georgia.- Cooperation with Georgia was begun during the fiscal year 1937 as the result of an industrial revival. For years paper manufacturers had looked with longing eyes on southern pine as a possible source of pulp for making paper. It is one of the fastest growing species in the United States, and reaches maturity in from 7 to 10 years, but the pitch and turpentine in it had defied successful attempts at paper making. Dr. C. H. Herty, a chemist of Savannah, Ga., became interested in the problem, which was so important that in 1931 the Georgia legislature

made an appropriation of $40,000 to the State Forest Service for the erection of an experimental plant. About the same time the Chemical Foundation of New York made a grant of $50,000 for the same purpose. With these combined funds the plant was erected and Herty started his experimental work. He finally overcame the pitch and turpentine difficulties and in January 1938 the first commercial plant was opened, not in Georgia, but just across the State line in Florida.

When it was evident that certain grades of paper, known as kraft, could be manufactured from southern pine, there was an urge for industrial development in the State and various organizations, including the State Planning Board and Chambers of Commerce were, as W. D. Collins expressed it, 46/ "trying to work up enthusiasm." Dr. Herty took an

46/ Statement to author.

active part in this campaign. He realized the necessity for a State-wide investigation of the water resources as shown by the following extract from a letter written in that connection: 47/

47/ Statement of E. B. Rice to author.

> Our dreams of a development of industries in the South * * * will be more apt to be realized if each of the Southern States will undertake a systematic survey from year to year of its water resources.

In its early stages C. E. McCashin, who had for several years indicated a receptive attitude towards State cooperation, was asked by the State geologist to assist in a broad educational campaign. The Georgia Forestry Association and the Georgia Association of Commercial Secretaries (Chamber of Commerce) were especially active and sponsored meetings. Dr. Herty was frequently present and to arouse interest at several meetings where McCashin explained stream gaging, he would, at the end of McCashin's talk, ask questions as to the value of stream-flow records. Dr. Herty was so highly regarded that his own interest created interest on the part of the audience. 48/ At these meetings

48/ Letter from C. E. McCashin to author.

large signs bearing the inscription, "Measure the streams and analyze the water", were displayed. As a further step in the campaign, a joint committee of the Forestry Association, which contained many legislators among its members, and the Commercial Secretaries, appeared before county commissioners and city officials of the larger communities and explained the value of stream gaging.

When the legislature met in 1937, a group headed by Dr. Herty, with the State geologist, C. G. Paulsen, and C. E. McCashin, called upon the Governor. Before the spokesman was fairly started on his statement the Governor interrupted him to say, "Dr. Herty, I know of this work and I think well of it. If you say it should be done, you may tell the chairman of the Appropriations Committee that I have sent you to him and that an item for it should be inserted in the Appropriation Bill." 49/ With this strong backing, the legislature made a lump sum

49/ Op. cit.

appropriation for both stream gaging and investigating the chemical quality of water. This appropriation was made to the Division of Mines, Mining, and Geology, the successor to the State Geological Survey. Cooperation was arranged and a district office was opened in Atlanta on March 1, 1937. A division of funds between stream gaging and quality of water was worked out and F. M. Bell, the district engineer, was the Survey representative for both programs. Cooperation continued during the remainder of the period.

Annual expenditures from State and Survey funds were:

Year	State	Survey
1937	$4,450	$4,421
1938	9,495	9,679
1939	6,010	6,264

Note: $1,000 of the reduction in 1939 funds was due to transfer of that amount of State funds to ground-water investigations.50/

50/ Letter from F. M. Bell to author.

Florida.- During the winter of 1929-30, W. R. King, whose district included Florida, in which nine stations were being maintained in connection with Federal Power Commission permittees, contacted a number of State agencies that were interested in cooperative stream gaging. As a result, Dr. Herman Gunters, the State geologist, arranged to contribute $1,000 and the State Road Department $2,500 for the fiscal year 1931. A suboffice was opened in Ocala on May 1, 1930, with D. S. Wallace in charge. On August 4, 1930, Florida was made a separate district with Wallace as district engineer. The State geologist's funds were so limited that he was unable to cooperate in both stream-gaging and ground-water investigations, and at the end of the first year he chose the latter as being in the State Survey's more immediate field of interest. Cooperation in stream gaging was continued with the State Road Department, the annual allotments varying from $2,000 to $5,000.

In the fall of 1930 Wallace had several conferences with officials of the Okeechobee Flood Control District, a State agency recently created to cooperate with the Army Engineers in flood-protective works for the Lake Okeechobee region. Prior to the formation of the Okeechobee Flood Control District, the Everglades Drainage District had collected records of stage on Lake Okeechobee and Kissimmee River, its principal tributary, and had made discharge measurements of the river and of some drainage canals. This work had been started in 1913 by the Survey in cooperation with the Everglades Drainage District but had been discontinued for lack of funds.51/ Cooperation

51/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 397.

with the Okeechobee Flood Control District, in the amount of about $1,500 annually, began on January 1, 1931, and continued through the fiscal year 1937. Subsequently, the Army Engineers took over all hydrologic investigations in the Lake Okeechobee region, and cooperated with the Survey in the stream-gaging program. Minor cooperation with

the cities of Jacksonville and Tampa was also effective beginning in 1931.

Annual expenditures from State funds (including District and municipal) and from Survey funds were:

Year	State	Survey	Year	State	Survey
1931	$5,144	$4,438	1936	$7,069	$5,428
1932	5,517	6,505	1937	5,920	5,201
1933	5,620	4,823	1938	4,886	4,628
1934	4,413	3,037	1939	4,762	4,551
1935	5,268	4,746			

The reduction in State funds subsequent to 1936 was due to the action of an economy-minded governor who reduced the funds offered in co-operation by the Road Department. 52/

52/ Letter from D. S. Wallace to author.

Alabama.- Cooperation with the State geologist of Alabama, which had ceased in 1926 largely because of lack of interest in the State's water resources, was revived in 1931, discontinued in 1933, revived again 1935, and continued during the remainder of the period.

After C. E. McCashin established a district office in Alabama in 1928 for the purpose of operating the Army Engineer stations in the southeastern States, he became acquainted with several newspaper editors who sought his assistance in writing articles of a "promotional nature" as he termed them. 53/ These articles were published in various

53/ Letter to author.

papers in Alabama and in other States of his district, and were favorably received. Thereafter, the editors wrote editorials on the need for stream gaging, thus acquainting the public with stream-gaging activities of which it had been ignorant previously.

The Alabama legislature met only once in four years, and the 1931 session was the first one in which this publicity began to be effective. In 1931 the depression was becoming pronounced and all existing activities were seriously curtailed. The State geologist, the logical cooperating official, had his own appropriation cut so drastically that his energies were devoted to salvaging what he could from the wreckage. Therefore, if a cooperative program was to be started, it was necessary for the interested legislators to act vigorously. They were successful and an appropriation of $5,000 annually to enable the State geologist to cooperate with the Survey was the only new appropriation made at that session. The appropriation was of course subject to the approval of the Governor who also had to approve each expenditure. The Governor signed the bill but apparently without considering it carefully, nor did he notice the early expenditures from the cooperative State funds. In May 1932 he became aware that such expenditures were being made from a new appropriation, and he refused to approve any additional expenditures. As a result the cooperative funds and the cooperative agreement became dormant. When the legislature met at its next regular session in 1935, a new governor had taken office and

the State geologist with D. H. Barber, who had succeeded McCashin as district engineer, satisfied him as to the importance of the cooperative program and he released for use in 1935 part of the funds which had been appropriated for that year by the 1931 legislature.

At the 1935 session the State geologist obtained an annual appropriation for the next 4-year period of $7,500, the minimum amount needed to maintain a fairly adequate stream-gaging program in the State. 54/ But the depression years continued and during 1936 and 1937

54/ Letter from D. H. Barber to author.

expenditures from all State appropriations were drastically cut. Thereafter the full amount became available.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1931	$ 140	0	1936	$4,380	$3,523
1932	2,231	$1,723	1937	3,188	2,263
1933	0	510	1938	8,195	7,597
1934	0	0	1939	6,903	8,998
1935	1,885	1,596			

Mississippi.- Prior to 1931, Mississippi had not cooperated in stream-gaging, although it had experienced many floods. By that time the Army Engineers' "308" investigations had perhaps focused the attention of the people on the flood hazard, helped by the publicity efforts of an active press. Sufficient funds were supplied to the Mississippi Geological Survey in 1931 to permit cooperation with the Survey and thus prevent the complete cessation of stream-gaging when the "308" investigations ended. Cooperation continued on a modest scale until 1937. By that time the growing industrial activity in the southeastern States 55/ was being felt in Mississippi and many

55/ p. 27.

companies were seeking sites for plants which required large quantities of water; they wanted facts, not guesses, regarding available supplies. Inquiries coming to the Industrial and Advertising Commissions, and Chambers of Commerce aroused interest in the State's water resources. Also, the Highway Department, partly as a result of recent floods, felt strongly the need for stream-flow records, and the State Health Department was becoming concerned over pollution of streams with the increases in population to be expected from the industrial growth.

Early in 1938 the State Planning Commission enlisted the support of various State agencies and local groups of citizens, and presented to the legislature a strong recommendation from which the following has been abstracted: 56/

56/ Letter from E. B. Rice to author.

> The gaging and measurement of streams is of utmost importance in flood control, erosion control, all types of conservation, public health, highway planning and construction,

and in the development of industry. For all of these purposes a knowledge of total yearly flow, the seasonal flow, the monthly flow, and the extreme high and low-water stages are basic information upon which to build an intelligent plan of control and development. To a lesser extent, a knowledge of the chemical analysis and turbidity is also basic information; these are particularly important in erosion control and industrial development.

* * * The State has contributed only $1000 per year for cooperative work, a sum which is entirely inadequate and which may eventuate in the abandonment of several stations. Practically all industrialists considering Mississippi for possible location of a plant inquire regarding the water supply, and many of them inquire specifically concerning the surface waters. Since no long-term program of study has been initiated many of these inquiries cannot be satisfactorily answered. Several industries have been lost to the State through lack of this information.

With such a widespread demand for an enlarged water-resources investigation, the legislature increased greatly the cooperative appropriation for the State Geological Survey. With the increased funds available, a suboffice of the Montgomery district was established at Jackson, Miss. on August 5, 1938.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1931	$ 287	$1,037	1936	$1,724	$ 988
1932	1,713	727	1937	1,000	1,386
1933	1,000	1,245	1938	1,000	819
1934	1,046	482	1939	10,000	11,274
1935	979	781			

Louisiana.- The first cooperation with a State agency in Louisiana began in 1933 when the Department of Civil Engineering of the State University wished to make an intensive study of the Bayou Duplantier drainage basin having an area of 0.8 square miles near the University, which would include records not only of run-off but also of rainfall and evaporation. Cooperation was arranged with the University in March 1933 whereby the Survey furnished a low-velocity current meter and a water-stage recorder for the one gaging station which was constructed by the university. The Survey supervised the collection of records by students of the University. This minor cooperation continued during the period. The Dean of Engineering became much interested in a stream-gaging program for the State and endeavored to obtain a State appropriation for that purpose. But as McCashin phrases it, 57/ "Those

57/ Letter to author.

were days of Huey Long and everything in Louisiana was in turmoil and (the Dean) did not get very far."

In 1937, D. H. Barber by chance met the State geologist at the University and discussed the matter of cooperation. The State geologist

stated that when conditions in the State became more nearly normal he would present the matter to the proper authorities. The next year a favorable opportunity was presented and the State geologist and Barber conferred with the Commissioner of the Department of Conservation, under whom the State geologist functioned. The Commission authorized a program of $5,000 annually by means of funds already allocated to the geologist's department and the cooperative agreement was signed on July 23, 1938. So satisfactory was the cooperation that later in the year the State allocation was increased to $10,000. With substantial cooperation assured, a suboffice was opened August 16, 1938, at the University.

Annual expenditures from State and Survey funds were:

Year	State University	Department of Conservation	Survey
1933	$888		$500
1934	420		156
1935	411		195
1936	358		190
1937	507		202
1938	415		195
1939	415	$10,478	10,170

West Virginia.- Prior to the present period the State geologist of West Virginia had cooperated to the extent of a few hundred dollars annually for the payment of gage observers. This cooperation continued except during the depression years 1932 to 1935, when the State geologist's funds were greatly reduced. In 1929, while West Virginia was still a part of the Middle Atlantic States district, Horton informed the State geologist that unless cooperation could be increased it would probably be necessary to curtail stream-gaging in the State, when the Army Engineers' "308" investigation had been completed. The State geologist wished to prevent, if possible, such curtailment, as it was the duty of his office to investigate the State's natural resources. He had no funds for increased cooperation, but the State had recently enacted a water-power law which authorized the State Public Service Commission to grant permits to develop water power. That agency needed stream-flow records, and to prevent curtailment of the program the Commission contributed $4,500 from its funds during the fiscal year 1930. With total State cooperation amounting to $5,000 and with substantial Army Engineer cooperation, West Virginia was separated from the Middle Atlantic States district and became an independent district on July 1, 1929, with William Kessler as district engineer.

The State water-power act was declared unconstitutional in 1931. Although the Public Service Commission no longer had jurisdiction over the State streams, it continued cooperation though in decreasing amounts as its interest waned. The streams were becoming seriously polluted by industrial and municipal wastes and in 1933 the legislature at the request of the State Board of Health, created the State Water Commission to regulate and reduce such pollution. Although, like agencies in other States, the Commission was not given sufficient funds to enable it to function adequately, it made small annual contributions to the cooperative program during the fiscal years 1936 to 1939.

Annual expenditures from State and Survey funds were:

Year	State Geol.	Public Service Com.	Water Com.	Total	Survey
1929	$500			$ 500	$ 400
1930	500	$4,500		5,000	2,921
1931	500	3,800		4,300	4,298
1932		3,500		3,500	3,494
1933		3,500		3,500	3,415
1934		3,000		3,000	1,521
1935		3,000		3,000	2,284
1936	500	1,200	$500	2,200	1,846
1937	500	1,500	500	2,500	2,251
1938	500	1,500	500	2,500	2,172
1939	500	1,800	500	2,800	2,808

Kentucky.- The State geologist of Kentucky who had contributed a few hundred dollars annually for gage observers during a part of the previous period, contributed $100 during 1929. In 1930, when it was known that Army Engineer cooperation would cease in the near future, Grover conferred with the State geologist to determine whether State cooperation on a more substantial scale could be arranged in order to continue the "308" stations, and cooperation to that end was arranged for the fiscal year 1931. The succeeding years of depression so reduced the State geologist's funds that he was unable to continue the cooperation.

About 1937, T. H. Cutler, formerly chief engineer of the Missouri Highway Commission, became chief engineer of the Department of Highways of Kentucky. While in Missouri he had seen the value of stream-flow records in highway work, and in his task of constructing a new highway system in Kentucky, realized more strongly than before the need for stream-flow records. He accordingly entered into cooperation with the Survey in 1938, and a district office was opened in Louisville on April 18, 1938, with F. M. Veatch as district engineer.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1929	$ 100	$ 0	1938	$2,259	$1,090
1931	1,096	2,480	1939	5,858	7,767
1932	354	0			

Tennessee.- Cooperation with the Tennessee Geological Survey continued through 1932. Thereafter, through a change in State organization, the Geological Survey became the Division of Geology of the Department of Conservation, and continued as the cooperating agency.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1929	$11,253	$5,000	1935	$9,460	$7,268
1930	14,628	6,683	1936	8,000	6,263
1931	17,563	17,886	1937	8,325	7,845
1932	13,511	13,258	1938	8,100	7,626
1933	14,962	15,200	1939	8,850	8,890
1934	9,850	5,751			

Ohio.- Cooperation was continued through the fiscal year 1935 with the State of Ohio, acting through its Cooperative Topographic Survey, 58/

58/ p. 28, 1919-1928.

although on a substantially reduced basis after 1932 when the Governor reduced all appropriations on a flat percentage basis. In January 1935 a new governor who was determined to reduce State expenses, was inaugurated. Instead of reducing appropriation items in a systematic manner he cut out various items apparently more or less at random, as he eliminated such an essential item as that for purchasing coal for the State University. The stream-gaging item was among those eliminated, beginning with the State's fiscal year, January 1, 1936. However, as the State funds previously allotted were good during the biennium, a small amount was carried into the Survey's fiscal year 1937. This governor was reelected on the "plank" that he had saved the taxpayers $8,000,000 during his first 2-year term, and the legislature made no appropriation for stream gaging at its 1938 session. A new administration took office on January 1, 1939, with a legislature whose leaders appreciated the need for stream gaging. They thought, however, that the agencies which would be most benefitted, such as the Highway, Conservation, and Health Departments should pay for the stream gaging from their own funds and refused to approve a separate item for that purpose. The Highway Department then transferred $5,000 of its funds to the Cooperative Topographic Survey to be used for stream gaging during the period March 1 to December 31, 1939. 59/

59/ Letter from C. V. Youngquist to author.

With practically no State funds available, Lasley Lee, the district engineer, arranged cooperation with other public agencies. The comparatively small cooperation which had been in effect with the Miami Conservancy District since the early days of the Ohio District, was now increased to take care of stations in the Miami River Basin which otherwise would have been discontinued. The Muskingum Watershed Conservancy District which had been created in 1933 for flood prevention and other conservation objectives under the same law as that which created the Miami Conservancy District, paid for its operation of some 33 stations in the Muskingum River Basin which otherwise would have been discontinued. The Mahoning Valley Sanitary District was created in 1926 under the Sanitary District Act which permitted cities, counties, and other political sub-divisions to incorporate in one large unit for the purpose of solving their problems of water supply and sewage disposal. The Mahoning Valley is the third largest steel-producing center in the United States and its problems of water supply, where the demand at times exceeded the supply, were serious. The latter cooperation ceased in 1937 and the Army Engineers financed the operation of those stations during the remainder of the period. The City of Columbus cooperated in the operation

of two stations beginning in 1937.

The annual expenditures from State and other funds were:

Year	State	Miami Conservancy District	Muskingum Watershed Conservancy District	Mahoning Valley Sanitary District	City of Columbus	Total
1929	$23,865					$23,865
1930						32,487
1931	23,092	$1,200				24,292
1932	15,617	2,000				17,617
1933	15,060	2,200				17,260
1934	16,500	2,941				19,441
1935	16,009	2,896				18,905
1936	1,665	3,953	$3,400	$3,400		11,418
1937	1,469	3,861	13,857	1,600	$287	21,074
1938	-	3,000	6,851		674	10,525
1939	5,000	5,000	9,420		500	19,920

Note.- The total expenditures are exact but those for each agency are approximate.

The expenditures from Survey funds were:

1929	$5,000	1933	$13,626	1937	$16,684
1930	5,000	1934	9,111	1938	9,972
1931	25,904	1935	14,801	1939	15,068
1932	21,518	1936	11,731		

Indiana.- In 1930 cooperation was started with the Department of Conservation of Indiana through its Division of Engineering. That agency was created by Act of the 72nd General Assembly, [60] for the purpose of

[60] Chap. 238, p. 695.

obtaining and disseminating information and to make recommendations relative to drainage and reclamation, in order that those interested might proceed "more intelligently with their work." The Division was also directed:

> To determine and define natural drainage areas and to place at the disposal of public officials such information as will enable them to plan their work for the ultimate accomplishment of an integrated drainage system for an entire watershed.
>
> To prepare computations as to flow likely to occur in any natural or artificial channel, or to be impounded by any levee or dike. * * *

As a basis for meeting those requirements a stream-gaging program had been started in May 1922. Although it did not cooperate in this program, the Survey furnished complete information as to its standards of equipment and procedure. [61] The program grew steadily until, in 1930,

61/ Surface water supply of Indiana. Publication 72, Dept. of Conservation, June 1928, p. 12.

30 stations were operated.

The Survey began stream gaging in Indiana in 1928 when Army Engineers desired records at 13 stations of which 10 were State stations. The Army Engineer cooperation was scheduled to close in June 1931, and to provide funds for the Survey to continue its work, Grover, in 1930, went to Indianapolis and conferred with Denzil Doggett of the Division of Engineering. Cooperation was arranged on the basis that the Survey would establish a district office in Indianapolis and cooperate in the operation of all of the State stations. The district office was established August 18, 1930, with H. E. Grosbach as district engineer. Beginning July 1, 1934, the Indiana Highway Commission joined with the Division of Engineering in the stream-gaging program. Both agencies were then in the Department of Public Works which became the cooperating State agency.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1931	$2,782	$4,010	1936	$4,321	$3,667
1932	4,692	4,185	1937	4,693	4,037
1933	4,427	4,325	1938	6,205	5,229
1934	4,307	1,176	1939	6,142	5,357
1935	4,556				

The increases during 1938 and 1939 reflected a greater interest in streamflow records after the 1937 flood.

Illinois.- The Illinois Department of Purchases and Construction, which was the State agency cooperating with the Survey at the beginning of the period, had as its chief function the construction and supervision of the Illinois River Waterway. At the request of local interests, the Federal government took over that waterway by the River and Harbor Act of July 3, 1930. Thereafter there was little reason for continuing the Department of Purchases and Construction and it was abolished on June 30, 1933. The Department's Division of Waterways had been the actual cooperating State agency, and its future hung in the balance for some time although State funds had been appropriated for its use during the biennium ending June 30, 1933. The Division of Waterways was finally retained in the Department of Public Works and Buildings where it had been prior to the creation of the Department of Purchases and Construction. Cooperation with the Division of Waterways continued until June 30, 1933, the end of the biennium.

Anticipating the discontinuance of the Division of Waterways, J. H. Morgan, district engineer, early in 1932, at the suggestion of the Division of Waterways, contacted the State Water Survey, an agency of the Department of Registration and Education, having its headquarters in Urbana, the seat of the University of Illinois. The State Water Survey, which had been created in 1895, was engaged chiefly in determining the yield of deep wells and in analyzing the mineral content of their waters. It had just started a small stream-gaging program in which one gaging station had been established. As the Civil

Administrative Code (1917) directs that agency to cooperate with the United States Geological Survey, as well as other Federal agencies, the Director of the State Water Survey wished to cooperate with the Survey, and cooperation was started in February 1932. The contract for the fiscal year 1933 contained the provision that the Survey office should be in Urbana instead of Chicago, and the change was made on June 30, 1932.

During the period from February 1932 to June 1933 there were two cooperating State agencies, but, at its next session, the legislature made the cooperative appropriation to the State Water Survey instead of the Division of Waterways. Thereafter until the end of the period the State Water Survey continued as the cooperating agency.

The Ohio River flood of January-February 1937 caused great damage in southern Illinois, and the legislature which was then in session made an appropriation to the Division of Waterways for flood prevention studies. In June 1939, with funds available from that appropriation, the Division of Waterways entered into a 25-month agreement with the Survey for stream gaging, and thus again became a cooperating State agency. That it had been interested in stream-flow records during the non-cooperating years is shown by the following statement of the Division of Waterways: [62]

[62] Stream-flow data of Illinois: Dept. of Public Works and Buildings, Division of Waterways, 1937.

> Accurate long-time records of stream flow and precipitation are vitally necessary to prevent both under- and over-development of engineering projects, and the cost of gathering such records is more than justified by the results achieved.
>
> The conservation of the natural resources of Illinois, control of floods and droughts, and the development of power and recreational projects, are all engineering problems requiring detailed knowledge of stream flow and basin characteristics. Therefore, while the maintenance of present gaging stations and the establishment of strategically located new stations is essential, further stream-flow studies are necessary.

Annual expenditures from State and Survey funds were:

Year	Division of Waterways	State Water Survey	Total	Survey
1929	$3,926		$3,926	$5,000
1930	3,974		3,974	2,738
1931	5,995		5,995	5,707
1932	6,171	$1,349	7,520	7,453
1933	6,937	2,421	9,358	9,565
1934		5,372	5,372	5,483
1935		5,644	5,644	5,646
1936		6,000	6,000	6,076
1937		6,000	6,000	5,726
1938		9,042	9,042	8,754
1939	45	10,958	11,003	10,542

Michigan.- Cooperation with the Michigan Stream Control Commission was started in August 1930. Pollution was the chief problem related to the streams of that highly industrialized State. The Stream Control Commission was created as a separate agency by the 1929 session of the legislature,[63] to handle pollution problems which previously had been

[63] Act 245 P. A. 1929.

divided among several agencies. The Commission was charged with the responsibility of protecting unpolluted streams and of finding means to lessen the pollution of those seriously affected. Section 5 of the Act creating the Commission states:

> * * * the authority to ascertain and determine for record in making its orders, what volume of water actually flows in all streams and the high and low water marks of lakes, and other waters of the State, affected by the waste disposal or pollution of municipalities, industries, public, and private corporations, individuals, partnerships, associations or any other entity.

At that time, the only current stream-flow records were those obtained at four gaging stations maintained by private interests. It was therefore necessary for the Stream Control Commission to start a stream-gaging program for which funds were available. Cooperation was arranged with the Survey. It appears that Dr. R. A. Smith, State geologist, informed the Washington office in June 1930 that cooperation would be offered during the next fiscal year and he was the moving spirit in arranging for such cooperation.[64]

[64] Letter from N. C. Grover to author.

A district office was opened in Lansing on August 24, 1930, with Berkeley Johnson as district engineer. This cooperation was short lived as the new Governor who took office in January 1931 was faced with a huge deficit in State finances, and was determined to reduce expenditures drastically during the next fiscal year. In accordance with that program the legislature reduced the Stream Control Commission funds to such an extent that State funds were not available for continuing cooperation during the fiscal year 1932, and the district office was closed in June 1931.

In September 1932, Mr. Paulsen had a conference with the Commission and as a result cooperation was resumed on a limited scale in November 1932, and continued during the remainder of the period. The basis of this cooperation was that State employees were to perform the field work, and the Survey was to supervise the field work and compute the records.[65] As funds were not sufficient to support a separate district,

[65] Statement of H. E. Grosbach to author.

Michigan was made a part of the Indianapolis district.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1931	$6,072	$5,828	1936	$4,798	$5,072
1932	96	294	1937	4,033	2,972
1933	2,007	2,005	1938	4,237	3,533
1934	1,215	1,110	1939	4,852	4,700
1935	4,150	3,090			

Wisconsin.- The activities of the State Railroad Commission, the cooperating State agency in Wisconsin, had expanded so greatly that on July 1, 1931, its name was changed to the State Public Service Commission, as being more nearly descriptive of its functions. Survey cooperation continued with that agency during the period. An important function of the Commission was the valuation of water powers and for that work the stream-flow records were essential. Beginning with the fiscal year 1938, cooperation was also effective with the State Statutory Committee on Water Pollution. This committee was composed of members of several State departments concerned with water pollution problems. To obtain basic data for their studies the Committee cooperated with the Survey in the amount of $1,000 annually.

Describing the use made of the stream-flow records, the Public Service Commission stated: 66/

66/ Bien. Rept., July 1, 1934, to June 30, 1936, p. 25.

> * * * Stream gaging work is useful in development of plans for power projects, construction of highway bridges and dams, and in navigation, flood control, sewage disposal, irrigation, and soil erosion control work. It is also used in arriving at the amount of stream-flow regulation by two water storage reservoir systems on the Wisconsin and Chippewa-Flambeau River systems in order to fix tolls which water power users shall pay to the companies operating these reservoir systems under special legislative charters.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1929	$6,485	$3,250 1/	1935	$6,891	$5,052
1930	7,232	4,079	1936	6,766	5,718
1931	7,043	6,771	1937	8,142	7,265
1932	6,985	7,227	1938	8,359	7,141
1933	6,759	6,833	1939	8,942	8,770
1934	6,704	3,497			

1/ Allotment.

Minnesota.- The Minnesota Department of Drainage and Waters was the cooperating State agency until 1931. In that year, at the insistence of various influential groups interested in aggressive conservation, the legislature, by the Conservation Act, created a unified Department of Conservation for the purpose of bringing under one

head all conservation activities of the State. 67/ The State had dis-

67/ First Bien. Rept. Commission of Conservation, 1931 and 1932, p. 9.

continued cooperation with the Survey in water investigations in 1917. 68/

68/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 328.

As the former Department of Drainage and Waters became the Division of Drainage and Waters in the Department of Conservation, there was no actual change in the cooperating agency which continued unchanged during the remainder of the period. However, the interest in conservation which caused the legislature to pass the Conservation Act resulted in a substantial increase in cooperative funds. 69/

69/ p. 41, 1919-1928.

In describing the cooperation, the Director of the Division of Drainage and Waters stated: 70/

70/ Second Bien. Rept. Dept. of Conservation, 1933-34, p. 47.

> The importance of this work cannot be over estimated, especially during present drouth conditions. The value of authentic data on the behavior of surface waters is recognized whenever water is of value for promoting human welfare and industry. It is of particular value in a State like Minnesota where surface waters play such an important part in the State's every phase of development. * * * The records of low discharge which are being secured at the present time are going to be of inestimable value in preparing for similar conditions in the future.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1929	$ 372	$ 300	1935	$4,027	$3,869
1930	322	324	1936	4,781	1,983
1931	1,981	3,427	1937	5,332	3,252
1932	2,438	656	1938	3,725	3,452
1933	1,378	1,271	1939	3,077	2,937
1934	2,154	2,316			

Iowa.- Cooperation with the State of Iowa, which had ceased because of lack of funds in June 1927, was resumed in October 1932. The drought of 1930 had made the citizens more water-conscious than they had been previously, and Prof. Floyd A. Nagler, then professor of hydraulic engineering at the State University of Iowa, and Director of the Iowa Institute of Hydraulic Research, thought it a favorable time to raise State funds to resume the cooperation. As R. G. Kasel writes, 71/

71/ Memorandum, Stream Gaging in Iowa, Dec. 15, 1935.

It was no small task to collect together enough support from State agencies, cities, and others to warrant the Water Resources Branch of the U. S. Geological Survey in again cooperating. It was Prof. Nagler's hope that the State legislature eventually would appropriate sufficient funds to provide for the State's share of the work, once the collection of stream-flow records had again been started and the value of such records demonstrated.

Prof. Nagler succeeded in obtaining contributions from the Iowa Institute of Hydraulic Research, State Fish and Game Commission, and the State Conservation Commission, the Des Moines Water Works, the City of Cedar Rapids, and several power companies. These contributions were made to the Institute of Hydraulic Research and Prof. Nagler became the cooperating State official. With funds assured, cooperation was arranged with the Survey, and a district office was established in Iowa City on October 17, 1932.

Prof. Nagler died in the following year, and for a time there was no State official sufficiently interested to direct State efforts for cooperation. The State agencies however continued their allotments. In July 1935, Dr. A. C. Trowbridge became director of the Iowa Geological Survey which had been the cooperating State agency for some years prior to 1927, and Dr. Trowbridge became interested in putting State cooperation on a better basis. He sponsored a movement by the various State agencies to obtain an appropriation for the cooperative stream-gaging program at the 1935 session of the legislature. As that effort was unsuccessful, the Legislative Retrenchment and Reform Committee which had funds at its disposal for special State needs, was requested to make an allotment for the cooperative work. Before that request was granted, the interested State agencies were required to contribute as much as possible from their own funds. The Conservation Commission, Geological Survey, Planning Board, and Department of Health made contributions for the biennium, and then the Legislative Committee allotted to the State Geological Survey $4,325 for the cooperative work during the biennium. In 1937 a direct appropriation was again refused, and again the Committee on Retrenchment and Reform made an allotment to the State Geological Survey in the amount of $6,000 for the biennium. The Institute of Hydraulic Research continued its cooperation independently of that of other agencies. Thus there were two separate cooperative agreements, one with the State Geological Survey and the other with the Iowa Institute of Hydraulic Research.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1933	$3,191	$3,142	1937	$8,834	$8,077
1934	5,667	2,795	1938	9,962	7,891
1935	4,701	4,064	1939	8,908	8,903
1936	6,212	4,578			

During the previous period of cooperation the chief use of stream-flow records had apparently been made by the State Highway Commission in connection with design of waterway openings to carry flood flows. When cooperation was resumed the drought had drawn attention to other uses

for stream-flow records, particularly in connection with municipal water supplies as indicated by the following statement of the Water Resources Division of the Iowa State Planning Board: 72/

72/ Stream-flow records of Iowa 1872-1932.

> One of the uses of stream-flow records in this state is in connection with municipal and industrial water supply. Many of the larger cities located on streams are dependent on surface water supplies, and many other cities and towns may find it advantageous to develop surface water supplies to replace inadequate or unsatisfactory wells. If adequate records of stream flow had been available it is not unlikely that some of the recent failures of municipal water supplies might have been avoided.

The Planning Board stated also that stream-flow records were needed for stream pollution surveys, water-power development, flood-control works, and design of waterway openings.

Missouri.- Cooperation with the State geologist of Missouri continued during the period. By 1930 the State Highway Commission had made frequent use of the stream-flow records in determining from the high-water records the size of the waterway openings needed at each new bridge as it was designed. In that connection it was stated by the Commission that the records obtained at certain single stations were of greater value than the cost to the State of maintaining the whole State-wide program for a year. 73/ So necessary were additional

73/ Water-Resources Bulletin, May 10, 1930, p. 15.

stations that the Commission proposed cooperation whereby 18 gaging stations would be established on streams with drainage areas ranging from 10 to 100 square miles,--a size for which Survey records were notably deficient. Highway engineers assigned near the proposed stations were to be furnished with current-meter equipment and would assist in making flood measurements, and other employees would read both the stream gages and the rain gages to be installed in each basin. This proposal was accepted and continued during the period, the number of stations being gradually reduced to 12. The average annual allotment for this cooperation was about $800.

Minor cooperation which consisted chiefly in furnishing gage observers was arranged with the Game and Fish Department, Park Department, and with the cities of Joplin and Springfield.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1929	$8,929	$4,750	1935	$9,692	$7,342
1930	10,579	5,746	1936	10,168	7,988
1931	12,376	10,814	1937	10,107	9,611
1932	11,244	8,756	1938	11,127	9,481
1933	7,633	11,083	1939	11,222	12,000
1934	8,360	4,653			

Arkansas.- Cooperation with the State geologist of Arkansas which had been started in September 1927, continued through 1933 in decreasing amounts. By 1933 the funds available to the State geologist had become so small that the Budget Committee of the legislature presented a separate cooperative stream-gaging bill. As this failed of passage, no State funds were available during the depression years of 1934 and 1935. Cooperation was resumed in 1936.

Because of reduced and temporarily suspended cooperation with the State geologist, it was desirable to arrange, if possible, for cooperation with other State agencies. The ground work for such cooperation had been laid in 1930 when officials of Fort Smith were considering Lee Creek as a new source of water supply. J. H. Gardiner, district engineer, suggested that the city cooperate in the installation of a gaging station to determine the available supply. This suggestion was accepted and the station was established with the result that the records which were furnished promptly, enabled the consulting engineers to revise their plans and reduce by $100,000 the estimated cost of developing the new source of supply. The gaging station caused so much favorable comment that, as Mr. Gardiner writes, 74/ "There seemed to be a continuous

74/ Letter to author.

series of articles on it, which I made no attempt to stop." In 1936, Mr. Gardiner consulted with the chief engineer of the Arkansas State Highway Commission and subsequently Paulsen and Gardiner met with the Commission for the purpose of arranging a cooperative program which related particularly to waterway openings to withstand floods. This program was started in July 1937 with an allotment of $5,000.

Annual expenditures from State and Survey funds were:

Year	State Geologist	State Highway Commission	Total	Survey
1929	$2,500		$2,500	$1,250
1930	2,494		2,494	1,372
1931	2,489		2,489	2,600
1932	1,122		1,122	1,100
1933	1,092		1,092	985
1934	0		0	15
1935	0		0	0
1936	849		849	826
1937	1,168		1,168	1,217
1938	950	$5,000	5,950	5,950
1939	700	5,000	5,700	5,737

North Dakota.- Cooperation with the State engineer of North Dakota, which had ceased in 1925, was resumed in 1931. As a result of the interest aroused by the Army Engineers' "308" investigations, and the desire to continue certain Army Engineer stations when that cooperation should cease. A substantial appropriation was made by the legislature for the years 1932 and 1933, but thereafter the drought years so reduced the State's income that the State engineer's funds were curtailed to the point where it was impossible for him to continue cooperation except in the payment of one or two gage observers. During the last two years of the period improved economic conditions made

possible an increase in the State's allotment.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1931	$ 494	$ 499	1935	$ 165	$ 78
1932	2,346	2,427	1936	60	79
1933	3,846	3,652	1937	140	94
1934	35	187	1938	980	809
			1939	1,063	1,054

Nebraska.- Cooperation with the State engineer of Nebraska had ceased in 1914 and thereafter the State carried on its stream-gaging program in the North Platte and Platte River Basins.[75] As a result of

[75] Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 330.

the Army Engineers' "308" investigations the Survey, in 1928, established and operated 15 gaging stations in Nebraska. Looking forward to a continuation of those stations when the Army Engineer investigations were finished, Grover and the author conferred with the State engineer in February 1931. At that time the State was operating gaging stations in the Platte River Basin, chiefly in the North Platte Basin and was making miscellaneous measurements in other basins.

The North Platte River, an interstate stream, had been over-appropriated, and the shortage of water was creating serious conflicts of interest between Wyoming and Nebraska. An important question related to the amount of return water from extensive irrigation, and R. H. Willis, chief of the Bureau of Irrigation, Water Power, and Drainage, a bureau under the State engineer, was desirous of having an intensive study made of the return flow. He stated that if that study could be included in the program, he wished to cooperate with the Survey on the basis that both State and Survey personnel would be used. That proposal was accepted and cooperation was started on August 1, 1931.

Interstate problems reached the U. S. Supreme Court when Nebraska sued Wyoming in 1934, and Colorado was brought into the suit. At the beginning of the testimony before the Special Master, the attorneys for the three States agreed that as the stream-flow records to be introduced had been made under the supervision of the U. S. Geological Survey, and were considered Survey records, they would be accepted as evidence without question. So far as the author is informed that attitude was maintained.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1932	$15,278	$15,212	1936	$15,191	$12,204
1933	14,719	14,224	1937	14,866	14,228
1934	12,024	6,812	1938	15,011	13,098
1935	12,424	9,303	1939	15,383	15,003

Kansas.- State and Survey funds in Kansas had been so small during the latter part of the previous period that cooperation had ceased in June 1927. Army funds for the maintenance and operation of 21 stations and a small amount of Survey funds made possible the resumption of cooperation on July 1, 1928. J. B. Spiegel, who had been an employee of the State during the previous year for the purpose of continuing the stream-gaging program was reinstated in the Survey and resumed his old position as district engineer. The State Board of Agriculture, through Geo. S. Knapp, chief engineer of the Water Resources Division, again became the cooperating State agency. It was Knapp's interest in the Kansas streams that had kept the stations in operation during the interim.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1929	$3,254	$2,000	1935	$6,448	$4,459
1930	5,103	2,239	1936	7,684	6,036
1931	3,988	4,528	1937	7,137	6,518
1932	6,096	8,151	1938	6,498	6,601
1933	7,241	6,922	1939	6,857	7,027
1934	7,015	3,253			

Oklahoma.- Cooperation with the State of Oklahoma began on September 1, 1935. The State Planning and Resources Board had been created by the legislature at its 1935 session, and J. C. Hoyt and J. H. Gardiner, district engineer of the Fort Smith district, conferred with the Director of the Board on the needs for stream gaging in the State. As a result, the Director allotted $4,000 from the Board's funds for cooperation during the remaining 10 months of the fiscal year 1936. As a result of an interplay of State politics, the State funds for the next fiscal year were so drastically curtailed that less than $600 was available for continuing the cooperation. At the 1937 session of the legislature, the State Planning and Resources Board was reorganized, with the same Director, and obtained a small cooperative appropriation which was increased from other available funds.

Before the end of the biennium the value of stream-flow records was brought forcibly to the attention of the State authorities. The State was much interested in the possibilities of irrigation in the Cimarron River Basin and proposed the Kenton project of 20,000 acres. This proposal was studied by the Bureau of Reclamation which reduced the irrigable area to 5,000 acres on the basis of the meager stream-flow records available. The report by the Bureau of Reclamation dated July 1938, contained the statement that 5 years of stream-flow records must be obtained before further consideration could be given to the project. The Grand River Dam Authority, a State agency operating under a PWA grant, was constructing a dam on the Neosho River, for both flood control and power development. In 1938, State authorities were checking the plans for this dam, the cost of which was about $20,000,000, and in that connection made use of Survey stream-flow records. This study showed not only the value of the available records but also the need for additional records.

As a result of the increased realization of the value of stream-flow records, the allotments during the ensuing period were practically doubled.

Annual expenditures from State and Survey funds were:

Year	State Planning & Resources Board	Oklahoma City	Total	Survey
1936	$4,000		$4,000	$2,660
1937	596		596	1,185
1938	6,310		6,310	5,428
1939	7,676	$250	7,926	7,551

Texas.- Cooperation with the State Board of Water Engineers of Texas continued during the period.

Annual expenditures from State and Survey funds were:

Year	State	Municipal Water Districts, etc.	Total	Survey
1929	$30,708	0	$30,708	$5,000
1930	16,709	$12,578	29,287	5,758
1931	18,025	12,683	30,708	32,990
1932	18,208	9,666	27,874	36,070
1933	18,600	8,944	27,544	18,866
1934	11,831	8,682	20,513	11,474
1935	10,862	5,672	16,534	13,998
1936	15,138	6,805	21,943	14,643
1937	1/		19,286	19,992
1938	1/		27,943	24,252
1939	1/		29,287	35,074

1/ Not segregated.

Montana.- Cooperation with the State engineer of Montana was continued during the period. The newly-created Water Conservation Board also became a cooperating State agency during the latter years of the period. In 1933 the Water Conservation Board was created by the legislature 76/ to provide the legal machinery whereby the State

76/ Extraordinary Session, 1933, Ch. 35.

could cooperate with the Public Works Administration. A revolving fund was provided by the sale of bonds payable from the revenues derived from the sale of water. From this fund the money needed to obtain grants for water conservation projects could be furnished. As stream-flow records were essential in its work, the Board made allotments from its funds to the stream-gaging program, beginning with the fiscal year 1936.

Annual expenditures from State and Survey funds were:

Year	State Engineer	Water Conservation Board	Total	Survey
1929	$6,100		$6,100	$3,400
1930	4,464		4,464	3,546
1931	7,599		7,599	7,343
1932	8,657		8,657	9,169

Year	State Engineer	Water Conservation Board	Total	Survey
1933	$9,430		$9,430	$9,173
1934	5,485		5,485	2,501
1935	9,479		9,479	7,287
1936	9,311	$4,490	13,801	10,529
1937	8,661	5,503	14,164	12,905
1938	8,945	5,007	13,952	12,542
1939	10,212	2,749	12,961	12,150

The dry years during the present period were largely responsible for the very considerable increase in State funds as compared with those during the previous period. A. H. Tuttle writes, 77/

77/ Letter to author.

> It is a very common expression among the legislators of the last two sessions that "the water resources of Montana are its greatest asset."

Wyoming.- Cooperation with the State engineer of Wyoming was continued during the period. The intensification of interstate problems on the North Platte River culminating in a suit brought by Nebraska against Wyoming, in 1934, caused the State to increase its funds for investigations in the North Platte Basin beginning in 1932. The drought years intensified interest in irrigation, and caused the State Water Conservation Board to make an allotment of $1,500 to the State engineer's office for the cooperative stream-gaging program in 1939. The State Water Conservation Board had been created by the Legislature in 1937 for the purpose of studying the development and conservation of the State's water resources.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1929	$8,064	1/	1935	$11,471	$8,694
1930	6,069	$4,867	1936	9,654	7,565
1931	6,202	6,223	1937	8,713	8,136
1932	10,965	10,859	1938	9,993	9,124
1933	11,473	9,629	1939	11,546	11,323
1934	7,984	5,973			

1/ Allotment for Colorado and Wyoming not segregated.

Colorado.- At the beginning of the period, the State engineer of Colorado was furnishing the field data for a few stations which were being maintained by Federal Power Commission permittees, and the Survey was maintaining only a few stations including a number of Army Engineer stations which were discontinued in 1931. In 1933, when PWA funds were first allocated to the Survey, it was necessary to have formal cooperation with the State before such funds could be allotted to Colorado, and the State engineer entered into cooperation as of October 1, 1933, in order that such funds might be made available for the rehabilitation of gaging stations which had been operated

by his organization. These stations were included in the cooperative program which was expanded by the establishment of additional stations needed for the intensive investigation of irrigation projects then being started by both the Bureau of Reclamation and the State. The State was also much concerned with interstate water problems which had confronted Colorado for many years, and which were then becoming acute. Cooperation continued during the remainder of the period.

The Denver Water Board paid gage observers' salaries amounting to $150 annually, and in October 1936 allotted $1,000 toward the cost of installing four new stations.

Annual expenditures from State, City, and Survey funds were:

Year	State	City	Total	Survey	Year	State	City	Total	Survey
1929	$ 497	$150	$ 647	1/	1935	$25,670	$150	$25,820	$19,547
1930	389	150	539	1/	1936	37,599 2/	150	37,749	21,469
1931	376	150	526	1/	1937	28,273 3/	1,150	29,423	31,598
1932	400	150	550	1/	1938	26,706	150	26,856	22,998
1933	500	150	650	1/	1939	26,934	150	27,084	25,446
1934	15,823	150	15,973	7,199					

1/ No definite allotment for Colorado.

2/ Includes $11,986 for Rio Grande Joint Investigation.

3/ Includes $2,647 for Rio Grande Joint Investigation.

New Mexico.- Subsequent to the discontinuance of cooperation with New Mexico on January 1, 1915, 78/ the State engineer carried on a State-

78/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 407.

wide stream-gaging program. In 1931, a governor was elected who announced that his program would be one of economy. As the Survey was in position to cooperate on a 50-50 basis, and thus aid the economy program, the Washington office addressed a letter to him suggesting the practicability of resuming cooperation. This suggestion was accepted and cooperation was resumed in July 1931 and was continued during the period. A district office was established in Santa Fe on July 1, 1931 with Berkeley Johnson as district engineer. In describing the cooperation during the first year, the State engineer said: 79/

79/ Tenth Bien. Rept., p. 14.

> That portion of the records subsequent to July 1, 1931, has been produced by the United States Geological Survey through a cooperative agreement with the State Engineer. * * *
>
> The stream gaging studies of the State Engineer's Office have been enlarged during the past biennium and the methods utilized in carrying out the work have been improved insofar as consistent with economical operation. Under the present system of stream investigation there has been greater frequency in obtaining measurements and therefore a resultant of greater accuracy in the estimate of stream flow. Many new gaging

stations have replaced those in bad repair and * * * stations have been installed in new localities.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1932	$15,030	$17,023	1936	$17,219	$12,798
1933	12,920	13,766	1937	27,052	20,169
1934	9,907	7,174	1938	31,413	34,326
1935	12,991	9,121	1939	28,297	23,646

The decreases for 1933-35 show the effect of the depression years. The increases for 1936-37 were due chiefly to the additional cost of the Rio Grande Joint Investigation, and for 1938-39 to the special hydrographic survey in the San Juan River Basin.

Idaho.- Cooperation with the Idaho Department of Reclamation continued during the period with State funds divided between the Boise and Idaho Falls offices on the basis of the number of gaging stations of State-wide interest operated by each 80/. Of the total

80/ p. 38, 1919-1928.

State funds, slightly more than two-thirds were allotted to the Boise office.

In January 1937, the Water Conservation Board was created for the purpose of aiding in the development of small streams. That work had originally been started by the Governor's Emergency Drought Committee appointed in 1934 to develop temporary emergency irrigation and domestic water supplies. In the late spring of 1938, the Board entered into cooperation with the Boise office of the Survey for the establishment of additional stations and continued the cooperation during the remainder of the period.

Annual expenditures by the Boise and Idaho Falls offices from State and Survey funds were:

Year	Department Reclamation	Water Cons. Board 1/	Total	Survey
1929	$17,000		$17,000	$ 5,000
1930	18,800		18,800	5,000
1931	18,178		18,178	20,617
1932	14,724		14,724	20,755
1933	22,936		22,936	13,602
1934	16,967		16,967	11,965
1935	22,304		22,304	14,454
1936	23,118		23,118	19,969
1937	22,872		22,872	22,869
1938	26,109	$150	26,259	20,229
1939	19,327	1,375	20,702	23,543

1/ Letter from T. R. Newell to author.

Utah.- Cooperation was continued with the State engineer of Utah. Under the stress of the depression, the legislature, in 1933, cut the specific cooperative appropriation for stream gaging to $2,500 for the biennium. In describing this situation the State engineer stated: 81/

81/ 19th Bien. Rept., 1933-34, p. 9.

> This amount was insufficient to carry on the State's part of the work and cooperate on a workable basis with the Geological Survey. Water users were appealed to for financial aid but without success. Finally, on June 30, 1933, except for the Governor's act in allocating $5,000 from emergency funds for expenditures during the biennium, stream-gaging work of necessity, would have been discontinued, a condition which would have resulted in an irreparable gap in the records.

Subsequent legislatures made larger appropriations for cooperative stream gaging, and with the aid of other available funds the program was continued.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1929	$6,042	$3,400	1935	$5,474	$4,041
1930	6,534	4,818	1936	7,994	6,954
1931	5,421	5,483	1937	7,907	7,779
1932	8,492	8,413	1938	8,630	8,304
1933	6,187	6,793	1939	9,750	8,960
1934	5,325	2,925			

Nevada.- Cooperation with the State engineer of Nevada continued, although reduced in the depression years.

Annual expenditures from State and Survey funds were:

Year	State	Survey	Year	State	Survey
1929	$ 673	$1,250	1935	$ 701	$ 357
1930	1,788	730	1936	1,500	1,345
1931	1,392	1,369	1937	1,332	1,399
1932	1,050	1,500	1938	1,321	1,180
1933	1,344	1,344	1939	1,422	1,269
1934	815	385			

Arizona.- Cooperation with the State Water Commission of Arizona continued through 1933. The cooperative item for the 1934-1935 biennium had passed the House and came to a vote in the Senate on the day that the President closed all national banks. The psychological effect of that evidence of deep depression caused the rejection of the stream-gaging item by the slender margin of one vote. 82/ Two years later the

82/ Letter from W. E. Dickinson to author.

legislature resumed its former procedure of appropriating funds for cooperative stream gaging. During the previous period the State

appropriations had divided the funds between the Colorado River stations and those for other Arizona streams. Beginning with the fiscal year 1929, separate Survey funds were available for the maintenance of the Colorado River base stations, and thereafter State funds were not available for those particular stations. 83/

83/ Op. cit.

To fill the void left by the failure of the State to appropriate cooperative funds for 1934 and 1935, the Salt River Valley Water Users' Association, a State agency which relied on records of Salt and Verde Rivers, and Tonto Creek, cooperated in the maintenance of stations on those streams. This cooperation was continued in decreased amounts after the regular State cooperation was resumed.

Annual expenditures from State and Survey funds were:

Year	State Water Com.	Salt River Valley W. U. A.	Total	Survey 1/
1929	$18,127	0	$18,127	$6,609
1930	16,075	0	16,075	5,001
1931	16,075	0	16,075	13,508
1932	20,610	0	20,610	19,361
1933	21,031		21,031	15,009
1934	1,244		1,244	6,273
1935	0	$11,666	11,666	9,239
1936	15,092	11,914	27,006	22,417
1937	15,000	7,200	22,200	27,198
1938	15,297	6,000	21,297	23,112
1939	14,739	6,000	20,739	23,391

1/ Reported by District office.

In addition, from July 1, 1935, to June 30, 1939, the Metropolitan Water District of Southern California contributed $5,000 annually, through the Tucson office. 84/ This cooperation, however, is credited to California.

84/ p. 56.

Washington.- Cooperation was continued with the Department of Conservation and Development of Washington, through the Supervisor of Hydraulics. Except in 1930 and 1931, State funds were increased greatly during the period. In 1927, the Washington Irrigation Institute had advocated a greatly enlarged stream-gaging program which would increase the number of gaging stations to 240 within six years. The interest in the State's water resources shown by that program undoubtedly influenced the State legislature to increase the State appropriations.

In 1932, a State fund of $10,000,000 for relief purposes was raised by a bond issue and of that amount $20,000 was allotted to the Tacoma office for use in constructing new gaging stations and preparing a summary report of published records including those for 1933. This allotment was in addition to the regular State cooperative funds.

Referring to cooperation, the State Supervisor of Hydraulics stated: 85/

85/ Ninth Bien. Rept. Dept. Conser. and Devel., Oct. 1, 1936-Sept. 30, 1938, p. 60.

> Fortunately, responsibility of the Supervisor of Hydraulics for the collection of daily records of stream flow, as required by the Water Code (sec. 8, regulation of diversions) can be furthered quite advantageously by cooperating with the U. S. Geological Survey.

With reference to the value of the records, he stated: 86/

86/ Op. cit.

> At the outset stream-flow records were obtained primarily to study feasibility of irrigation projects. Soon, however, the State's predominance in water power possibilities became apparent, so that records were started for that purpose. Other needs have arisen, the latest being of vital urgency in making plans for adequate control of floods.

Cooperation with the cities of Seattle and Tacoma continued in substantial amounts and with other municipalities and counties in lesser amounts. Beginning with the fiscal year 1932, direct cooperation with cities on a percentage basis made possible the enlargement of the cooperative program with Seattle and Tacoma.

Annual expenditures from State and municipal funds were:

Year	State	Seattle	Tacoma	Other	Total
1929	$4,084	$ 130	$ 433	$ 426	$5,073
1930	1,682	456	1,157	541	3,836
1931	3,221	384	656	1,223	5,484
1932	6,093	2,250	7,143	1,377	16,863
1933	8,492	2,363	2,001	904	13,760
1934	20,940 1/	2,898	1,449	900	26,187
1935	12,479 2/	2,114	1,334	1,825	17,752
1936	14,000	1,918	1,231	2,929	20,078
1937	-	-	-	-	23,786
1938	14,747	2,256	1,062	247	18,312
1939	15,005	1,800	1,066	1,484	19,355

1/ Includes $14,725 relief funds.

2/ Includes $ 4,320 relief funds.

Annual expenditures from Survey funds were:

1929	$5,027	1933	$11,454	1937	$22,345
1930	1,181	1934	8,025	1938	17,399
1931	4,714	1935	15,927	1939	17,338
1932	13,644	1936	16,975		

Oregon.- The State engineer of Oregon cooperated in the stream-gaging program during the period. The divided program which had been started in 1924 [87] was discontinued in 1932 and thereafter all of the

87/ p. 42, 1919-1928.

State's stream-gaging activities became a part of the cooperative program. In addition, the cities of Portland and McMinnville cooperated in the maintenance of a few gaging stations.

Annual expenditures from State, municipal, and Survey funds were:

Year	State	Municipal	Total	Survey
1929	$5,610	$ 201	$5,811	$3,400
1930	7,046	484	7,530	3,686
1931	6,773	404	7,177	7,009
1932	36,735	670	37,405	37,747
1933	32,178	795	32,973	28,077
1934	21,977	769	22,746	13,174
1935	25,004	769	25,773	19,517
1936	22,778	699	23,477	19,816
1937	26,416	850	27,266	25,765
1938	25,395	700	26,095	22,986
1939	26,309	1,097	27,406	25,952

California.- Cooperation was continued during the period with the Department of Public Works of California, through its Division of Water Resources, of which the State Engineer was chief. During the previous decade the cooperative State expenditures had been about $23,000 annually, as contrasted with an average Survey allotment of some $5,000. When the 50-50 principle was recognized by Congress, Edward Hyatt, the State Engineer, believed that California should take full advantage of the changed ratio between State and Federal allotments, and as the existing stream-gaging program was not keeping pace with the increasing needs for records, he requested, and obtained, larger amounts for the cooperative program. As a result, except during the depression years of 1934 and 1935, the State expenditures were considerably greater than during the previous period.

Cooperation with Los Angeles, San Bernardino, Riverside, and Orange counties continued during the period substantially as in previous years. [88] Beginning in 1935, cooperation was arranged with Ventura

88/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 340.

County. This was a continuation on a reduced scale of an investigation of the surface and ground waters started three years previously by the State Engineer. Ventura County cooperated with the Survey in the amount of $1,000 annually.

Cooperation with the East Bay Municipal Utilities District which had been started in 1927, [89] continued on a larger scale, the average

89/ p. 44, 1919-1928.

annual District expenditures being about $7,000. Cooperation with the Santa Clara Valley Water Conservation District was started in 1934. As a result of a series of dry years the ground-water supply on which Santa Clara depended for its water was so depleted that it was necessary to resort to artificial recharge. A number of detention reservoirs were constructed and water released from them at a rate that could be absorbed in the stream channels without wasting into San Francisco Bay. 90/

90/ Letter from H. D. McGlashan to author.

Several gaging stations were required in connection with these operations and the Conservation District cooperated in the amount of $1,000 annually for the operation of those stations.

Cooperation with the City of San Francisco in connection with its Hetch Hetchy development was continued, and increased by the maintenance of a gaging station on Alameda Creek near Niles. The cooperation on Alameda Creek was a continuation of a special investigation carried on for three years by the State Engineer to determine the amount of percolation from Alameda Creek between the Niles station and San Francisco Bay. As the City received a part of its water supply from Alameda Creek, that station was included in the City's cooperation. About $3,000 annually was contributed by San Francisco for both investigations.

Cooperation with the City of Santa Barbara was started in 1936, and continued during the remainder of the period. Previously the City had operated half a dozen stations in the Santa Ynez Basin in connection with its water supply. The City contributed about $3,000 annually to the cooperative program.

The City of San Diego, like most Southern California cities, needed an additional water supply and in 1936 requested cooperation with the Survey in operating nine gaging stations and compiling data on all city reservoirs. One of the streams, Tia Juana Creek, is an international stream and records were of special value, as a treaty with Mexico would be required before further use of the Creek can be made. 91/

91/ Op. cit.

San Diego contributed about $1,800 annually during the years 1937 to 1939. Cooperation was started with the City of Santa Cruz in 1938, and with San Luis Obispo in 1934, involving the operation of one station for each city. The total allotments by these two cities was $250 annually.

In 1931, Stanford University became concerned over its water supply which was derived from ground water, and requested cooperation in maintaining several gaging stations to determine whether additional storage was feasible and also the loss of water by seepage from San Francisquito Creek. The University contributed about $500 annually for this cooperation.

Annual expenditures from State, County, City, District, and Stanford University funds, and also Survey funds, were:

Year	State	Counties and Cities	Districts and Stanford Univ.	Total	Survey
1929	$32,184	$9,767	$4,717	$46,668	$5,000
1930	47,003	10,470	7,622	65,095	7,361
1931	47,166	5,427	15,748	68,341	49,221
1932	47,497	4,871	4,622	56,990	59,851
1933	35,406	4,364	6,392	46,162	38,999
1934	23,174	10,909	9,311	43,394	19,450
1935	26,824	15,480	7,474	49,778	27,209
1936	29,925	19,090	7,984	56,999	42,994
1937	33,207	18,654	6,755	58,616	51,748
1938	31,280	20,889	6,943	59,112	51,371
1939	42,362 1/	16,721	5,873	64,956	55,764

1/ Includes $10,000 allotted by Governor from his special flood relief appropriation, for preparation of special flood report, Water-Supply Paper 843, which was available only for the area covered by the Central Valley Project.

In addition to the cooperative funds listed, the Metropolitan Water District of Southern California cooperated during the latter part of the period. That agency was created to bring water from the Colorado River to communities in Southern California. The District was very much interested in having records of the flow of the Colorado River, particularly in the vicinity of Parker Dam, and when J. C. Hoyt suggested cooperation in 1935 his suggestion was accepted. This cooperation, made through the Tucson office which was maintaining other stations on the Colorado River, began on July 1, 1935 and continued during the remainder of the period in the amount of $5,000 annually by each party.

Hawaii.- Cooperation with the Commissioner of Public Lands of Hawaii and with the cities of Honolulu and Hilo was continued during the period. Referring to the Territorial cooperation, the Annual Report of the Governor to the Secretary of the Interior for the fiscal year 1929, stated: 92/

92/ p. 59, Territorial Annual Report, 1929.

> The work * * * consists chiefly in gaging the streams to determine the water supply of the Territory of Hawaii and investigations and prevention of waste of artesian waters. Funds do not permit the measurement of all streams so representative streams are selected and preferably those draining Territorial lands or in the waters of which the government has some direct interest. The value of any particular stream flow is hard to establish. It is entirely dependent upon possible future utilization of the water; but the longer the accurate record of stream flow has been maintained the more valuable it becomes to the Territory, as any proposed expansion in homesteading or industry immediately raises the question of the amount of available water. Ninety per cent of the records from 85 stations are the measurements of government waters upon which water and land rentals are, or will be, based.

Annual expenditures from Territorial and Survey funds were:

Year	Territory	Survey	Year	Territory	Survey
1929	$23,202	$5,000	1935	$ 9,858	$15,418
1930	24,301	5,630	1936	26,042	18,740
1931	32,264	24,596	1937	23,881	26,625
1932	26,635	24,990	1938	25,233	25,986
1933	19,949	17,257	1939	25,204	29,216
1934	17,468	11,155			

Federal cooperation

The efforts of the Roosevelt administration to combat the depression were in part responsible for the great increase in Federal cooperation with the Survey in the investigation of water. Newly-created agencies--the Public Works Administration, the National Resources Committee, the Soil Conservation Service, and the Flood Control Coordinating Committee of the Department of Agriculture--cooperated generously with the Survey. The Tennessee Valley Authority which took over and expanded many of the Federal activities in the Tennessee River Basin continued cooperation on an enlarged scale.

Of the older agencies, the Army Engineers cooperated to the greatest extent by far. That cooperation was not at first attributable to new policies of the administration, as it was started in 1928 under the Hoover administration. Later cooperation was due largely to the newly-declared flood-control policy after passage of the Flood Control Act of 1936. Existing cooperation was continued with the State Department, Bureau of Reclamation, Indian Service, National Park Service, and Weather Bureau, and new cooperation was arranged with the Biological Survey.

The total Federal (non-Survey) cooperative funds expended annually by the Survey for surface-water investigations, were:

1929	$388,475	1935	$763,301
1930	418,158	1936	327,485
1931	354,680	1937	385,323
1932	195,820	1938	342,294
1933	108,648	1939	1,135,647
1934	696,003		

The large increase in 1929, in comparison with the total Federal cooperation of $88,334 in 1928, 93/ was due to the Army Engineers' "308" investi-

93/ p. 46, 1919-1928.

gations which were started about the beginning of the period and continued through 1932. The large increases in 1934 and 1935 were due chiefly to emergency funds allocated by the Public Works Administration, and in 1939, to cooperation by the Army Engineers and the Public Works Administration.

Another type of Federal cooperation (not included in the above tabulation) was that afforded successively by the Civil Works

Administration, the Federal Emergency Relief Administration, and the Works Progress Administration, and consisted chiefly in furnishing relief labor, engineers, and stenographers for office projects, and skilled and unskilled labor with some foremen and construction supplies for field work in construction. This type of cooperation was started in the fiscal year 1934 and continued during the period. The total amount expended by those agencies for the labor furnished was about $200,000 for office projects, and about $475,000 for construction, or a total of about $675,000.

Army Engineers.- During the previous period Army-Engineer cooperation had been confined chiefly to the Tennessee River Basin, and two other small stream-gaging programs. 94/ The Tennessee River Basin

94/ p. 50, 1919-1928.

cooperation continued until July 1, 1933, when it was succeeded by cooperation with the newly-created Tennessee Valley Authority (TVA). During the present period, however, cooperation with the Army Engineers became effective in nearly all parts of the country, as a result at first of the so-called "308" investigations, and later of the flood-control investigations. Preliminary conferences regarding cooperation had been started in March 1927 by the Topographic Branch but it was not until a year later, in March 1928, that the Army Engineers made the first request for stream gaging and that was limited to the Alabama and Appalachicola River systems. This was soon followed, however, by a conference on general stream-gaging requirements, which resulted in cooperation in nearly all parts of the country.

"308" investigations: Interest in water power during the twenties, particularly as it affected navigable streams, where the Federal Power Commission had jurisdiction, led Congress to insert the following language in the River and Harbor Act of March 3, 1925:

> Sec. 3. The Secretary of War, through the Corps of Engineers, United States Army, and the Federal Power Commission, are jointly hereby authorized and directed to prepare and submit to Congress an estimate of the cost of making such examinations, surveys, or other investigations as, in their opinion, may be required of those navigable streams in the United States, and their tributaries, wherever power development appears feasible and practicable, with a view to the formulation of general plans for the most effective improvement of such streams for the purposes of navigation and the prosecution of such improvement in combination with the most efficient development of the potential water power, the control of floods, and the needs of irrigation: Provided, That no consideration of the Colorado River and its problems shall be included in the considerations or estimates provided herein.

The exclusion of the Colorado River appears to have been due to the fact that the Bureau of Reclamation was then making an intensive study in that basin.

In accordance with the requirement of Section 3, the Army Engineers and Federal Power Commission made a joint report on April 12, 1926,

which was published as House Document 308, 69th Congress, 1st Session. The report included in the streams to be studied, the principal rivers used for navigation, water power, and irrigation and in which there were flood-control problems. In listing the type of investigations needed for those streams, the collection of stream flow was given prominence, and in that connection the report stated:

> The estimates for the determination of stream flow include the establishment of the necessary stream gauging stations and their operation during the period of the survey. In most cases, the subsequent operation of these gauging stations should be provided for, but it is not included in the estimates. Upon the completion of the surveys, the operation of the important gauging stations should be continued by the United States Geological Survey, whose annual appropriation should be increased by the additional amounts required for this purpose.

The report went on to state:

> At the present time the Geological Survey is preparing contoured maps of the entire United States and is engaged in the collection of stream-flow data, so far as the funds at their disposal will permit. A continuation of these activities of the Geological Survey is desirable, and if they are carried on at a reasonable rate with due regard to the need of the immediate future, when supplemented by special investigation under the legislation suggested above, they will supply the specific data needed.

The joint report was favorably considered by Congress and the River and Harbor Act of January 21, 1927 contained an appropriation to enable the Army Engineers to make the investigation. Later in the year the great Mississippi River flood caused an immense amount of damage in the lower Mississippi valley. Congress at its next session enacted a flood control act approved May 15, 1928. Section 10 of that act read as follows:

> That it is the sense of Congress that the surveys of the Mississippi River and its tributaries authorized pursuant to the act of January 21, 1927, and H. D. 308, 69th Congress, 1st Session be prosecuted as speedily as practicable and the Secretary of War is directed to prepare and submit to Congress at the earliest practicable date projects for flood control on all tributary streams of the Mississippi River system subject to destructive floods.

Because of this Act, the "308" investigations which were designed to give coordinate consideration to navigation, water power, irrigation, and floods, actually stressed the problems of flood control.

The first contact with the Army Engineers relative to the "308" work was made early in 1927 by the Topographic Branch in connection with topographic mapping. At that time the subject of stream-gaging was brought up and the Chief of Engineers desired to know how far the Survey could help in that phase of the work. In reply to that

inquiry the Director on March 11, 1927, in a letter to the Chief of Engineers, stated:

> There are so many factors covering the selection, establishment, maintenance and operation of gaging stations that I will need further information before I can say how much we can help you in this phase of the work. We have, as you know, cooperated for several years with your district engineer in Chattanooga in stream gaging in the Tennessee River Basin, and I see no reason why similar cooperation cannot be arranged in other districts. I feel very sure that you should utilize our experiences in the work in order that the records collected may be comparable with and have the same standard of accuracy as those collected throughout the country by the Geological Survey. If you are interested in having the assistance of our hydraulic engineers, who form the only available group skilled in stream gaging, I suggest a conference between some one from your office and the Chief Hydraulic Engineer of the Geological Survey.

Although a conference was held as suggested, nothing tangible resulted until the following year when on March 10, 1928, the Chief of Engineers wrote the Director relative to the proposed installation of three water-stage recorders on the Alabama River, in connection with the "308" investigations by the Army's district engineer at Montgomery, Ala., and quoted the latter, as follows:

> As the United States Geological Survey maintains gauging stations on streams forming a part of the Alabama River System, it is recommended that the Chief of Engineers, U. S. Army, and the Director, U. S. Geological Survey, authorize the District Engineer, U. S. Geological Survey, at Chattanooga, Tenn., and the District Engineer, U. S. Engineer Department, Montgomery, Ala., to confer on the proposed establishment of gauges with a view to avoiding duplication of effort and securing the greatest amount of data with the funds expended by both on this river system. (Further recommended that this authority be applied also to the Appalachicola River system.)

The Chief of Engineers in endorsing this recommendation requested the Director, if agreeable, to comply with it.

This opened the way for a conference on general stream-gaging requirements of the "308" work throughout the country, the outcome of which was shown by a circular letter issued by the Chief of Engineers on April 19, 1928, which contained the following:

> 3. It is contemplated by this office that in general, stream gaging, river profiling and the necessary topographic mapping will be executed by the Geological Survey. This matter has been discussed with the officials of that Survey in Washington and meets with their approval. In certain cases District engineers will have available regular employees who can be utilized for this purpose, and in such cases

it is of course contemplated that such employees will be used. District engineers should not, however, form new parties for the purpose of executing work which can be done by the Geological Survey.

4. District engineers are authorized to confer directly with the District engineer of the Geological Survey concerned and arrange details as to the stream gaging and mapping to be done. Insofar as practicable, it is desired that this operation be so conducted as to coordinate with the general stream gaging and mapping work of the Geological Survey.

5. The Geological Survey will be reimbursed by the District engineers for all work done for the Engineer department. * * *

The Survey engineers by letter of the Chief Hydraulic Engineer dated May 2, 1928, were

> authorized to enter into cooperative arrangements with the District engineers of the War Department for the conduct of stream gaging in connection with investigations to be made as contemplated in House Document No. 308, 69th Congress, 1st Session, on the following basis: The conduct of the work to be under your direction; the work to be done in accordance with Survey standards with the understanding that the records of stage may be collected if necessary where stage-discharge curves are either unnecessary, or impracticable; expenses are to be met in the first instance by means of Survey funds; and thereafter reimbursement is to be obtained from the Army engineers for the full cost of the work in accordance with the procedure usually followed.

As the work progressed, it was found necessary for the Survey to request an advance of funds from the Army Engineers from which the Survey's expenses were paid. The allowable expenses were limited to those incurred by the district offices, that is to say, no Washington office expenses were to be included.

All but a few of the Army's district engineers cooperated with the Survey and nearly every Survey district performed such work except in the Great Basin where the streams are not navigable, and by no stretch of the imagination can they be considered tributaries of navigable streams, and in Arizona which is wholly in the Colorado River Basin. More than 700 cooperative gaging stations were maintained in 38 States, of which the following had 15 or more such Army cooperative stations each:

Alabama	28	Oregon	39
Georgia	15	South Dakota	19
Kansas	22	Texas	16
Kentucky	31	Virginia	33
Montana	31	Washington	66
Nebraska	15	West Virginia	30
North Carolina	30	Wyoming	16

The cooperative stations supplemented those that were being maintained by the Survey, and a very considerable number were established in States where the Survey had not been active because of lack of State cooperation. At first this situation was met by attaching the "orphan" stations to the nearest district, but later a number of new districts were organized to serve the needs of groups of "308" stations.

When this cooperation was started the Army Engineers contemplated that it would continue for several years, or until the "308" reports on the various streams were prepared. In 1931, the Chief of Engineers advised the Survey that in general the "308" work would cease on September 30, 1931. In a few districts where the Army Engineers had projects under construction, notably the Fort Peck Dam on the Missouri River, and the Bonneville Dam on the Columbia River, cooperation continued. Also, the Army Engineers cooperated in the establishment and maintenance of several stations on the Mississippi River, and for the first few months subsequent to September 30, 1931, the cooperation took the form of transferring directly to the War Department the five Survey engineers who had been conducting the field work. The Survey took the "strict-constructionist" view that it could no longer accept transfer of funds from the Army Engineers for a continuation of the Army-Engineers' work, as Congress had provided the Survey with funds for carrying on the more important of those stations as Federal-type stations, and would provide needed additional funds for carrying on the other stations through cooperation with the States. When the House hearings were held in January 1932, on the 1934 appropriation bill, the matter of accepting Army-Engineer funds was discussed with members of the House Committee who informally approved such procedure.95/

95/ House hearings on 1934 appropriation bill, p. 744.

Thereafter the Survey engineers were retransferred to the Survey in March 1932 and the cooperation followed normal procedure.

Flood-control investigations: Disastrous floods during 1935 and the spring of 1936 made the country flood conscious, and as the Administration was committed to a policy of constructing large-scale public works in order to furnish employment, Congress enacted the Flood Control Act of 1936, which was approved on June 22, 1936.96/

96/ 49 Stat. L, 1570.

Section 1 of that act stated:

> Sec. 1. It is hereby recognized that destructive floods upon the rivers of the United States, upsetting orderly processes and causing loss of life and property * * * constitute a menace to national welfare; that it is the sense of Congress that flood control on navigable waters or their tributaries is a proper activity of the Federal Government in cooperation with States, their political subdivisions and localities thereof.

Mindful of the serious soil erosion during the preceding years of drought and resulting scant vegetation, the flood-control act provided that both flood control and prevention of erosion were to be considered. Section 2 of the act stated:

> That hereafter, Federal investigations and improvement of rivers and other waterways for flood control and allied purposes shall be under the jurisdiction of and shall be prosecuted by the War Department * * * and Federal investigations of watersheds and measures for run-off and waterflow retardation and soil erosion prevention on watersheds shall be under the jurisdiction of and shall be prosecuted by the Department of Agriculture. * * * Provided, That the foregoing grants of authority shall not interfere with the investigations and river improvements incident to reclamation projects that may now be in progress or may be hereafter undertaken by the Bureau of Reclamation * * * pursuant to any general or specific authorization of law.

The act authorized preliminary investigation of many streams in various parts of the country, including those in the Colorado River basin which had been excluded from the "308" investigations. In January 1937, a record flood on the Ohio River again focused public attention on flood control, and Congress revised and expanded the 1936 Act by another flood-control act, approved on August 28, 1937, 97/ which in addition

97/ 50 Stat L, 876.

to increasing the list of streams contained in the Act of 1936, appropriated funds for carrying out its provisions.

With funds available, the flood-control investigations by the Army Engineers became a reality, with the attendant need for additional stream-flow records. The cooperative arrangements during the "308" investigations had been so generally satisfactory to the Army Engineers that in considering the new needs for stream-flow records the Chief of Engineers on June 10, 1938, issued a letter to the Division and District engineers of the Army from which the following is quoted:

> The Water Resources Branch of the Survey is well organized to do river-measurement work and is prepared to perform such services for the Department on a cooperative basis. It has been the policy of the Department to obtain the assistance of the Survey for such additional stream-gaging work as has been necessary for the preparation of authorized reports for flood control and other purposes. The Department desires to continue this cooperative work, as it is both economical and generally satisfactory.

At this time the Survey was much stronger in both finances and experienced personnel than during the days of the "308" work, and sought to make the new arrangements truly cooperative by paying a part of the cost of establishing and operating the new stations that were needed. In announcing this policy, the Chief Hydraulic Engineer stated in a letter to the District engineers: 98/

98/ June 18, 1938.

> It is anticipated that some if not a considerable amount of such cooperation can be arranged on the basis that both the Corps of Engineers and the Geological Survey will participate in the cost of the work. * * * Whenever it is practicable and possible to do so, the Survey should, therefore, participate in the operation costs of those gaging stations of interest to the Corps of Engineers and to our State cooperating parties by the use of Survey cooperative and unrestricted funds.

The degree of such participation by means of Survey funds varied in the different districts, depending upon the availability of funds, but nearly all districts concerned contributed something. As a result of cooperation, about 500 stations were established and maintained in cooperation between the Army Engineers and the Survey in 35 states of which the following had 10 or more stations each:

Florida	18	Louisiana	18	Oklahoma	13
Illinois	12	Minnesota	11	Pennsylvania	24
Iowa	20	Mississippi	20	Texas	53
Kansas	14	Missouri	14	Virginia	15
Kentucky	30	North Carolina	13	W. Virginia	41
Alabama	14	Ohio	35	Tennessee	15
Indiana	11	New York	20	Wisconsin	12
Montana	10	South Dakota	15		

This list differs widely from that for the "308" investigations. One reason for this difference lies in the fact that many stations, in the latter list, were continued as Federal-type stations and their records were available to the Army Engineers for flood-control studies. Another and perhaps more important reason was that the floods of recent years which resulted in the flood-control legislation, had occurred chiefly in the Ohio and lower Mississippi River Basins and in Texas. Hence, many more stations in those areas were deemed necessary for the new purpose than for the earlier investigations. The "308" stations had been installed and operated almost entirely by the Survey, but the stations under the flood-control acts ranged from installation and entire maintenance by the Survey to operational field work and computation of field data obtained by the Army Engineers at stations established by that agency.

Certain requirements regarding the costs of rights-of-way for flood structures to be borne by the communities benefitted, which had been contained in the Act of 1936, retarded construction because of the unwillingness of such communities to assume such costs--a truly human and American trait where the Federal Government is concerned--and in 1938 Congress enacted another flood-control act, approved June 28, 1938, 99/

99/ 52 Stat. L, 1215.

providing for the payment for rights-of-way by the Federal Government. That act contemplated a long-range program and authorized the appropriation of an additional $10,000,000 to be divided equally between the Army Engineers and the Department of Agriculture, during the 5-year period ending June 30, 1944.

Army Engineer funds expended annually by the Survey under the various activities described, were as follows:

1929	$288,434	1935	$ 57,514
1930	309,399	1936	71,421
1931	244,018	1937	69,014
1932	127,359	1938	84,204 [100]
1933	45,647	1939	255,392
1934	41,591		

100/ Includes $3,894 from Mississippi River Commission funds in 1938 and $106 in 1939, account Vicksburg station.

The funds were limited by the Army Engineers to expenditures wholly by the Survey district offices. In addition, the Army Engineers during 1930 and 1931 constructed, with their own organization and at their own expense, 30 gaging stations in California at a cost of $39,704, [101] and

101/ Letter from H. D. McGlashan to author.

after the floods of 1937 and 1938, other stations at a cost of $12,500. These stations were operated by the Survey.

From September 1, 1935 to November 30, 1936, the Army Engineers expended directly about $6,000 in the construction of gaging stations on the Willamette River in Oregon, which were built under supervision of and operated by the Survey.[102]

102/ Letter from G. H. Canfield to author.

In the last month of the period, the Army Engineers furnished WPA funds for the construction of 9 stations in the Boston District, the work to be completed by the end of the fiscal year--three weeks time. The details of that rush order are described under the district operations.

State Department.- Cooperation with the State Department which was started in 1923 [103] on the Rio Grande through the International Boundary

103/ p. 56, 1919-1928.

Commission, United States and Mexico, was continued during the period, was increased in 1928 be investigations on the Canadian boundary through the International Joint Commission, and was decreased in 1931 by the discontinuance of the Rio Grande work. At first the funds furnished by the State Department were limited to specific problems but later they became available for general use in furthering the solution of the various problems involving international waters, largely by making base data available that are acceptable to both governments for use in connection with these problems.[104]

104/ Statement of R. W. Davenport to author.

The annual expenditures from State Department funds were:

1929	$93,400	1933	$57,953	1937	$43,968
1930	83,704	1934	46,376	1938	46,700
1931	86,070	1935	47,758	1939	47,642
1932	60,030	1936	48,576		

The details of the cooperation are given under Operations for State Department. 105/ The State Department's appropriations provided for the

105/ pp. 155-163.

transfer of funds to the Survey.

Tennessee Valley Authority.- The comprehensive survey of the Tennessee River, a navigable stream, carried on by the Army Engineers during the previous period 106/ showed large water power resources. The Wilson

106/ p. 50, 1919-1928.

dam at Muscle Shoals had been completed by the Government and was standing idle. This dam had been started during World War I when there was a shortage of power and was built to develop power for use in the manufacture of munitions. However, the war ended before the dam was completed, and although proposals were made to install power machinery and manufacture fertilizer by the fixation of atmospheric nitrogen, nothing was done on the theory that the Government should not compete with private enterprise. During the Hoover Administration a furious controversy raged in Congress over a proposal for governmental development of water power at the Wilson dam, and the proposal had been defeated.

The Roosevelt Administration and the Congress which came into office on March 4, 1933, were both favorable to governmental development of the power resources in that basin, not only for the benefits which would accrue to that section but for furnishing a "yardstick" whereby the reasonableness of power rates not only in that section but also in other sections might be measured. There was a strong belief by the Administration that power rates were generally too high. The Tennessee River basin appeared also to be suited to a demonstration of the effects of reforestation on stream flow and of Government planning on industrial and agricultural development. Senator Norris of Nebraska was the leading advocate of such demonstration, and he pushed the idea so vigorously that Congress enacted a statute, approved May 18, 1933, 107/ the purposes

107/ 48 Stat. L, 58.

of which were:

> To improve the navigability and to provide for the flood control of the Tennessee River; to provide for reforestation and the proper use of marginal lands in the Tennessee Valley; to provide for the agricultural and industrial development of said valley; to provide for the national defense by the creation of a corporation for the operation of Government properties at and near Muscle Shoals in the State of Alabama, and for other purposes.

The Tennessee Valley Authority was created to carry out the purposes of this Act. By Section 4 it was given authority to construct dams, reservoirs, power houses, power structures, transmission lines, navigational and incidental works in the Tennessee River and its tributaries, and to unite the various power installations into one

or more systems by transmission lines. To provide funds for initiating the ambitious program contemplated, Congress allotted to TVA $50,000,000 from the $3,300,000,000 provided by the National Industrial Recovery Act of June 16, 1933.

The Act creating the TVA terminated investigations by the Army Engineers in the Tennessee River Basin, and their Chattanooga office, which had been the Survey's cooperating agency, was transferred to Nashville. Although the TVA assumed jurisdiction over the Tennessee River Basin on July 1, 1933, it was not until November that cooperation was arranged to replace that previously in effect between the Army Engineers and the Survey's Tennessee, North Carolina, and Virginia districts. The original basis of cooperation was that TVA would make up during the fiscal year 1934 the deficiencies in funds caused by the discontinuance of Army Engineer cooperation and the reduction in State and Survey cooperative funds [108], in order that the existing

108/ Water-Resources Bulletin, Apr. 10, 1935, p, 21.

stream-gaging program of 100 gaging stations in the Tennesee River Basin of which 70 were in the Tennessee, 23 in the North Carolina, and 7 in the Virginia districts, could be continued.

Soon after cooperation became effective, the TVA obtained CWA authorization for the construction of 54 standard concrete recorder stations as a relief measure. This work was started in December 1934 and continued until April 1935, when the CWA went out of existence. Of these 54 concrete shelters about half replaced staff or chain gages used previously, five were replacements of temporary structures, and the remainder were built at new stations. Sixteen cableways were also erected of which one was 1,650 feet long, and another 1,600 feet long. A few additional stations were established each year. The total number of cooperative stations in 1939 was 141.

The cooperative program under the Army Engineers had been an intensive one, requiring a large amount of field work. In 1932, three subdistrict offices with an engineer detailed to each, had been established in Tennessee, of which two operated wholly within the Tennessee River Basin, and one operated partly within and partly without the basin. With the beginning of TVA cooperation, the stream-gaging program became even more intensive, and at the request of the TVA engineers, two more subdistrict offices were established. These latter offices were operated jointly, one by two and the other by three Survey districts. The subdistrict offices were so situated that each engineer had a maximum of 22 stations, and normally divided his time between field and office work.

The TVA cooperation was perhaps the most exacting of any cooperation entered into by the Survey. Not satisfied with recorders built to Survey specifications the TVA purchased recorders on its own specifications which were designed to obtain a somewhat higher degree of accuracy, with less chance that instruments would fail to operate at critical periods. The TVA construction program made it necessary for their engineers to forecast floods, and in that connection Survey engineers checked the recorders frequently to insure accuracy of time and gage height. The TVA was making extensive and intensive studies of sediment, the amount of which varies with the

discharge of the streams, and for both the flood forecasting and the sediment studies the Survey furnished each month discharge records from 40 stations. This number was increased to 47, but during 1939 the curtailment of TVA funds made necessary a reduction in their activities and the number of stations for which monthly records were required was reduced to 22. The TVA engineers required that peak discharge measurements be made for every flood at every station, regardless of the hour when such peak occurred. To meet that requirement, equipment for making night measurements from cable, bridge, or boat was obtained and used.

A night measurement from a cableway has been described by J. I. Perrey.[109] In February 1936, Perrey, accompanied by a TVA employee,

109/ Letter to author.

set out to make high-water measurements in the Hiwassee River Basin. Having completed the first measurement at 11 p.m., and as the streams were falling rapidly, it was necessary to measure the next station on the list as soon as possible, and that station was reached at 2 a.m. The recorder shelter was surrounded by water too deep to be traversed by waders. A nail was driven in a nearby tree to mark the stage. At the cableway 400 feet upstream the A-frame was in 3 feet of water and as the assistant had no waders Perrey carried him to the cable support, also the necessary equipment, including a reel and 75-pound weight. The water was unusually cold and the assistant "was shaking so that he shook the whole car." However, he was soon warmed by lifting the meter cable, with a 75-pound weight attached, to replace it on the guide sheave from which it was frequently displaced by the swift current. The distance to the water surface was about 13 feet and a flashlight was used in setting the meter at the water surface. When the measurement was finished the river had fallen enough so that the recorder could be reached by wading, and the stage noted. The experience acquired in these flood measurements indicated that peak discharges were not of as great value in defining rating curves as were measurements made on rising and falling stages, because of the loop characteristic of those curves.[110]

110/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 134.

The construction of dams for both storage and slack-water navigation changed the character of a considerable number of gaging stations from the usual type that was free from backwater at all stages, to stations having varying degrees of backwater. To obtain accurate records under these adverse conditions, the Chattanooga office carried on a year's extensive research, which required the installation of two 70-foot recorder installations, seven staff gages, and two boat-range discharge-measurement sections capable of measuring 100,000 second-feet. The cost of that investigation was about $15,000.[111]

111/ Letter from C. E. McCashin to author.

In describing the conditions under which the cooperation was carried on, C. E. McCashin writes:[112]

112/ Op. cit.

> When I first came here in the fall of 1934, the Tennessee Valley Authority was growing very rapidly and their needs for our data were almost insatiable, and it kept us extremely busy for several years supplying the great volume of regular monthly data which they demanded. For a long time their demands, due to the urgency of their needs and their lack of knowledge of what it takes to gather stream-flow information, made it awfully hard on the Chattanooga district, but in recent years their * * * attitude has softened considerably, both because their need is now not as urgent as it was before, and because they have learned more about what it takes to produce stream-flow records under adverse conditions.
>
> In a way their * * * demands were beneficial because they spurred all of us to greater effort (sometimes almost to the breaking point) to obtain for them what they asked for, and in this way we achieved ends that possibly would not have been accomplished otherwise. They asked for many things that we might otherwise have overlooked obtaining and asked for many things that possible we would have thought were impossible, but as the old saw goes, "Fools rush in where angels fear to tread." They asked and we accomplished.

Annual expenditures from TVA funds transferred to the Survey were:

1934	$29,156 1/	1937	$58,080
1935	39,856	1938	60,066
1936	45,482	1939	51,869

1/ In addition, TVA expended directly about $45,000 in connection with the CWA program.

The allotments from which these expenditures were made were based on the difference between the total estimated expenditure in the Tennessee Valley each year, and the total funds available from other sources. As McCashin states:113/

113/ Letter to author.

> We must be careful not to make a mistake and spend more TVA funds than the amount transferred, because then we would have to pay the cost of such over-expenditures, and there would be no official funds with which to make such a payment. Also, any mistake in other expenditures would affect this balance.

Public Works Administration.- When the Roosevelt Administration took office on March 4, 1933, the country was in the depths of the depression that followed the boom days of the twenties which culminated in the debacle of the stock market in October 1929. Confidence was so shaken that industry was curtailing production and laying

off many employees. Roosevelt, with what proved later to be characteristic action, proposed new and drastic measures to halt the depression and stimulate reemployment. His proposal was made in a message to Congress on May 17, 1933, in which he asked among other things for full power to start a large program of direct employment. He stated that a careful survey had convinced him that about $3,300,000,000 could be invested in useful and necessary public construction that would put the largest possible number of people to work.[114]

[114] 73d Cong., 1st Sess., Rept. 159.

Congress at once began consideration of the necessary legislation and enacted the National Industrial Recovery Act, approved June 16, 1933.[115] The declaration of policy was made as follows:

[115] 48 Stat. L, 195.

> Sec. 1. A national emergency productive of wide-spread unemployment and disorganization of industry which burdens interstate and foreign commerce, affects the public welfare, and undermines the standards of living of the American people, is hereby declared to exist. It is hereby declared to be the policy of Congress to remove obstructions to the free flow of interstate and foreign commerce * * * to increase the consumption of industrial and agricultural products by increasing purchasing power to reduce and relieve unemployment * * * and to conserve national resources.[116]

[116] This reference to the conservation of national resources was reminiscent of the days of Theodore Roosevelt.

Referring to Public Works, the Act stated:

> Sec. 201. * * * the President is hereby authorized to create a Federal Emergency Administration of Public Works * * *
>
> The Administrator (of Public Works) may without regard to the civil service laws * * * appoint and fix the compensation of such experts and such other officers and employees as are necessary to carry out the provisions of this title.
>
> Sec. 202. The Administrator, under the direction of the President, shall prepare a comprehensive program of public works which shall include among other things * * * conservation and development of natural resources.

The President appointed as Public Works Administrator, Harold L. Ickes, Secretary of the Interior, who created the National Planning Board to assist in formulating a comprehensive plan of public works.

With the very considerable stress placed by the Public Works Administration on conservation of water resources, and with plans for many water projects under consideration, the value of the Survey's stream gaging and the need for its expansion became apparent. When the drastic cut was made in the regular appropriation for 1934,[117]

117/ p. 6.

which would have curtailed seriously the Survey's work and reduced its personnel, a ray of hope was seen in the possibility that the forthcoming emergency legislation might make additional money available. Therefore, when the Public Works Administration began to function, the Survey and other Federal bureaus made applications for grants of Public Works funds. During the ensuing negotiations it was accepted without argument that information related to water was of special importance in connection with public works activities, and the recognized necessity for such information was an important factor in obtaining allocations of funds for the Survey's use.118/

118/ Letter from Chief Hydraulic Engineer, Aug. 23, 1933, to author.

Indicative of the importance of stream gaging and of the effectiveness with which the Survey's claim was presented, is the fact that the first allocations of PWA funds to any Federal agency were those made to the Survey. The first allotment became available August 12, 1933, when the warrant transferring the funds was countersigned in the Treasury Department for the following purposes:

> For the rehabilitation of river-measurement stations, repairs, replacements of equipment, and improvement of records, $500,000.

In requesting this allotment the Survey stated that the rehabilitation program would remove to a very considerable extent the necessity for expenditures for certain replacements for a period of perhaps 10 years. The need for additional records in certain areas was soon recognized by a second allotment which was

> for the establishment and operation of new stations on Colorado, Mississippi, and Ohio Rivers, $70,000.

Of this amount, $30,000 was for the Colorado River, $20,000 for the Mississippi, and $20,000 for the Ohio.119/

119/ Op. cit., Dec. 11, 1933.

By this time the studies of the Mississippi Valley Committee120/

120/ p. 74.

had shown the inadequancy of the existing stream-gaging program in the Mississippi River Basin, due in part to the failure of several States in that area to cooperate with the Survey. The allotment for Federal-type stations in the regular appropriation for the Survey was not large enough to supply the deficiency, and the Committee recommended an allotment of $180,000 of PWA funds. It was seen also that the allotments of $30,000 for new stations on the Colorado River and $20,000 in the Mississippi River Basin were insufficient, and an additional $100,000 ($75,000 for the former and $25,000 for the latter)121/

121/ Letter from Chief Hydraulic Engineer, Dec. 11, 1933, to author.

was added to the Committee's recommendation, so that in December 1933 the following allotment was made:

> Construction, repairs, replacement of equipment, and maintenance of river-measurement stations on Colorado River, on tributary streams of Mississippi River, and at 805 existing stations in Mississippi Basin, $280,000.

In November 1933, the Weather Bureau received an allotment for the rehabilitation of its river stations maintained for flood forecasting purposes. The Survey was making discharge measurements at many of those stations in order to translate gage heights into discharge. As the Weather Bureau had no construction facilities, it turned over to the Survey about $112,000 for rehabilitating Weather Bureau stations.

The need for stream-flow records was recognized by other Federal agencies, and the Director of the Soil Erosion Service requested an allotment to the Survey of funds which was granted

> for the establishment and operation of stream-flow measurement stations and for obtaining records of silt movement at eight erosion-control projects of the Soil Erosion Service, $150,000.

Certain Indian lands in New Mexico had, perhaps, the oldest water rights in the Rio Grande Basin, and little or no record of the diversions made by the Indians had ever been kept. To protect those rights the Office of Indian Affairs requested an allotment to the Geological Survey, which was made

> for construction of 58 measurement stations on canals and tributaries of the Rio Grande in New Mexico, $42,800.

Floods during 1936 and 1937 resulted in allotments for flood studies. In March 1936, two extraordinarily heavy storms with ensuing serious floods occurred in close succession over northeastern United States. To enable the Survey to make a study of these storms and the resulting floods an allotment was made in March 1936,

> for surveys of stages and discharges of recent disastrous floods and for the preparation and printing of reports thereon, $125,000.

Floods during the summer and early fall of 1936 in central Texas were of such great magnitude that an allotment was made

> for investigating the stages and discharges of central Texas floods of the autumn of 1936, and preparing and publishing a report thereon, $10,000.

So great was the damage to Survey gaging stations during those floods that another allotment was made

> for replacement and rehabilitating river-measurement stations damaged or destroyed by the central Texas floods of the autumn of 1936, $10,000.

During January and February 1937, the Ohio River and the mid-section of the Mississippi River experienced the greatest flood of record and following the precedent established, an allotment was made

> for investigating the stages and discharges of the January-February 1937 floods on the Ohio and Mississippi Rivers and their tributaries, and preparing and publishing a report thereon, $78,000.

PWA funds were now running low, and no further allotments were made until the Recovery Act of 1938, which was enacted to stem the recession which set in during the spring of 1937, made another appropriation to the Public Works Administration. Floods and droughts during the past few years had assumed such serious proportions that the first allotment to the Survey under the new appropriation was made in July 1938, for

> surveys of floods and droughts, $100,000.

Continuing investigations of water-resources projects had shown the need for more complete stream-flow records, and to meet that need an allotment was made in the same month for

> construction, repair, and improvement of river-measurement stations, $590,000.

Expenditures from those allotments were, by years:

1934	$522,688 1/
1935	577,636 2/
1936	64,453
1937	137,444
1938	70,268
1939	669,707
Total	$2,042,196

1/ Includes $24,657 transferred by Weather Bureau. Does not include $106,300 for ground water.

2/ Includes $87,209 transferred by Weather Bureau.

Other agencies, notably the Tennessee Valley Authority, and the Army Engineers, transferred PWA funds which are not included here as they merely augmented regular funds used by those agencies in continuing cooperation. The National Resources Committee also allotted for specific purposes certain funds derived from the PWA.

Regulations for the expenditure of PWA funds were somewhat different from those related to regular appropriations. The National Industrial Recovery Act of 1933 had waived the Civil Service laws in the employment of personnel paid from funds appropriated to the Public Works Administration, because quick action was needed in putting the employment program into effect--action which would be delayed if the Civil Service Commission was required to certify the great number of emergency temporary employees. Instead, any additional engineers, foremen and clerks needed in connection with PWA work were given so-called PWA appointments by Secretary Ickes in his

capacity as Public Works Administrator. Such employees could only be paid from PWA funds. As the chief objective of the public works program was to provide employment at fair rates, labor was classified as skilled and unskilled, and hourly rates for each class were prescribed--such rates varying somewhat for different parts of the United States. Employment offices were set up in each county where lists of available labor of various kinds were maintained. Under the Recovery Act preference was given to ex-service men with dependents, then to citizens of the United States or aliens who had declared their intention of becoming citizens, resident in the locality, and finally to citizens and aliens who had declared their intention of becoming citizens who were residents of the State. These preferences applied only where labor was available and qualified. Where construction work was to be performed in the vicinity of an employment office, it was necessary to obtain labor from such offices, if available. Otherwise, authority was given to obtain labor wherever it could be found. Also, the act stipulated that so far as practicable and feasible, no laborer directly employed should be permitted to work more than 30 hours in any one week. A minor change in regulations was an increase from $100 to $300 in the limit for purchases which could be made without competitive bidding.

In connection with the allotments made in 1938, speed was emphasized more strongly than previously, and although the allotments were to be expended before June 30, 1939, the Chief Hydraulic Engineer urged that the program be completed within three to five months.[122] Under the

122/ Letter of June 25, 1938.

terms of the Recovery Act, no PWA funds made available thereby were available for expenditure in the District of Columbia, whereas previous funds had not been thus restricted. The $300 limitation on purchases was not in effect with respect to the 1938 allotments and it was necessary to return to the standard limit of $100.

National Resources Committee.- The National Resources Committee had its origin in the National Planning Board which was created by the Public Works Administration in 1933 to assist in formulating a comprehensive plan of public works. This Board was concerned with both land and water projects. Under the terms of the National Industrial Recovery Act, funds were to be granted and loaned to State and political subdivisions for the construction of approved projects. Soon after the creation of the National Planning Board, applications for funds to construct water projects in the Mississippi Valley, particularly in the lower part, were so numerous that the Public Works Administrator on August 24, 1933, appointed the Mississippi Valley Committee, whose duty it was to make a careful and rapid (the two adjectives being obviously somewhat conflicting) study of the entire Mississippi Valley situation. In a letter to the various members of the Committee who, with the exception of a representative of the Army Engineers, were prominent engineers not connected with the Federal government, the Administrator said:

> You realize a tremendous amount of engineering data and study has been accumulated through the Army engineers, Reclamation Service, and organizations of the States. We feel that this is an opportune time to study this data and where necessary to supplement it by further work, set up

> a program of projects in sequence of necessity so that money expended from time to time may be a part of this comprehensive program, taking into consideration the entire Mississippi drainage area and its flood control, as well as the local flood-control problems. * * * We are being pressed by unemployment and necessity for relief, so that as quick action as possible in some of these problems should be obtained.

The National Planning Board with which the Mississippi Valley Committee was connected was a temporary organization created by the Public Works Administrator to meet an emergency situation. In its report at the end of the fiscal year in June 1934, the Board recommended the creation of a permanent National Planning Agency. This recommendation, which was in line with the Roosevelt policy, resulted in an Executive Order on June 30, 1934, creating the National Resources Board as the successor of the National Planning Board to aid the Executive in carrying out the terms of the Public Works Act. On August 6, 1934, the Mississippi Valley Committee was transferred to the National Resources Board, becoming the Water Planning Committee of the Water Resources Section. Its field was enlarged to cover the entire country.

The National Industrial Recovery Act, which gave the President authority to create the National Resources Board, expired June 30, 1935. On April 8, 1935, the Emergency Relief Appropriation Act became law and under it the President, by Executive Order, on June 7, 1935, abolished the National Resources Board and transferred its duties to the newly-created National Resources Committee to aid the Executive in planning the expenditure of $4,000,000,000 before June 30, 1937. The Water Planning Committee was reorganized as the Water Resources Committee and included representatives of eight Federal agencies having responsibilities in the water-use field. The personnel of the Water Resources Committee, with 8 Federal and 4 non-Federal members, was therefore very different from that of its predecessor, the Mississippi Valley Committee, which had one Federal and several non-Federal members. The Survey was represented on this Committee by the Chief Hydraulic Engineer.

Until the very end of the period the National Resources Committee was financed by funds allotted to it by the Public Works Administration. Under Reorganization Plan No. 1, which was made effective by Joint Resolution 20, 76th Cong. of June 7, 1939, the functions of the National Resources Committee and those of the Federal Employment Stabilization Office were consolidated in the National Resources Planning Board.

From the beginning, the Mississippi Valley Committee and its successors, the Water Planning Committee and the Water Resources Committee, being primarily concerned with the development of the water resources of the country, cooperated whole-heartedly with the Survey as the governmental agency charged with investigating the Nation's water resources. Not only did it sponsor Public Works allotments[123] to the Survey, but also it requested Public Works funds

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123/ p. 71.

for use by itself in cooperation with the Survey. Such latter funds were used to finance two specific projects, one pertaining to floods and rainfall-runoff relations, and the other to interstate problems on the Rio Grande. The Committee's views on flood problems for which the records of floods were desired are expressed as follows: 124/

124/ Part III, Report of the Water Planning Committee, Nov. 15, 1934, p. 325.

> No year passes without the occurrence of more or less serious floods somewhere in the United States, and destructive inundations may occur at any time in any section of the country. The aggregate direct damages caused by them has been estimated roughly to average $35,000,000 annually. In addition, there are indirect and intangible losses for which no allowance commonly is made. These are more widespread by far than the direct tangible losses, and may, indeed, affect the entire country.

The first allotment was made to the Survey in February 1934 for a flood study consisting of a compilation of data showing flood magnitude and frequency, and a study of the relation between rainfall and runoff.

The need for the flood study is described by the Water Planning Committee in the following language: 125/

125/ Water-Supply Paper 771, pp. 10-11.

> In planning public works for the control of floods * * * two basic requirements are (1) accurate and reliable records of stage and discharge of past floods, and (2) development of methods for the analysis of such data, to determine the frequency of floods heretofore experienced and to estimate the magnitude and frequency of future floods. It is the purpose of this study to present for certain rivers in the United States much of the basic information of the sort now available.

The study which began in March 1934 was under the direct supervision of R. W. Davenport. The personnel consisted in part of Survey engineers and in part of engineers from other Government departments. This study was considered so important that the American Society of Civil Engineers' Committee on flood protection data, and an American Geophysical Union's Committee from the Section of Hydrology acted as advisors. The results were published as Water-Supply Paper 771 by C. S. Jarvis and others.

The need for the rainfall-runoff relation study was stated by the Water Planning Committee, as follows: 126/

126/ Water-Supply Paper 772, p. 10.

> Early in its consideration of Public Works water projects, the Mississippi Valley Committee realized the great need for more information on the conditions affecting rainfall, runoff, and related factors. It was recognized that to a great extent the available climatic and hydrologic

> data have never been adequately analyzed with a view to deducing the particular knowledge that would be helpful. Moreover, it was believed that such broad fundamental questions were largely outside the field in which private individuals and institutions could generally be active and hence were especially suited to investigation by an agency or agencies of the Federal Government.

This study was carried on concurrently with that of floods and was under Davenport's supervision, with W. G. Hoyt as responsible head of the studies relating to rainfall, runoff, and related factors. The personnel consisted of regular Survey employees and temporary PWA employees. Committees of the American Society of Civil Engineers and the American Geophysical Union acted in an advisory capacity. The results were published as Water-Supply Paper 772 by W. G. Hoyt and others. Both the flood and rainfall-runoff studies were discontinued in June 1935 as available funds were exhausted at that time. The National Resources Committee was influential in setting up in New York City a WPA project for a continuation of those studies.127/

127/ p. 95.

The Rio Grande Joint Investigation, as the Water Resources Committee states:128/

128/ Regional Planning, Part VI, Upper Rio Grande, Feb. 1938, National Resources Com., P. VI.

> constituted a unique approach to the underlying problems of a grave controversy over an interstate river. For the first time the States engaged in such a controversy joined with one another and with the Federal Government in an endeavor to find a satisfactory basis for the allocation of the waters of a river through the assembly of the factual data essential to such an allocation.

Controversies over the use of the waters of the Rio Grande by Colorado, New Mexico, and Texas, which are too involved to be described here, were of long standing. In 1923, influenced by the recently-signed Colorado River compact,129/ the legislatures of Colorado and

129/ p. 99, 1919-1928.

New Mexico authorized their respective governors to appoint commissioners to study the water supply and draft a compact for the equitable division of the waters of the Rio Grande. The President appointed a commissioner to represent the United States, and later the Governor of Texas appointed a commissioner. The States of Colorado and New Mexico made extensive investigations and studies, acting independently of each other. In January 1929, a temporary compact was signed which did not allocate the waters of the Rio Grande but merely provided that, during the period of the compact which was to expire June 1, 1935, neither Colorado nor New Mexico could cause or suffer the water supply in the Rio Grande to be impaired by new or increased diversions or storage in Colorado unless and until the closed basin drain in Colorado, and the State-line reservoir had been constructed, unless and until such

depletion is offset by increase of drainage return;[130] that the three

130/ Rio Grande Compact: Ninth Bien. Rept. State Engr., New Mex., 1928-1930, pp. 48-55.

States would maintain certain key gaging stations and exchange the records therefrom; and that before the expiration of the compact a commission should be constituted to conclude a permanent compact for the allocation of the water between the three States. Many proposals were made as the basis for a permanent compact but no agreement was reached. One reason for this failure was the fact that the results of the special investigations made by each State acting independently, were more or less concealed from the other two States. Full confidence in the basic data was, therefore, lacking. In a further attempt to reach an agreement the effective date of the temporary compact was extended to June 1, 1937.

The controversy over the waters of the Rio Grande concerned the Federal Government not only because of the interstate aspects but also because the delivery of water to Mexico in accordance with treaty was involved; the Rio Grande irrigation project had been constructed by the Reclamation Service by use of Federal funds that had not been repaid; the bonds of the recently-completed Middle Rio Grande Conservancy District had been purchased by the Reconstruction Finance Corporation; and water for the irrigation of the lands of its Indian wards was in jeopardy. These several Federal interests were in conflict with each other and with those of the three States. In an effort to obtain a settlement of the conflicting claims to the over-appropriated waters of the Rio Grande, the National Resources Committee proposed a conference with the Rio Grande compact commissioners and others interested in the problems, to ascertain whether some means could be found by which the National Resources Committee could render a public service by assisting the three States in gathering the facts needed as a basis for the equitable division among them of the inadequate waters of the basin.

This conference was held at Santa Fe on December 2-3, 1935, and resulted in the adoption of a resolution by the Rio Grande Compact Commission, requesting the National Resources Committee to arrange, in consultation with the Compact Commission, for an investigation of the water resources of the Rio Grande Basin above Fort Quitman, the past, present, and prospective uses and consumption of the water in the basin in the United States, and the opportunity for further use and for augmenting such water resources by all possible means. Fort Quitman was selected as the lower limit because the greater part of the water originating in the upper basin is consumed above that point. The flow of the Rio Grande below Fort Quitman is dependent chiefly on the inflow from lower tributaries. PWA funds were allocated to the National Resources Committee for the proposed investigation on condition that certain additional funds would be contributed by the three States and by certain other Federal agencies. A second conference was held in Santa Fe in February 1936, at which final arrangements were made. The Comptroller General finally approved the proposed allocation of PWA funds early in April and the investigation was started. It was known as the Rio Grande Joint Investigation.

In accordance with the cooperative agreement, the Geological Survey was to make the measurements of stream flow, drainage, waste, and diversions, study the ground water and make chemical analyses of the ground water; the Bureau of Agricultural Engineering was to map and classify the vegetative cover, map and study the irrigated acreage, and other water-consuming areas, and study the consumptive duty of water; the Bureau of Reclamation was to investigate the possibilities of storage and transmountain diversions; the Bureau of Plant Industry (C. S. Scofield) was to interpret the chemical quality of the water in terms of its use for irrigation; the Soil Conservation Service, Resettlement Administration, and Indian Service cooperated on various phases.

Headquarters were established in Santa Fe with Harlowe M. Stafford employed by the National Resources Committee as the engineer in local charge of the whole investigation under an executive committee consisting of Prof. Harlan H. Barrows of the University of Chicago and Prof. Frank Adams of the University of California. The stream gaging in Colorado was handled from headquarters in Alamosa, with L. F. Hanks of the Denver district in immediate charge. In New Mexico, the stream gaging was handled from the Survey's district office in Santa Fe. Seventy-six gaging stations were established in Colorado, and 144 stations in New Mexico. The ground-water work is described on pp. 349-350 and the quality of water work on p. 373.

The investigation was planned to continue through the 1936 field season only, in order that the existing data could be correlated with one year's intensive and comprehensive investigation, and conclusions reached as soon as possible, for use in the negotiation of the interstate compact. In the San Luis Valley, Colorado, the investigation was terminated in January 1937. In New Mexico, however, the State engineer desired longer records, and the investigation was continued until June 1938. The data collected through the 1936 field season were published by the National Resources Committee.131/ The results of the investigation

131/ Regional Planning: Part VI, Upper Rio Grande, February 1938.

served as a basis for the negotiation of an interstate treaty which was approved by the three States and by Congress--an accomplishment which had appeared to be well-nigh impossible.

The amounts expended for surface-water investigations from funds transferred by the National Resources Committee to the Survey during the period were:

1934	$6,087	1937	$14,399
1935	32,008	1938	3,207
1936	14,642		

There were a number of other activities of the National Resources Committee which had an indirect bearing on the Survey's work. In 1936, the National Resources Committee, through its Water Resources Committee, made a study of existing hydrologic data, and pointed out the deficiencies in such data. One of the greatest deficiencies was either lack of records or inadequate and discontinuous records for large areas. This was due either to failure of the States to cooperate in those areas, or to reductions in the amounts of both Federal and State funds. To

remedy this defect the Committee made the following recommendation:[132]

132/ Deficiencies in basic hydrologic data; National Res. Com., Sept. 1936, p. 25.

> The Committee believes that a network of Federal stations is absolutely essential to a consistent and productive program of stream-flow measurement. Without such a network, the Government will continue to invest in stream-gaging work likely to be cut off at any time on the failure of State authorities to cooperate and which may be invalidated by interruption or termination within a period of time that is altogether too short to serve the needs of the country and its citizens. A system of base stations would be a sound precaution against wasteful expenditures for short records which are of little value unless supported by long basic records.

To remedy the deficiency, it was recommended that 500 base stations be established and maintained at Federal expense. It was also recommended that 1,000 existing cooperative stations be rehabilitated. The estimated cost of these recommendations for the first year was $1,450,000 from Federal funds, and $450,000 from cooperative State funds. In conformity with the first recommendation the Survey prepared lists of needed stations, and presented the estimates for them to the Bureau of the Budget, together with the estimates for the regular work. Neither the Budget, nor later Congress itself, looked with favor upon this large increase in expenditures. The Committee's recommendation, however, undoubtedly influenced favorably the Public Works Administration to make allotments of funds to the Survey in 1938.[133]

133/ p. 73.

In describing the deficiencies in basic hydrologic data the National Resources Committee recommended the inclusion of additional data in the published reports and these recommendations were generally adopted.[134]

134/ p. 130.

The National Resources Committee sponsored the creation of State Planning Boards in many States, and supplied funds for technical advisors. Some of these State Boards cooperated with the Survey.

Soil Conservation Service.- The prevention of soil erosion, the purpose of the Soil Conservation Service and its predecessor, the Soil Erosion Service, was apparently first advocated by the Department of Agriculture's Bureau of Chemistry and Soils in the late twenties, but at that time little popular interest was aroused. The enactment of the National Industrial Recovery Act[135] provided the means for

135/ p. 70.

studying the prevention of erosion. Section 202 of that act provided for a comprehensive program of public works which included among other objectives the prevention of soil erosion. In October 1933 the Public Works Administrator created the Soil Erosion Service in

the Department of the Interior and financed its activities by a PWA grant. The stated objectives were:136/

136/ Secretary of the Interior: Ann. Rept. for 1934, p. 353.

> (1) To demonstrate that the impoverishment and destruction of our remaining areas of good agricultural land by continuing erosion can be largely controlled; and (2) to lay the foundation for a permanent national erosion-control program of adequate scope to meet the acute land crisis created by wasteful methods of land utilization.

By the terms of the Recovery Act, agencies created under it ceased to exist at the expiration of two years from the date of enactment (June 16, 1933). On March 25, 1935, the Soil Erosion Service was transferred by Executive Order to the Department of Agriculture, and on March 27 the Secretary of Agriculture directed the unification of all Department of Agriculture activities pertaining to soil erosion under the Soil Erosion Service. To continue its activities after the expiration of the two-years limitation, Congress passed the Soil Erosion Act, approved April 27, 1935.137/

137/ 49 Stat. L 163.

In this act it was declared to be the policy of Congress to provide permanently for the control and prevention of soil erosion and for that purpose the Secretary of Agriculture was directed to establish an agency to be known as the Soil Conservation Service, utilizing at his discretion the Soil Erosion Service. By this legislation the Soil Erosion Service became the Soil Conservation Service, was given legislative status and thereafter received annual appropriations by Congress.

Since the days of the Soil Erosion Service the program has been one of demonstrating to land owners the effects on erosion of various methods of tillage. When the Soil Erosion Service was created, representative drainage-basin demonstration areas were established within the different major geographic and agricultural regions of the country where destructive erosion is prevalent. Each area was equipped with a staff of specialists in the technical aspects of erosion, land use, agronomy, forestry, etc., in order that all physical factors causing or affecting erosion might be studied.138/

138/ Secy. of Interior Ann. Rept. for 1934, p. 355.

An important indicator of soil erosion is the amount of sediment carried in the streams, particularly during floods, when erosion is most active. Quantitative information as to sediment movement, stream flow and sediment load were, therefore, required. As the collection of records of stream flow and of sediment movement are functions of the Survey, the Soil Erosion Service sought the Survey's cooperation and the director of the Soil Erosion Service obtained a PWA grant of $150,000 which was made to the Survey in January 1934 for the establishment and operation of stream-flow measurement stations and for obtaining records of sediment movement at eight specific erosion-control projects.139/

These projects were: Tarkio, near Tarkio, Mo., Deep River near High Point, N. C., Stillwater near Stillwater, Okla., Limestone Creek near Mankato, Kans., Elm Creek near Temple, Tex., Tiger River near Spartansburg, S. C., Coon Creek near La Crosse, Wis., and Pacific Northwest near Pullman, Wash. The general plan of investigation was to select on each project two adjacent, similar areas. On one, experimental methods of erosion retardation were tried, and on the other no change was made, in order that a comparison between the amount of sediment carried by the streams in the two areas might be made, and the effect of the experimental methods thereby determined. For each project, the Soil Erosion Service had a large organization of its own, engaged in the various activities pertaining to soil erosion control, but the stream gaging and collection and analyses of sediment samples were turned over to the Survey. As rainfall is associated with stream flow in the relation of cause and effect, the Survey was also given the task of installing and operating numerous rain gages on each project. The Division of Ground Water suggested that records of water level from observation wells be included in the program and this was done. Several gaging stations were maintained on each experimental area and usually one station on the so-called "control" area. The drainage areas were relatively small, two-thirds of them being less than 100 square miles, and several were less than 15 square miles. To obtain as accurate records as possible, the stations were equipped not only with recorders, but many of them with artificial controls and cableways. The Survey operated a total of 33 stations on the eight projects. All records collected during the project operations were compiled and reviewed by the appropriate Division of the Branch.

The program was started in January 1934. Survey headquarters were established on each project to which an engineer was detailed who was responsible to the district engineer for the installation and maintenance of the gaging stations, collection of sediment samples, and records of rainfall and ground-water levels.

The most important phase of the stream-gaging was the measurement of floods, and as the areas were small, the floods were of short duration and frequently occurred at night. The engineer had a fireman's job, "to go when the bell rang day or night." To give warning of approaching floods some of the recorders were equipped with an electirc device which rang a bell in the engineer's residence when the float rose a certain distance. In making night measurements, lights strapped to the engineer's head and operated by dry batteries were used.

During periods of flood, sediment samples were obtained every half hour or even oftener on the smaller streams, and for that purpose additional assistants were furnished by the Soil Erosion Service.

PWA funds were exhausted in June 1935, and thereafter the Soil Conservation Service allotted funds for the continuation of the projects. For the Stillwater project cooperative funds ceased June 1936, but Survey funds were used to continue the project until December 1937. The Elm Creek project was discontinued in October 1936, and the Tiger River and Mankato projects in June 1938 due primarily to lack of funds for the intensive type of work required. The remaining projects were continued

during the period.

In addition to the PWA allotment of $150,000 the annual Survey expenditures from Soil Conservation Service funds were:

1935	$ 3,064	1938	$38,836
1936	66,974	1939	29,320
1937	38,709		

Bureau of Reclamation.- The decrease in cooperation with the Bureau of Reclamation, which was noted during the previous period, continued until 1937, and the number of stations was further reduced from the 20 stations that were operated in 1928, exclusive of those in the Idaho Falls district.10/ Complete records for other stations were furnished as previously.

10/ p. 47, 1919-1928.

The authorization of the Central Valley project in California required additional gaging stations and the Bureau of Reclamation transferred funds to the Survey for the installation and operation of three stations in 1937. The flood in the Sacramento Basin during the spring of 1937 was so severe that the Bureau of Reclamation desired as full information regarding it as possible, and transferred funds to the Survey to rehabilitate the damaged stations and prepare a flood report.

The annual expenditures from Bureau of Reclamation funds were:

1929	$1,198	1933	$192	1937	$13,167 1/
1930	684	1934	227	1938	2,838
1931	711	1935	204	1939	17,930 1/
1932	986	1936	210		

1/ Chiefly in California.

In addition to the cooperation described, there was considerable direct expenditure by the Bureau of Reclamation. For the years 1934 to 1939, $200 annually was expended by the Bureau for gage observers' pay in the upper Colorado River Basin. In 1936, the Survey constructed a gaging station on the Columbia River, with the gage well built into a pier of a highway bridge just below Grand Coulee Dam. This station replaced one that had been rendered inoperative by the construction of the dam. The Bureau of Reclamation cooperated in the construction of the new station and expended an amount estimated at $1,000. The Grand Coulee Dam will cause backwater in the Columbia at the International Line, and the Department of State furnished funds for the construction of a station at that point in 1939. The Bureau of Reclamation paid for the cable equipment, the cost being about $2,550.

In 1937, the Bureau of Reclamation was making an investigation of possible transmountain diversions from the San Juan River Basin to the Rio Grande Basin in Colorado. As the State of Colorado was interested in this investigation, the State cooperative program was enlarged to include seven stations which were installed by the Survey at the partial expense of the Bureau of Reclamation which amounted to $1,000.

That agency did not contribute to the operation of the stations. In the fall of 1938 the Bureau of Reclamation began an intensive investigation of the irrigation possibilities in the upper Green River Basin in Wyoming and installed 23 stations, using Survey plans. This work was done by a former Survey employee who was stationed in that area. Arrangements were made whereby the Bureau of Reclamation should perform the field work not only for the new stations but also for the seven Survey stations in that area. In return, the Survey was to compute and publish the records for all of the stations. This arrangement was continued during the remainder of the period.

Indian Service.- Cooperation with the Indian Service continued with the maintenance of an average of 14 stations until 1936. Of these stations five were in Arizona, four in Wyoming, and one or more each in Washington, California, and Nevada. The cooperation in Wyoming consisted chiefly in furnishing observers. The cooperation in Arizona, which was the most extensive, was the principal support of the gaging stations on Gila and San Carlos Rivers in connection with the Indian Service irrigation project of about 80,000 acres in the vicinity of Coolidge. Of this area, half was used by Indians and the remainder by white settlers.[141]

141/ Letter from W. E. Dickinson to author.

The Indian Service had filed suit in Federal Court against all water users in the Gila River Basin above their project both in Arizona and in New Mexico. A consent decree was issued as of January 1, 1936, in which jurisdiction remained in the Federal Court and a Federal Court Water Commissioner was appointed to administer the water rights. As a result, the Indian Service reduced its cooperation materially for the fiscal year 1937, and discontinued it thereafter as the Department of Justice contributed funds subsequently.[142]

142/ p. 91.

In 1939, the Indian Service, under Survey supervision, installed recorders at four stations in Montana and allotted $500 to the Survey for the operation of the stations during the remainder of the year.[143]

143/ Statement of A. H. Tuttle to author.

The annual expenditures by the Survey from Indian Service funds for the maintenance of the stations in Arizona, California, Montana, Washington, and Nevada, were:

1929	$4,198	1933	$3,571	1937	$6,404
1930	3,068	1934	4,035	1938	2,002
1931	2,700	1935	3,328	1939	1,763
1932	4,640	1936	5,206		

Of these amounts, about $2,800 was spent annually for the Arizona work prior to 1938.

Beginning in 1936, an extensive program was started to record the flow in ditches serving Indian lands in the Rio Grande Basin in New Mexico. W. W. Follett, one of the early investigators of irrigation in

the Rio Grande Basin, gives the following historical sketch of irrigation by the Indians:[144]

144/ Equitable distribution of the waters of the Rio Grande, Senate Doc. 229, 55th Cong., 2nd Sess., p. 54, 1896.

> Before the middle of the sixteenth century the Spaniards entered New Mexico and the valley of the Rio Grande and there found the Pueblo Indians, living in their many-storied towns and cultivating the land of the valleys, bringing water onto it by acequias or irrigating ditches, many of which are in use to this day. How long these Indians had been on the ground is unknown but they were even then old inhabitants, and raised not only grain and fruit, but even flowers, as one poetical and doubtless homesick Spaniard wrote that roses bloomed along the acequia banks "as bloomed the roses of beautiful Aragon."

From the foregoing account is is evident that the Indian ditches had rights reachinginto the misty past. Later, Mexican settlers occupied some of the land under the Indian ditches. The water rights were never adjudicated nor was any attempt made to regulate the use of water under the various ditches. The resulting chaotic condition is best described by the current saying that it takes two men to irrigate from the Indian ditches, one to put the water on the land and the other to go to the head gates near the head of the ditch and fight for the water.[145]

145/ Statement of F. F. LeFever to author.

Realizing that with the growth of irrigation in the Rio Grande Basin, the Indian ditch rights would be jeopardized if they were not adjudicated, the Indian Service in 1935 made a request for an allotment of WPA funds by which gaging stations could be established for the purpose of determining the amount of water actually used from the Indian ditches, and the available water supply in the streams supplying the ditches. The estimated cost per person employed was too high for the WPA program, and the allotment was refused. A successful attempt was then made to obtain a PWA allotment, and $42,800 was allotted to the Survey for that purpose.[146] This amount was sufficient to establish

146/ p. 72.

the desired stations and operate them during the fiscal years 1936 and 1937. The Survey had informed the Indian Service that it would not be interested in the cooperative program unless it could be continued for five years,[147] and during the remainder of the period the Indian

147/ Statement of Berkeley Johnson to author.

Service allotted the following amounts:

1938	$15,000
1939	15,000

The initial program called for the installation of 58 stations, mostly on ditches, all of which were small. Although this work was sponsored by the Indian Service, it was necessary to obtain the consent

of the Indian Pueblos to install the stations on their lands. The Indians of the various Pueblos are self-governing, electing annually a governor at each Pueblo. At some of the Pueblos it was a comparatively simple matter to obtain the necessary permission from the governor, but at other Pueblos, the governor declined to assume the responsibility of making such a momentous decision, and called a council meeting. Such meetings were usually held at the homes of the governors, where, instead of smoking the proverbial peace pipe as had been the custom of their ancestors, the present generation smoked cigarettes rolled from tobacco furnished by the host. When the council members were assembled the governor announced the purpose of the meeting, and then called upon the Survey representative to explain his proposal, which was done through an interpreter. Many of the older Indians do not understand English, Spanish being the common language among the various Pueblos where different Indian dialects are spoken. After this explanation the governor called upon each member in turn to express his opinion. Sometimes additional information was desired before the final decision was reached, which in the end was favorable.

To show that the matter of personal appearance is of importance in dealing with the Pueblo Indians, two incidents that occurred during the negotiation stage may be mentioned. One Survey engineer met with the council after a day of arduous field work, during which he had covered his rough-and-ready field costume with mud. After presenting his case, the unusual request was made that he prove his identity as a member of the Survey, as the Indian making the request said that he looked like a sheep herder instead of a Government engineer. At another time a Survey engineer obtained permission from the governor to install the gaging stations, but when he appeared on the scene ready to start operations he was stopped. When he obtained the governor's permission he had been bareheaded, but when he started the field work he was wearing a hat, and this so changed his appearance that the Indians did not believe he was the engineer to whom permission had been granted. When the difficulty was straightened out the governor said, "You can go ahead with the work but don't wear a hat around here again."

The installation of the gaging stations was started during the spring of 1936. Concrete controls were constructed, with concrete shelters at one end. The number of stations was increased from the original 58 to 63 during the first year, and later to 80. Many of the ditches are so small that, as one Survey engineer stated, if two could be placed side by side they could easily be straddled.

National Park Service.- Cooperation with the National Park Service was in the form of service, except in Rock Creek Park, D. C., where in 1929 that agency contributed $525 for the construction of a recorder shelter on Rock Creek. Subsequently the closely allied agency of Public Buildings and Parks (in the District of Columbia) contributed annually to the operation not only of that station, but also of a second station in Rock Creek Park, which was operated for a few years. The annual expenditures for the Rock Creek Park stations were:[148]

148/ Letter from A. H. Horton to author.

1929	$525	1933	$684	1937	$350
1930	548	1934	344	1938	350
1931	300	1935	350	1939	898
1932	800	1936	311		

The increase in 1939 was due to the additional funds furnished for constructing a standard reinforced-concrete structure. The service cooperation consisted in furnishing gage-height records for seven stations in Yellowstone Park, three in Yosemite Park, and one in Zion National Park. The National Park Service also assisted by sending out daily reports by telephone from the Bright Angel Creek station on the Colorado River.

In addition to the cooperation mentioned, a project unique in Survey annals was undertaken in Virginia. The development of the Skyline Drive in the newly-established Shenandoah National Park created a demand for water near the crest of the Blue Ridge Mountains, and the National Park Service called on the Survey for assistance. In 1933, an agreement was entered into whereby the Virginia District made investigations and studies for the purpose of obtaining adequate supplies of water. The Park Service furnished CCC labor, construction equipment and tools, engineer-foremen, and transportation, and the Survey furnished technical equipment, general supervisory and investigational services, and made the observations and studies that were needed.[149]

149/ Letter from F. F. Schrader to author.

The preliminary work included the finding, describing, and measuring the flow of more than a hundred small streams. Most of the streams were so small that the Venturi flume and the pygmy meter were used in making the measurements. The more promising of the many possible sources of water supply were selected for further investigations, and concrete controls and metal V-notch weirs were installed on small streams and springs. At other sites the flow was scattered or underground, and it was necessary to investigate the general topography, rock formations, and outcrops for the proper placing of collecting galleries and measuring chambers. About a hundred weirs were installed with capacities ranging from 70 to 2,000 gallons per minute (0.15 to 4.46 second-feet). Enamel gages were installed and read either daily or several times per week. Recorders were used at some sites for short periods, and numerous measurements were made to check the weirs either by the volumetric method or by the use of pygmy and standard current meters.

When several years' records had been collected and studied, recommendations regarding the various supplies were made to the Park Service. Later, complete water-supply systems were installed by the Park Service and further studies of supply and demand were made. The various units of each underground system were located by transit surveys and referred to permanent concrete markers, and plans prepared for permanent record. The many unique problems connected with this project were successfully solved by Dirzulaitis.[150] This work was performed chiefly during the

150/ Letter from F. F. Schrader to author.

years 1938 to 1939.

Biological Survey.- Beginning in 1937, the Biological Survey expanded its work of providing migratory wild fowl refuges by means of small ponds. These ponds were formed by damming the natural streams and holding back the flow during low-water periods, thus interfering more or less with downstream water use. In order to determine the extent of such interference, the Biological Survey cooperated with the Survey in the establishment and operation of gaging stations on four projects.

The first of these projects was in the Souris River Basin, North Dakota, where the Biological Survey was constructing small ponds. Souris River is an international stream that enters North Dakota from Canada near Sherwood, and returns to Canada again near Westhope. International stations were being maintained at both of those points. C. L. Batchelder thought that the reduction in flow due to filling the ponds and keeping them at a constant level might so reduce the small flow of that stream as to create an international problem. In order to obtain definite information on the reduction in flow, he arranged with Biological Survey in the spring of 1937 to rehabilitate the Westhope station and to install two stations on the Souris River equipped with staff gages, a station on Wintering River equipped with a recorder, and a station on the Biological Survey reservoir known as Lake Darling. This was the extent of the cooperation, as the Survey operated these stations from other available funds.151/

151/ Statement of C. H. Prior to author.

The second project related to the Malheur refuge in Oregon where it was necessary to know how much water was available, and the Biological Survey in June 1937 requested the cooperation of the Survey in obtaining the needed information. The resulting agreement provided that the Biological Survey would install and operate the gaging-station equipment and furnish observers for the gaging stations, and the Geological Survey would make discharge measurements and compute and publish the records. The actual cost of this work to the Survey was repaid, by the Biological Survey. The equipment which was installed on the Survey's recommendation, consisted of recorders in rough rock shelters on concrete wells. Native stone was used for the external finish of the shelters, and CCC labor was employed. At two stations concrete controls of the Columbus type were constructed.152/

152/ Letter from G. H. Canfield to author.

A third project, larger than either the North Dakota or Oregon project, was that of the Seney Migratory Water Fowl Refuge in the Manistique River Basin in Northern Michigan. This project contemplated the construction of extensive pools by diking and this required a knowledge of the yield of small tributary streams. In addition, there might be a conflict with the water power company on the lower river. At the request of the Biological Survey cooperation was arranged whereby 16 gaging stations were established by the Geological Survey in March 1938. The construction was accomplished largely by use of CCC labor. The Biological Survey detailed a resident engineer to spend half of his time making measurements, reading staff or chain gages at 10 stations and inspecting recorders at the remaining six stations. The Geological Survey performed the other half of the field work and computed the records on a repay basis.153/

153/ Letter from F. C. Christopherson to author.

The fourth and last project during the period was on the headwaters of the South Fork of White River in South Dakota where the Biological Survey had constructed five ponds. These ponds had been constructed during a dry period and while the ponds were being filled, the flow was reduced near the mouth of the South Fork where a hydroelectric plant was in operation. The flow was further reduced by irrigation pumping by the Indian Service, a few miles upstream. The power company instituted a joint suit against the Biological Survey and the Indian Service to restrain them from storing and pumping water, and to adjust these differences the Biological Survey desired stream-flow records near their ponds and at the power plant and, to that end, entered into an agreement with the Survey in April 1938 whereby six gaging stations were installed and operated on a repay basis.154/

154/ Statement of H. C. Beckman to author.

The amount expended directly by the Biological Survey on these cooperative projects is not known, but the amounts expended for the Biological Survey on a repay basis were:

1937	$ 794
1938	4,419
1939	10,741

Flood Control Coordinating Committee.- The Flood Control Act of 1936 directed that investigations of measures for run-off retardation and soil erosion prevention should be undertaken by the Department of Agriculture.155/

155/ p. 63.

Three bureaus of that Department, the Soil Conservation Service, Forest Service, and Bureau of Agricultural Economics, were making studies of that character, and to coordinate their work under the flood-control act, the Department set up the Flood Control Coordinating Committee on January 7, 1937. Proposed projects which were submitted by the various bureaus were passed upon by the Committee and those that were approved were undertaken.

The truth of the adage that "The mills of the gods grind slowly" was shown by the fact that of the various projects proposed only four involving cooperation were approved and reached the operation stage before the end of the period. These projects and the amount of flood-control act funds spent by the Survey prior to June 30, 1939, were:

Boise River Watershed, Ida.	$20,793
Coosa River above Rome, Ga.	2,550
Little Tallahatchie River, Miss.	3,674
St. Francis River, Mo.	4,940
Total	$31,957

These investigations were broadly similar in character to those carried on previously for the Soil Conservation Service, except that the Survey was not called upon to maintain rainfall stations and on two of them sediment measurements were not made.

The Boise River Watershed project was started in November 1938. Its object was to determine sediment losses from different areas with particular reference to various types of cover. Four existing gaging stations and nine new stations were equipped with recorders, and the new stations were equipped with artificial controls. Sediment samples were analyzed in a local laboratory by a junior chemist. Three engineers devoted part or full time to the project.

The Coosa River project related to flood control. Above Rome, Ga., the floods are caused by the discharge of two streams having entirely different types of drainage basins. The natural synchronization of flood peaks was of importance and changes in land use which would cause the flood peaks to coincide would aggravate the flood problems. Before deciding on the program of such changes, the Department of Agriculture found it necessary to have knowledge of the run-off characteristics of the various portions of the drainage area. The Survey was then installing recorders on the major streams of the basin, but the Department of Agriculture needed stations on minor streams draining from 15 to 100 square miles each. Accordingly, an arrangement was made whereby the Survey furnished recorders and installed them in temporary structures at its own expense, and the cost of operation was paid from funds transferred by the Flood Control Coordinating Committee. As F. M. Bell writes,[156]

156/ Letter to author.

the cost of operation was relatively high since many measurements and much detailed information were needed. Because of inability to get recorders, the program was not placed in full operation until the spring of 1939.

The Little Tallahatchie River project in the upper part of the Yazoo Basin, Mississippi, was started in January 1939 under the direction of S. C. Moore, with two assistants who had headquartered at Oxford. Ten gaging stations were installed at sites selected by the Forest Service, of which 6 were equipped with recorders and 4 with staff or wire-weight gages. The drainage areas ranged from 9.3 to 29.3 square miles. An existing station on the Tallahatchie River was used as the control station. Hourly tabulations of stage and discharge were computed during the flood flows of each major storm. As flood flows were the chief consideration, every effort was made to obtain measurements at the crests. On one occasion, measurements were started on Sunday afternoon and continued for 24 hours. The project continued beyond the end of the period.

A side light on field conditions is furnished by E. B. Rice, as follows:[157] Most of the stations are reached by country roads composed

157/ Letter to author.

of clay, and as they receive little maintenance they become soft and sticky to a depth of a foot or more when soaked. On one occasion the resident engineer drove his truck in low gear at full speed up a small

hill to make the crest before the engine stalled. He failed to reach the top and it required a team of four mules and the usual language applied to mules by drivers to pull the truck back down the hill to another road.

The St. Francis River project in Missouri was temporary and related to a preliminary report made by the Department of Agriculture. An existing station equipped with a recorder was used as the control station, and 12 stations equipped with staff gages were installed in February 1939. Two engineers were detailed to the project. Sediment samples were collected and analyzed in a laboratory at Rolla, under the direct supervision of S. K. Love of the Quality of Water Division. The project was continued until September 30, 1939.

Department of Justice.- With the appointment of a Federal Court Water Commissioner for the Gila River, Arizona,[158] the Department of

158/ p. 84.

Justice assumed liability for a part of the cost of maintaining the gaging stations in the Gila River Basin, previously paid by the Indian Service.

Annual expenditures were:

1937	$ 496
1938	1,490
1939	1,305

Federal Power Commission.- For the Federal Power Commission, the Survey continued to perform or supervise most of the stream-gaging required under the permits and licenses, to investigate proposed projects as requested, and to supervise the construction and operation of certain projects. The expenses incidental to the stream gaging were borne by the permittees and licensees as determined by the Survey's district engineers having such responsibility, but those incidental to investigations and supervision of projects were paid by the Commission itself. The expenses paid by the Commission did not include salaries as by the terms of the Federal Water Power Act the Interior Department, as well as the Departments of War and Agriculture, were to furnish services as required.

Until 1932, the Survey would estimate each year the amount of Federal Power Commission funds needed for the supervision of projects and such amount was transferred to the Survey for that purpose. In 1932, however, the Commission started the procedure of paying such expenses direct, and to make that procedure possible, the Survey "designated as representatives of the Commission to perform for the Commission such field work as may be assigned to them,"[159] those district engineers,

159/ Director's Ann. Rept. 1932.

about 30 in number, whose fields of activity included water-power sites subject to the Commission's jurisdiction. The projects over which the Survey exercised supervision of construction and operation were chiefly transmission lines on public land. The number of supervised projects increased from about 90 to 160 during the period.

The annual expenditures from Federal Power Commission funds for field expenses, were:

1929	$ 500	1933	$381	1937	$248
1930	535	1934	99	1938	14
1931	520	1935	183	1939	640
1932	1,610	1936	544		

Assistance by permittees and licensees in connection with stream-gaging requirements is described on p. 97.

In addition to expending its own funds, the Federal Power Commission, in connection with an application of the Rocky Mountain Power Company to construct a dam below Flathead Lake, Montana, required the power company to cooperate with the Survey in obtaining additional data[160]

160/ pp. 229.

and to defray the cost of such work by depositing funds with the State Treasurer of Montana.

Survey expenditures from that fund were: 1929, $7,033; 1930, $3,021, 1/ of which $1,334 was for ground-water investigations. 2/

1/ Letter from A. H. Tuttle to author.

2/ pp. 355-7.

Weather Bureau.- Weather Bureau cooperation consisted chiefly in furnishing gage heights for 76 flood-warning stations. For a few Survey stations the Weather Bureau paid the gage observers and incidental expenses. In addition, the Weather Bureau turned over to the Survey a PWA allotment of about $112,000 for the rehabilitation of its flood-forecasting stations, many of which were being operated in cooperation with the Survey.

Annual expenditures from Weather Bureau funds, exclusive of transferred PWA funds, were:

1929	$220	1933	$220	1937	$1,050
1930	220	1934	200 1/	1938	200
1931	657	1935	200 1/	1939	43
1932	395	1936	1,508		

1/ Estimated.

Forest Service.- Forest Service cooperation was limited chiefly to furnishing an hydrographer for the Los Angeles County project, California, which had originally been started through the efforts of the Forest Service.[161] When that hydrographer was retired in 1936, cooperation ceased.

161/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 345.

Bureau of Public Roads.- In September 1929 the Division of Agricultural Engineering, in connection with its investigation in the Santa Ana basin in southern California, requested H. D. McGlashan to obtain certain discharge measurements in connection with the Survey's regular field work during that fiscal year. To meet this request fully, Jarrett Oliver and K. R. Melin were detailed to that work during February and March 1930. Expenditures from Bureau of Public Roads' funds were $492. In addition, a similar amount was expended from the Bureau's cooperative State funds.

CWA-FERA-WPA.- The Civil Works Administration (CWA), the Federal Emergency Relief Administration (FERA), and its successor, the Works Progress Administration (WPA) made several allocations to the Survey of funds for the employment of relief labor, of both professional and non-professional classes for office work, and of both skilled and unskilled labor for construction of gaging stations--the latter commonly in connection with rehabilitation work financed by funds of the Public Works Administration.

The National Industrial Recovery Act approved June 16, 1933,[162]

162/ 48 Stat. L 195.

authorized the creation of the Federal Emergency Administration of Public Works for preparing and partially financing a comprehensive program of public works, in order to produce opportunities for large-scale employment. The preparation of this program required time, and to provide employment during the winter of 1933-34, the President by Executive Order under authority of the National Industrial Recovery Act, created the CWA on November 9, 1933. It was intended to be a very short-lived expedient for creating employment during a critical winter, and was not limited to those on relief. The CWA program was ended in April 1934 with about 190,000 white-collar employees on its rolls.

Prior to the creation of the CWA, the FERA had been created on May 12, 1933,[163] for a period of two years to make grants to the States

163/ 48 Stat. L 55.

for the purpose of furnishing relief and work relief. Many CWA office projects were continued by the FERA to provide employment for many of the white-collar workers previously employed by the CWA, who would otherwise have been on relief. The FERA expired May 12, 1935. There was such a strong demand for a continuation of the work-relief program that the Emergency Relief Act of 1935 was enacted on April 8, 1935.[164]

164/ 49 Stat. L 115.

Under this Act the Works Progress Administration was created by an Executive Order issued on May 6, 1935.

Many Survey districts collaborated with the successive agencies created, and the various State administrators of those agencies set up Survey work projects and paid directly the employees required. Under the CWA and FERA programs, the Survey districts sponsored the projects and the district engineers arranged directly with the State administrators for the organization of projects that would employ engineers

and clerks in office projects, and engineers and skilled and unskilled labor in the field. These projects were supervised by the Survey. Subsequent to the end of the FERA, Federal agencies could not sponsor projects, and cooperating State officials generally sponsored them. Under all of these agencies no employee was permitted to work more than 30 hours per week. It was, therefore, necessary so to stagger the employment of men utilized in field projects that the work would proceed on the usual basis of 48 hours per week in 6 eight-hour days.

Each office project generally utilized several engineers and a clerk to compile stream-flow records and other pertinent data. Some projects were limited chiefly to computing current records but a few had much wider scopes. In November 1933, the Boston office sponsored an office project to bring its duration tables up to date, tabulate average monthly and yearly mean discharges for all stations, measure drainage areas for all stations, determine the lowest mean flow for periods of 1 to 6 consecutive days, 1 to 6 consecutive weeks, and 1 to 18 consecutive months of record at each station, determine the peak flow and the highest mean flow for periods of 1 to 30 consecutive days, bring data on developed water power up to date, and study variation in the rainfall-runoff relations in various drainage basins of the district. That project which was continued under State sponsorship after the discontinuance of the CWA, employed at first 10 engineers and 2 clerks. In describing the personnel, Kinnison writes:165/

165/ Letter to author.

> All the men were graduate engineers and many of them had excellent experience. As long as we could secure this type of personnel the number employeed on the project was about the same. As these better engineers found employment, the number decreased until the last engineer left for private employment this spring. (1940)

Another office study employing six engineers and two clerks was started about January 1939 for the purpose of studying drainage basin characteristics. The cost of these Boston office projects was about $27,000.166/

166/ Op. cit.

A somewhat similar office project was sponsored by the Albany office for compiling and publishing stream-flow records in New York State. As Harrington states:167/

167/ Water-Resources Bulletin, Feb. 10, 1934, p. 11.

> The Geological Survey has been continuously engaged in the collection of stream-flow data in New York for over 30 years, and many records have also been obtained by various State organizations, the New York City Board of Water Supply, and others. The result of all this work is a huge mass of data which is not readily accessible to those who desire to use stream-flow records. The project of assembling and digesting these records and later of making special studies is a large job and will require probably not less than two years to complete, providing adequate funds are available.

This project, which was under the immediate direction of Hollister Johnson, formerly principal assistant engineer of the Black River Regulating District, lasted from December 1933 to December 1935. The cost was about $5,000.

The Hartford office sponsored a project to measure the drainage areas of each stream within or draining into Connecticut, about 250 streams, for some of which measurements were made at several points. The areas were used extensively in runoff studies and analyses.

The office project requiring the largest number of employees, both men and women, was that located in New York City and sponsored by New York University through Dean Thorndike Saville of the College of Engineering. Saville had formerly been instrumental in starting cooperation with the Survey in North Carolina while he was hydraulic engineer of the North Carolina Geological and Economic Survey,[168] and was not only

[168] p. 24, 1919-1928.

interested in flood and other hydrologic data but was also familiar with the Survey's work. There were many unemployed engineers and clerks in New York City and with the cooperation of the Survey and of the Soil Conservation Service, he as dean of the College of Engineering, sponsored an office project which was established in New York City in November 1935 and continued through June 1936, employing from 20 to 40 men and women. Technical direction and guidance were supplied by the Survey, and by the Soil Conservation Service, the former furnishing supervisory personnel and paying their salaries, and the latter paying travel and subsistence incident thereto. Saville was director of the project with G. R. Williams of the Survey as vice-director. Williams was in direct charge of the project with the project under the supervision of N. C. Grover and R. W. Davenport. The Soil Conservation Bureau furnished the services of C. S. Jarvis as consultant. The project had three major objectives: (1) The compilation of a selective bibliography on erosion and silt movement. This bibliography contained no titles of English publications but listed only those publications in foreign languages. The cosmopolitan character of New York City's population furnished translators for the various languages. The results were published in Water-Supply Paper 797. (2) A compilation of flood data which subsequent to the close of the project was amplified and checked by the Survey, was published as Water-Supply Paper 847. (3) A study of water losses in the United States which was published as Water-Supply Paper 846. The cost of this project was about $30,000.[169]

[169] Letter from R. W. Davenport to author.

Two special projects for studying floods and preparing reports on them were set up in California. One was in the Los Angeles office following the floods of March 1938 in Southern California, and the other in the San Francisco office following the floods of December 1937 in Northern California. These two projects which lasted during the fiscal year 1939 cost $6,000. The total cost of all of the office projects was about $200,000.

The field projects utilizing CWA-FERA-WPA funds were arranged for the purpose of furnishing employment for labor in connection

with construction work at gaging stations. The first and largest field project of this character was that sponsored by TVA for the construction of 54 gaging stations in the Tennessee River Basin in the Tennessee, North Carolina, and Virginia districts. The wages of the laborers and foremen for the 14 construction crews employed were paid by CWA and the cost of materials and recording gages was paid by TVA. That project, which was supervised by Survey engineers, lasted from December 1933 to April 1934. It was one of the first undertaken by CWA before that organization was in smooth running order. Regarding its cost, Burchard writes:[170]

170/ Letter to author.

> I have no (exact) information as to the amount of funds expended under the CWA program. It was a rush job in the middle of a bad winter * * * with untrained labor and foremen and daily conflicting orders from Washington, Raleigh, and the County seat. * * * It must have cost at least $50,000.

The Trenton district had a project which involved the employment of 30 men for about 4 months in the improvement of the Great Egg Harbor gaging station. Two oxbows in the river were cut off and the improved channel widened and deepened. The cost was about $22,000.

The Honolulu district developed a project to construct models of gaging stations and rating the models in the University of Hawaii's hydraulic laboratory. Several models were rated during the length of the project. It may be stated that the rating of models was so helpful that construction of other models later became a part of the district's activities.

Severe floods during March 1936 in the northeastern part of the country either destroyed or damaged many gaging stations. WPA allotments amounting to $108,000 were obtained soon afterward to pay for relief labor in repairing and rebuilding those stations. Two allotments were made, one of $100,000 to pay for relief labor, and the second of $8,000 to pay for supervision furnished by the Survey. Later, $5,400 was withdrawn.

The following year, 1937, severe floods in the Ohio and Mississippi Rivers caused further damage to gaging stations and two additional WPA allotments were made, one for $9,000 for relief labor and the other for $2,100 for supervision. Later, $4,000 was withdrawn. These two projects were set up at the request of the Washington office to cover the needs of the several districts concerned. All payments were made through the appropriate State Treasury offices, as in the case of projects requested by the individual districts.

When the Louisville, Ky. district office was established a large construction program was contemplated and a WPA allotment of $142,769 was obtained for that purpose. In setting up the project, Mr. Veatch proposed the following installations:[171]

171/ Letter from F. F. Schrader to author.

11 6' x 6' concrete gage wells, average range of stage 60'
11 combination pipe-gage wells, average range of stage 60'
10 pipe-gage wells, average overall height 53'
1 cableway cable 800' long and accessories
1 rehabilitation of existing gage well
1 control or low dam

Up to June 30, 1939, $19,500 had been spent in the construction of 11 stations.[172]

[172] Letter from J. V. B. Wells to author.

With few exceptions, the Survey districts had various construction projects, most of them involving less than $10,000.

The various field projects cost about $475,000, and the office projects, about $200,000.

Private assistance

Assistance by private interests was affected by the depression, and the number of stations for which some private assistance was rendered was reduced from 698 in 1928 to 359 in 1932. Thereafter the number was gradually increased to 446 in 1939. Of these, permittees and licensees of the Federal Power Commission furnished full or partial support for about 300 stations required in connection with about 120 projects. Of the other stations which received private assistance, partial support was furnished in the use of materials and facilities or in records obtained by private parties for their own purposes, made available to and checked by the Survey to insure reliability. The total value of such private assistance is not available. The amounts expended through the Survey for permittees and licensees were:

1929	$29,128	1933	$31,508	1937	$22,922
1930	38,603	1934	25,549	1938	24,996
1931	50,419	1935	22,372	1939	27,199
1932	33,355	1936	25,002		

It was within the discretion of the district engineers having supervision over the stream-gaging requirements to accept from permittees and licensees such services, and materials as could appropriately be used, and in many instances such assistance was utilized in addition to the payment for Survey expenses for services, instruments, equipment and materials. The district engineers were required so to conduct or supervise the work that they could vouch for the reliability of the records. At least as great amounts as were expended by the Survey were expended directly by permittees and licensees under Survey supervision.

Current meters

At the beginning of the period the two types of current meters in general use were the combination and the improved meters, both manufactured by W. & L. E. Gurley. The responsibility for the current meters, their selection, purchase, care, and the accuracy of the ratings with the various types and sizes of weights used, and in short the general supervision over them, rested with the Branch as

previously. They continued to be rated by the Bureau of Standards. Minor repairs of the meters, including substitution of new parts, and arrangement for transmitting the meters to the Bureau of Standards for rating, were made in the Branch under the supervision of B. J. Peterson. Certain repairs, such as soldering meter cups or tail vanes, were made by C. H. Au.

The general repairing, adjusting, replacing of parts, and the work incidental to transmitting the meters, were transferred (by letter from the Chief Hydraulic Engineer to the Chief Clerk about November 1, 1930) to the Division of Field Equipment of which R. L. Atkinson was chief. The preparation of current-meter rating tables and contact with the Division of Field Equipment relative to the conditioning of meters remained with Peterson until those duties were transferred to C. H. Pierce in 1932, and to A. H. Frazier in April 1936 who performed them during the remainder of the period.

Soon after the Division of Field Equipment entered the picture, the Gurley catalogue numbers for the meters came into general use, and the combination meter became known as the 623-type meter, and the improved meter as the 622-type meter. At about that time Atkinson made special gages to check the alignment and dimensions of the new 622-type meters and parts. Previously, much time had been consumed in adjusting and fitting parts furnished by the manufacturer who did not work to exact dimensions. In passing, it may be noted that Atkinson substituted the term "bucket" for "cups" which had been in general use since the early days of the Survey. By rejecting all newly-delivered parts that did not conform to established standards, the replacement of worn or damaged parts on 622-type meters subsequently issued was greatly simplified. Detailed specifications for 622-type meter parts with a very small tolerance in the dimensions were prepared in 1931 and incorporated into the general specifications for current meters under General Schedule of Supplies contracts for the following year.[173] Complete 622-type

[173] Circular letter dated May 12, 1931.

current meters and parts had been available under General Schedule of Supplies contracts since their first appearance in a supplement to the General Schedule issued in the fall of 1928, but during the years between 1928 and 1932, the specifications under which the contracts were let were of a very general nature.[174]

[174] Circular letter dated Sept. 12, 1928.

Bids under the newly-prepared detailed specifications of 1931 were requested from several instrument makers, including Gurley, White, and Lietz. As patent rights on the combination meter had expired, and as the 622-type meter had not been patented,[175] no danger of infringement

[175] Statement of C. H. Pierce to author.

was involved in this procedure. The bids of both the Gurley and White companies for the various parts in 1932 and several succeeding years were so much lower than the bids for the assembled meters that parts were purchased and the meters assembled in the Division of Field Equipment. This procedure permitted the use of the type-A shaft assembly and the heat-treated pivots and lower bearings which were

made by the Division of Field Equipment, and were not obtainable under the General Schedule of Supplies until a later date.

An important change that improved the durability of current meters was the introduction by Atkinson in 1931 of a special heat-treated "A metal" for use in pivots and lower bearings. The relative hardness of those two parts was given special attention which, during the following year, resulted in the adoption of a Rockwell hardness of between C-57 and C-59 for pivots and not less than C-61 for bearings.[176] To determine

176/ Circular letter dated Aug. 23, 1932.

the performance of pivots and lower bearings made of different metals and having various degrees of hardness, Atkinson used a special testing device by means of which various pivots and bearings were revolved under water for periods of an hour each (9,000 revolutions) which indicated their useful life in a short period of time. Bearings were made harder than pivots in order that wear would be predominantly in the pivot which could be replaced more easily than the bearing.[177] Before deciding

177/ Water-Resources Bulletin, Sept. 1931, p. 4.

definitely upon the proper metals, a number of experimental meters were made and sent to the field for trial. The Alabama district was one to which these meters were sent and as McCashin writes,[178] "In one period

178/ Letter to author.

of about a week we ran five meters continuously (during daytime) in a stream to test out the wearing qualities of different types of meters."

A new shaft assembly was experimentally introduced in 1931, and current meters containing this assembly were first identified as of the 622-A type, and later merely as type A. In this new design, the pivot was much longer and of larger diameter than that for the 622-type meter. It was extended farther into the hub assembly in order that a larger air pocket would be provided to exclude silty water from the bearing surfaces. A bucket wheel-raising nut similar to that of the 623-type meters, which permitted the bucket wheel and lower bearing to be held away from contact with the pivot when the meter was not in use, was included in the design of the new shaft assembly.

The 622-type, and type A meters were not dependable for velocities below half a foot and as streams during low water were very sluggish in some districts, there was a real need for a meter that would measure accurately very low velocities. In 1937, 5 experimental meters containing changes in the construction of the hub assembly were constructed. The changes consisted in placing a 622-type bearing seat in the hub of an A-type meter, and locating the seat in such a position that the point of the pivot would be in the horizontal plane passing through the center of the bucket wheel. The pivot was similar to that of the 622-type except that it was longer. This type of meter, known as the type AA meter was found to give dependable results for velocities as low as about .06 foot per second, and became one of the standard Survey

meters.[179]

[179] Water Resources Bull. Aug. 1938, p. 201.

The primary purpose of having pivots and bearings made of suitable metal and tempered properly was to assure that the meters would retain ratings more satisfactorily. In that connection, the Idaho Falls district stated:[180]

[180] Water Resources Bulletin, Sept. 10, 1931, p. 18.

> It has been our experience that there is too much variation in velocities as indicated by different meters, even when the spin test indicates that the meters are working satisfactorily. Part of the work in this district involves the determination of losses and gains in sections of the Snake River by subtraction of river flows, and even a 1-percent error in the river ratings cannot be tolerated, as it would seriously affect the respective (water) rights * * *.

With parts standardized and made of suitable metals of the proper hardness, meters received from the field were standardized and fitted with new parts as needed before being rated. Thereafter, when meters were returned to the field they were, with respect to performance, as good as new.

Although improved at various times, the current meter still had its limitations, especially for use in shallow depths and measuring very low velocities. The need for a meter to measure low velocities had been apparent for many years, but this need was brought to attention and emphasized in the Kootenai River investigations in 1928.[181]

[181] p. 157.

A step towards a "low-velocity" meter was taken when the penta gear was removed from the regular meters, thus eliminating some of the friction. Comparisons of ratings of the same meter before and after periods of use generally showed greater percental changes for low than for high velocities, indicating that the low-velocity rating was more affected by use of the meter than the high-velocity rating. Therefore, it was suggested that meters intended for use in measuring low velocities should be used only for that work. One drawback to the use of the current meter in measuring very low velocities was the fact that even with the single revolution contact it was frequently necessary to wait for from 30 to 50 seconds before the initial contact was made. In order to cut this waiting period in halves, the shafts of certain specially-constructed type-A "low-velocity" meters were machined to provide for two contacts per revolution.

Pygmy meter: In the design of a meter for measuring velocities in shallow water, a logical approach was to reduce the size of the meter. The one-third scale type-A current meter, beautifully mounted with hanger and sounding weight, that was presented by the Division of Field Equipment to N. C. Grover on his twentieth anniversary as Chief of the Branch (June 3, 1933), was a forerunner of the later-designed "pygmy" current meters.

During the drought year of 1934, the need for a small current meter that would measure shallow streams at times of low flows was emphasized by the scarcity of water and the need for accurate measurements of small streams. The progenitor of the first pygmy meter was a very small meter of the horizontal-axis type exhibited at the University of California's Engineering Day in 1933, and was suggested by a similar one made at the Iowa State College at Ames, Ia. H. M. Orem and B. C. Colby of the San Francisco office became interested in the possibilities of this meter and decided to attempt its improvement to make it applicable to field use in the Survey. At their suggestion and expense, a mechanic connected with the University made an improved meter in his spare time at home. It had three rotors of different angularity for various velocities. This meter was rated at the University of California and was used in making more than a hundred vertical velocity curves, the results of which were encouraging.[182] The meter was sent to Washington in January

182/ Statement of Messrs. Orem and Colby to author.

1934 for a rating at the Bureau of Standards. Using it as a model, Atkinson made two similar meters but of somewhat heavier construction, completing the first in December 1934. Experimental use of these meters showed that they would not rate consistently to as low velocities as desired, and the substitution of different rotors as needed to cover the range of velocities normally encountered in field work was inconvenient.

Falling back on the cup-meter type, and perhaps mindful of the souvenir meter of that type, Frazier constructed three celluloid "bucket wheels;" one was identical in size with the 5-inch metallic wheel on the standard meter, another was 2 inches, and the third $3\frac{1}{2}$ inches in diameter. In January 1936, C. L. Batchelder, A. H. Frazier, O. W. Hartwell, Lasley Lee, and C. H. Pierce, in cooperation with Messrs. Stutz and Mason of the Bureau of Standards, made comparative tests of these bucket wheels by visually counting the revolutions made by the three celluloid bucket wheels in the same period of time when drawn through the water at the same velocity. These tests indicated that the 2-inch diameter wheel would probably be the most practicable for field use in shallow water.

The following month a meter, No. WR-C, having a bucket wheel 2 inches in diameter (two fifths the dimensions of the standard meter) was made by the Division of Field Equipment in accordance with designs suggested by Frazier. Another model of this reduced size but having a bucket wheel with cups machined from a bronze rod and whose other features were similar to the type-A current meter was later designed and constructed by the Division of Field Equipment. A partial rating of this model was made at the National Bureau of Standards on March 26, 1936, in the presence of Atkinson and Anderson of the Division of Field Equipment, Pierce of the Water Resources Branch, and Stutz and Mason of the National Bureau of Standards. This was the first bucket-wheel type pygmy current meter numbered in the WR-A series, its number being WR-A-3. Four additional pygmy current meters of this type were made, and field experience with them formed the basis upon which later alterations were made. Thirteen Survey bucket-wheel type pygmy current meters of the WR-A series had been used in the field prior to the end of the period.

Meter rating coefficients: Until elliptical weights, particularly in large sizes, came into use with the new hanger designed for them, meter rating coefficients were not important. Prior to that time the few commonly used meter hook-ups with torpedo weights had shown little difference in effect on the meter ratings. The Bureau of Standards in 1916 and 1917 had rated several meters to determine such differences, when the meter was suspended in different positions relative to the 15-pound weight or combination of 10 and 15-pound weights, and with a flat rod suspension. These ratings indicated that if the center of the meter was suspended .5 foot or more from the point of suspension of the weight there was less than 1 per cent difference, and that the difference between the rating for cable suspension with weights and rod suspension was similarly limited.[183]

183/ Results of Current Meter Test No. 6 "To determine the relative effect of placing the meter and weight at different positions on the standard hanger." (Mimeograph)

After the elliptical weights came into use, extensive tests were made in 1928 and 1929, using five improved and two combination meters with 15- and 30-pound torpedo and elliptical weights, to show the extent to which the ratings of the meters varied for various arrangements of meter and weight. Comparisons with the round-rod suspension were also made. The ratings covered velocities ranging from 0.25 foot to 9 feet. The standard of comparison selected was the rating of the meter suspended from the hanger hold 6.7 inches above the suspension hole of the 15-pound elliptical weight, as that suspension was the one most commonly used in the field. After the 50, 75, and 100-pound elliptical weights were made, the comparative ratings were extended to those sizes.[184]

184/ Supplement issued in July 1929.

The results of these tests[185] indicated that the nearness of the weights

185/ Meter ratings with various suspension arrangements, 1928-29 ratings.

to the meter had a greater effect on the rating at very low velocities than at medium and high velocities, and that the effect of the elliptical weight was greater than that of the torpedo weight. However, above a velocity of about half a foot per second the coefficient for either weight was about 1.01 as compared with the standard rating. For very low velocities it was found that ratings varied so widely that individual ratings were needed for a high degree of accuracy.

At that time there was no standard suspension for rating the meters, although the meters were usually rated on a cable with the center of the meter suspended 6.7 inches above the suspension hole for the 15-pound elliptical weight. In spite of the results of the tests the district engineers when sending meters to be rated, would frequently request ratings under more than one condition. With the increase in the number of meters being used, these requests for multiple ratings threw a great burden on the Bureau of Standards with the result that delays in obtaining the ratings were unavoidable.

With the appearance of the Columbus-type weights, it appeared undesirable to set up a formal test program such as that of 1928-29. As a temporary expedient, the round-rod rating was selected as the standard

method of suspension, and as meters were sent to the Bureau for rating, ratings with a Columbus-type weight were also requested. By varying the size of the Columbus-type weight requested for rating with the round-rod suspension as well as with cable suspension, it was possible to build up gradually a comparison with the various sizes of Columbus-type weights. A study of these ratings indicated that coefficients for the various hook-ups could be applied to the standard round-rod rating for the various weights and arrangement of hook-up, thus eliminating the necessity for having individual meters rated for various combinations as had formerly been done. The coefficients for the Columbus-type weights were smaller than for the elliptical weights and above a velocity of half a foot per second, the coefficient was well within 1.01. The round-rod suspension appeared to be so satisfactory for rating the meter that what had been adopted as a temporary expedient continued as standard during the remainder of the period.

Water-stage recorders

In 1928 the district engineers were purchasing more water-stage recorders than formerly and, following established precedent, were purchasing directly from the manufacturers. As many of the recorders cost more than $100 and were not purchased oncontract, the engineers were having considerable difficulty with the General Accounting Office in respect to payments. To avoid this difficulty, and to comply with the insistence of the General Accounting Office that recorders be purchased on contract, general specifications for both continuous and weekly recorders were prepared and sent to all manufacturers of recorders as a basis for bidding. The Friez Company was the successful bidder and the Au instruments and accessories were placed on the Schedule of Supplies for the fiscal year 1929. Practically the same specifications were used during the fiscal year 1930 to 1932.[186]

186/ Statement of Henry F. Hill, Jr. to author.

For the fiscal year 1931 the bids for Stevens and Au-Friez instruments were so close that both recorders were placed on the Schedule of Supplies. The reason for this was that when the cost of transportation was taken into account, the Friez recorders were cheaper in the east and the Stevens instruments cheaper in the west.

By 1931 it appeared that instead of using general specifications for recorders, the Survey should prepare more detailed specifications, as this would result in the procurement of recorders which would more fully meet the expanding needs of the Branch. Sample specifications were prepared in the Washington office and sent to the district engineers on July 13, 1931, with request for suggestions. With the proneness of humans to procrastinate, the district engineers' replies had not all been received when it was time to prepare specifications for the fiscal year 1933, and as a result the General Supply Committee prepared its own specifications which were much briefer and more generalized than those previously used. One change, however, was made. Instead of specifying bids f.o.b. factory as had been done previously, bids were called for both "f.o.b. factory" and "delivered at Washington." Both Stevens and Friez continuous types were placed on the schedule.

Specifications which were much more in detail were prepared in time for the 1934 fiscal year and sent to prospective bidders with

requests for bids at factory and delivered to the Survey in Washington. This time the Leupold-Volpel bid was the lowest for delivery in Washington, and the Friez bid lowest at factory. As a result of this situation, western district engineers who were using Stevens recorders almost exclusively, had new Stevens recorders delivered in Washington, and paid the transportation charges back to their districts. The Portland office, in the city where the Stevens recorders were manufactured, afforded the most striking example of the absurdity of that procedure. In an attempt to remedy the situation the Survey early in that fiscal year requested the General Supply Committee to place both Stevens and Friez recorders on the General Schedule, stating that the prices were very nearly the same and that the latter had some desirable features which the former did not have.[187] This plea was unsuccessful and the General Supply

187/ Letter of Aug. 9, 1933.

Committee on August 24, 1933, advised that recorders had been awarded to the lowest bidder complying with the specifications both as to design and workmanship, and added

> It is suggested that a detailed specification be submitted for a continuous recorder of a type which includes all features necessary to meet the need of the service for inclusion in our annual invitation for bids.

For the next year (1935) the specifications were made in greater detail and to avoid, if possible, a repetition of the delivery situation, the country was divided into four zones, and bids requested for delivery in each. This plan had previously been in use by some other bureaus. Competition was so keen and the resulting bids so close that during the remainder of the period the Friez recorders were cheapest in the eastern half of the United States and the Stevens in the western half. This arrangement was generally satisfactory, as by this time eastern districts were generally using Friez, and the western district, Stevens recorders.

As a result of the changes in specifications during the period and the keen competition between the manufacturers, the recorders were materially improved, and optional accessories were added to meet the needs, or wishes, of some districts. The Survey itself did no development work on recorders but simply specified what was required of the instruments.

Increase in use: As a result of the increase in available funds the number of recorders increased from 958 to 3,000 during the period, a greater percentage increase than in the number of stations. In 1928, 53 per cent of the stations were equipped with recorders, and in 1939, 72 per cent. The recorders installed were chiefly Stevens and Au-Friez instruments, and these two types had become practically standard equipment.

Recorder installations

The 2,581 recorder installations made during the period, represented a part of the extensive rehabilitation program financed by PWA funds.[188]

188/ pp. 71-73.

Of the 2,581 installations, the wells of 1,253 were all concrete, (110 with timber shelters), 25 masonry wells with timber shelter, 557 pipe, 13 masonry and brick, 708 timber, and 16 were built within bridge piers. In Hawaii, 9 consisted of a masonry well toped by a shelter consisting of an aluminum frame covered by masonite, plywood, or canec, the Hawaiian equivalent of celotex.

The reinforced-concrete structure was the Survey standard where available funds and permanency of stream bed and banks justified. Plans prepared by the Columbus office, based on the experience of the various districts, were considered standard for concrete structures. The first change in these standard plans during the period was made in 1933 when Lasley Lee prepared plans and specifications which revised those prepared and published in 1927.189/ The inside dimensions were increased from

189/ p. 67. 1919-1928.

3'6" x 4' to 4' x 4' and detailed plans were shown for a pump-flushing device and a sediment trap. This trap which had been devised by Ellsworth and used successfully on sediment-laden Texas streams subject to flash floods, was essentially a cylindrical vat built between the outer end of the intake and the shelter, with its bottom sufficiently below the elevation of the intake to provide a sump for sediment. Other minor changes were made in the plans. As a result of the experience gained in constructing many shelters during the 1933-34 rehabilitation program, plans were again revised and published in 1934. The chief change was an increase in the dimensions of the well to 4'6" x 4'6" to provide additional space not only in the well itself but especially in the shelter.

Another type of concrete structure was devised by Burchard in 1929. At the start of the cooperative Army-Engineer program in 1929, Burchard found it necessary to erect durable structures that were less expensive than the standard concrete structures. He designed a structure of circular cross section, 4 feet in diameter, and the steel forms needed for erection. About 60 circular structures were built chiefly in the Asheville and Austin districts, with a few each in the Chattanooga and Columbia districts. Regarding the circular structure, Burchard writes:190/

190/ Letter to author.

> These jobs are easy to build, cost less than the square design, are bug and bullet proof, are subject to less flood damage, and require a minimum of maintenance.

In 1936, the Harrisburg district began the use of concrete-block instead of monolith construction, except on large rivers subject to destructive floods. Nineteen concrete-block structures were built. Regarding this type, Mangan writes,191/

191/ Letter to author.

> It now appears peculiar to me that we did not use it before we did. It is relatively cheap and sturdy and in my estimation is equally serviceable and as attractive as poured concrete.

Many concrete structures erected during the period were higher than those built previously, and some required excavations of 40 feet or more in unfavorable ground. To overcome the difficulties, the open-caisson method was employed at several stations. So unfavorable were conditions at the stations on the Mississippi River at Cape Girardeau, and on the Ohio River at Louisville and Kosmosdale, that the pneumatic-caisson method was used. Some of the more outstanding structures of this period are described in more detail on subsequent pages under Gaging stations on the lower Mississippi River, Gaging stations on the Ohio River, and district operations for the Middle Atlantic States, Columbus, Indianapolis, Rolla, and Tacoma districts.

The only published plans for pipe wells and shelters were prepared by McGlashan in 1929. Some districts used these plans, modified them to meet their own views or constructed pipe wells with wooden shelters. The McGlashan type of structure was used either attached to piers (without intake pipe), or entrenched in the ground (with intake pipe). Most other types of pipe installations were used at bridge piers. The chief advantage of the pipe well was its relatively low cost, and the ease and speed of erection, as they were generally fabricated at the factory. Of the 557 pipe wells built in the period, the number of the McGlashan type is not known but was probably about 150.

No general plans for other nonstandard types of structures were published. It is probable that each district, as in the past, made its own design.

The following table lists all recorder structures having an over-all height of 60 feet or more:

Station	Type	Height (feet)
San Carlos Reservoir at Coolidge Dam	pipe	159
Cumberland at Burnside, Ky.	pipe	110
Tennessee at Paducah, Ky.	concrete and pipe	100
Alabama at Claiborne, Ala.	pipe	95
South Fork Cumberland at Nevelsville, Ky.	concrete	93
Ohio at Louisville, Ky.	concrete	91
Columbia at Grand Coulee, Wash.	concrete	80
Black Warrior at Tuscaloosa, Ala.	concrete	80
Tombigbee at Epes, Ala.	concrete	76
Tombigbee at Gainesville, Ala.	concrete	74
Potomac at Paw Paw, W. Va.	concrete	73
Ohio at Huntington, W. Va.	concrete	72
Tennessee at Savannah, Tenn.	concrete	72
Columbia at International Boundary	concrete	71
Locust Fork Black Warrior at Trafford, Ala.	concrete	71
Caney Fork near Silver Point, Tenn.	pipe	69
Tennessee at Meadow Lake near Chattanooga, Tenn.	concrete	68
Tennessee at Citico Bar near Chattanooga, Tenn.	concrete	68
Pend Oreille below Z-canyon, Wash.	concrete	68
Feather at Oroville, Calif.	concrete	68
Ohio at Metropolis, Ill.	pipe	68
Mississippi at Memphis, Tenn.	concrete	66
Ohio above Dam 53, Ill.	concrete	66
Rio Grande at Langtry, Tex.	concrete and pipe	66

Station	Type	Height (feet)
Mississippi at St. Louis, Mo.	concrete	65
Cumberland at Carthage, Tenn.	pipe	65
Columbia at Trinidad, Wash.	concrete	63
Columbia at Birchbank, B. C.	concrete	63
Columbia at Kettle Falls, Wash.	concrete	63
Trinity near Oakwood, Tex.	concrete (circular)	62
Brazos near Bryan, Tex.	concrete (circular)	62
Brazos at Richmond, Tex.	pipe	62
Stevens Creek near Modoc, S. C.	concrete	61
Potomac at Hancock, Md.	concrete	60
Little Colorado at Grand Falls, Ariz.	pipe	60

In addition to the preceding list, at least three installations were made in bridge piers greater than 60 feet high. The most notable was that on the Mississippi River at Vicksburg, Miss., where the height of the pier was 120 feet.[192] At the first installation on the Columbia

192/ p. 164.

River at Grand Coulee, Wash., the pier used was 77 feet high, and on the Cape Fear River at Fayetteville, N. C., it was 76 feet high.

Flushing devices: Riser pipes with funnels were used in flushing devices to a limited extent during the previous period.[193] In a few

193/ p. 70, 1919-1928.

instances pumps had been used, but had not proven satisfactory as the amount of water thrown was not sufficient to clean the intakes thoroughly, and difficulty was experienced also in keeping pump valves in working order. Therefore, the use of the few pumps that had been installed was discontinued and riser-pipe funnels were filled by means of buckets. This method required lifting water from the stream. For the higher structures that were erected during the present period, the manual method was laborious and time consuming. To overcome the chief difficulty formerly experienced in the use of pumps, the funnel was replaced by a tank, of such size that the water in it, when released, was of sufficient volume to clean the intake. A pump drawing water from the well was used in filling the tank. One of the first installations of pump and tank was made by Ellsworth on the Rio Grande at Roma, Texas, in March 1929, where a tank was placed in the shelter at an elevation of 35 feet, and a force pump set at an elevation of 14 feet, opposite the clean-out door in the well.[194]

194/ Letter from C. E. Ellsworth to author.

In the 1933 plans and specifications for the 5' x 5' (outside dimension) concrete shelter, Lee presented a design for a lift pump discharging into a tank, both of which were placed on the floor of the shelter. The key to operate the valve in the riser pipe was brought above the shelter floor. This design came into general use where pump-flushing devices were needed. The funnel-flushing device was also used extensively. Multiple intakes were frequently installed during the present period and where installed each intake was connected with the tank by a riser pipe.

Drawdown in wells: With an intake extending into the current at nearly right angle to it, the velocity of the water flowing past its end causes such a drawdown that the water surface in the well is lower than that in the stream. This drawdown is variable, and various devices have been used to eliminate it. In October 1933, Burchard built at the outer end of the Asheville station intake a low wall 8 feet long at an angle of from 5° to 10° with the current, the upstream end projecting into the current. This wall produced slack water at the intake and thus eliminated the drawdown.[195] This device was so successful in

195/ Water-Resources Bulletin, Feb. 10, 1934, p. 12.

the North Carolina streams which are not heavy silt carriers, that a headwall was subsequently installed at nearly every station in Burchard's district.

Various fittings attached to the end of the intake pipe were tried, the most common being 45° or 90° elbows or tees with a short pipe extending upstream, downstream, or downward in a vertical plane; the so-called "static tube" having holes on all sides and cutting the end of the pipe at various angles was also tried. At least three types of baffle were used: the Twitchell, having horizontal and vertical vanes of 1/8-inch sheet metal inserted in the end of the pipe and protruding beyond the end of pipe; the Ash, with a horizontal vane protruding beyond the end of the pipe; and the Canfield, a flat plate 8 inches square normal to current, held in position 3 inches upstream from the end of the pipe. These various devices were tested at the National Hydraulic Laboratory,[196] and as the static tube was found to give the

196/ p. 153.

best results under all conditions, a brief description of its development is presented.

In September 1935, F. F. LeFever, while working in the Denver district, devised an extension for the intake of the North Platte station at the Wyoming-Nebraska State line. The extension consisted of a short tube set at right angles to the current and having the outer end closed and eight 1/2-inch holes on the upstream side and the same number on the downstream side. This device, which was adapted from a discussion of the pitot tube, found in Kings Handbook of Hydraulics, practically eliminated the drawdown in the well. Unfortunately the upstream holes were quickly clogged by leaves and trash, and the drawdown became worse than originally. He remedied the difficulty by turning the tube downstream by means of a 90° elbow. LeFever subsequently, while working in the Santa Fe district, modified the design slightly and the device was installed at one or more stations in that district.[197] At about the time when LeFever was installing the first

197/ Letter from F. F. LeFever to author.

tube, and before that action was announced, P. R. Speer, then working in the Albany district, suggested from theoretical considerations the use of a similar tube, and added that the device had not been tried in his district.[198]

198/ Water-Resources Bulletin, Oct. 10, 1935, p. 6.

The San Francisco district was among the leaders in urging that something be done to eliminate drawdown in wells, and in July 1937 F. A. Johnson and B. C. Colby made a series of tests in the new flume on the American River near Camino of two devices which were called a Ser's disk and a "static tube," and the results indicated that the latter with axis parallel to the current gave satisfactory results.199/

199/ Op. cit., Aug. 10, 1937, p. 164.

This is believed to be the first use of the term "static tube" as applied to the flow of water, and was suggested by the static tube designed chiefly for aerodynamical research such as experiments in wind tunnels.200/

200/ Letter from F. A. Johnson to author.

The static tube recommended in Water Supply Paper 868 B, p. 69, as the result of laboratory experiments had several rows of holes extending around the tube, the total area of the holes being from 20 to 25 per cent greater than the cross sectional area of the tube, in order to insure effective flushing.

Although that Water-Supply Paper was not published until 1941, several articles describing the laboratory tests appeared in the Water Resources Bulletin in 1938 and 1939. As a result, about 70 static tubes were installed by a few districts during the period. Subsequently many more were used.

Cableway installations

With more adequate funds available for field work than previously, it was possible to meet the demand for records of large rivers at sites where long-span cables were needed. These cableways required high supports, and as steel was more economical than timber for such supports, steel A-frames and 4-legged towers came into the stream-gaging picture. Some of the more humid districts had found also that timber supports decayed so rapidly as to make their use uneconomical. During the previous decade, steel supports had been constructed at two stations by cooperating agencies, and early in 1929 the Washington Water Power Company raised the cable at Kettle Falls, Wash., using a 64-foot steel tower as one support.

The first Survey-erected steel A-frames were those on Caney Fork near Rock Island, Tenn., after the flood of March 1929 had destroyed the old cableway. The average rainfall of 50 inches annually caused such rapid decay in timber structures, that it was decided to use steel with design similar to that of the standard timber A-frame.201/

201/ Letter from F. M. Bell to author.

The first Survey-erected steel towers were on the Columbia River at the Dalles in the spring of 1930, where supports 54 feet high were needed for the cable of 1,237-foot span. G. H. Canfield designed

steel towers of that height which were set on concrete piers. While that installation was being made, engineers for a power company were designing steel towers 42 feet and 89 feet high for the support of a cable of 1,654-foot span on the Columbia River below Rock Island Rapids at Trinidad, Wash. G. L. Parker, as a result of his experience with the Kettle Falls installation, made suggestions which resulted in an improved design.202/ These towers were erected in October 1930. The next

202/ Letter to author.

steel towers were erected in November 1930, when C. E. Ellsworth installed 4-legged towers 20 feet high to support the cableway on the Colorado River (of Texas) at Eagle Lake, Texas. These low towers were designed by a steel company to carry the load specified, but after erection it was found that they were unnecessarily heavy. 203/ Profiting by this

203/ Letter from C. E. Ellsworth to author.

experience, when steel supports were needed in June 1931 for a cableway on the Brazos River, Texas, steel A-frames similar in design to the standard timber A-frames were used.

Because of the growing use of steel supports, the Columbus office took up the problem of their design; obtained the designs that had been tried by the districts; cooperated with the International-Stacey Company of Columbus, makers of oil derricks and airway beacons, in the design of steel towers, with landing platforms, in heights of 11 to 51 feet; and furnished blue prints to the district engineers.204/

204/ Proceedings of 1931 Conference, p. 29.

In the spring of 1933, W. E. Dickinson found that the timber A-frames installed on the Colorado River at Lees Ferry in 1928 had so deteriorated as to endanger the cableway, and designed a steel A-frame 31 feet high to be used on the original concrete pedestals. At the same time, he designed also a steel landing tower to be erected at some distance from the A-frame, in order to make it unnecessary to pull the cable car up the steep slope to the cable support in its almost daily use.

Making use of the designs from various sources, Lasley Lee in 1933 prepared and published plans and specifications for structures from which discharge measurements are made, as one of the series of "Equipment for river measurements." This publication stressed particularly the design of steel supports and in that connection stated:

> Fabricated steel towers are coming into general use and are recommended for safety and permanence. For towers over 35 feet in height, structural steel is more satisfactory and more economical than wood.

The recommendation was made that supports greater than 33 feet in height should be designed with either three or four legs.

While Lasley Lee was preparing his plans, Parker in the Tacoma district was also preparing designs for steel A-frames which finally resulted in standard plans for heights from 12 to 49 feet (for greater

heights, 4-legged towers were recommended). Parker stated that these standard plans required in general a somewhat smaller quantity of steel than was indicated by Lasley Lee's plans, and that they were easier to install.[205] Although steel supports were coming into use, the great

205/ Letter to author.

majority of supports erected during the period were the standard timber A-frames.

With the erection of longer-span cables, more attention was given to anchorages. The trapezoidal concrete anchorage first used by Parker[206] was developed further and plans for such anchorages and for

206/ p. 73, 1919-1928.

a design by Ganfield were presented in the 1933 plans and specifications.

During the period, 828 cables were erected of which the longest had a clear span of 1,727 feet. Cables having spans exceeding 1,000 feet were erected at the following stations:

Station	Length of span in feet
Columbia River opposite Maryhill, Wash.	1,727
Columbia River at Trinidad, Wash.	1,654
Tennessee River at Florence, Ala.	1,646
Tennessee River at Breedenton, Tenn.	1,600 1/
Missouri River below Fort Peck, Mont.	1,300
Columbia River at The Dalles, Ore.	1,237
New River at Radford, Va.	1,194
Muskingum River at McConnellsville, Ohio	1,152
Columbia River at International Boundary	1,148
Columbia River at Grand Coulee, Wash.	1,100

1/ Supported by central tower.

Development of equipment

Army Engineer cooperation resulted in the installation and maintenance of gaging stations on larger rivers than previously, and the need for heavier field equipment was felt. C. H. Au, in charge of the Section of Instrument Design, was given the task of devising the new equipment. The Columbus office was housed on the campus of Ohio State University, and through the good offices of the cooperating State official, Prof. C. E. Sherman of the civil engineering department, permission was given the Survey to use the University machine shop, foundry, and testing laboratory. Not only were these facilities made available, but material was furnished at cost. With this arrangement and a district personnel headed by Lasley Lee who was much interested in such development, the Columbus office, which was not too far distant from the Washington office for supervisory trips, was selected as the center of operations. Nearby streams also afforded sites for field trial. After Mr. Au resigned in May 1931, the work was carried on by the Columbus district personnel and a Branch committee on field

equipment, the members of which visited Columbus as occasion required.

The actual development work was performed largely by the personnel of the Columbus office. Following long-established precedent, the district engineers decided upon the type of the instruments needed, and the method of paying for the development. At the conference held October 17-22, 1927, the district engineers agreed that the cost should be divided among the various districts. For the year 1929, the Washington office, instead of making a direct assessment on each district allotment, paid the cost from the Washington office contingent fund. This was an indirect application of the assessment method as the contingent fund was reduced thereby, and less money was available for allotment to the districts.

The conference of January 20-25, 1930, in considering further development work, directed that the manner of assessment on each district be left to the Washington office. This resulted in direct assessments of $75 and $124 against each district allotment for the years 1930 and 1931, respectively. When the next conference was held, October 12-17, 1931, the need for further development work was apparent and realizing that the available funds varied widely among the districts, the district engineers decided that the assessment against each district should be based on the total funds available in each district. That procedure was followed during the years 1932 and 1933.

Early in the fiscal year 1934, it was decided that the only logical and practical way to pay the development cost was to prorate it on the basis of the Federal cooperative funds available to each district and beginning July 1, 1933, the Columbus office was authorized to charge the Gaging Streams account "Development of Equipment-Prorate-Columbus" not to exceed a definite amount for development work, the extent of which was planned at the beginning of each year.[207]

207/ Letter from H. F. Hill, Jr. to author.

The annual amounts charged to development work were:

1929	$3,000	1933	$1,870	1937	$3,483
1930	4,600	1934	1,718	1938	3,648
1931	4,085	1935	800	1939	4,000
1932	1,500	1936	1,500		

A. H. Frazier was developing various items of equipment and to prorate similarly that cost, the following charges were made:

1934	$528	1936	$975	1938	$1,807
1935	194	1937	213	1939	1,422

For the fiscal year 1933 the cost of the development work in Washington was $2,875 which was not prorated.

Reels.- The use of heavy weights during the previous period led to the construction of reels to handle them. The development of the Kinnison and Ellsworth cables at the end of that period[208] led to increased

[208] pp. 61-62, 1919-1928.

need for reels in several districts. Although a number of the districts had developed reels for their own use, there had been no attempt to develop standard reels that would be available to other districts. Near the beginning of the period, F. L. Le Mert of the Columbus office designed a reel with counter for use on a pipe boom. Drawings of this design were sent to Washington for comment. The reel was so designed that the cable was wound over and over on it. Realizing the growing need of the Survey for reels, the start toward standards that had been made by the Columbus office, and the facilities afforded for experimental work at the University, Mr. Au, spent four months in Columbus during the fall of 1928. A reel developed in the Chattanooga office was sent to Columbus for study. Mr. Au devoted his time chiefly to designing and making models of a portable meter-cable reel for general stream-gaging use. To be of the greatest use, especially in deep rivers, a depth indicator was needed that would record accurately the depth by means of the number of revolutions of the drum. For such use, a small threading sheave and shaft were necessary, which would insure the smooth laying of the cable on the drum in parallel rows without overlapping. Mr. Au designed the reel which consisted of a drum accurately machined to a circumference of 2 feet, and a depth indicator which showed by means of a dial the number of revolutions of the drum which became a true indicator of the depth. This reel, later known as the Lee-Au reel, had a capacity of 75 feet of cable. As the stations on the Colorado River had at that time the greatest need for reels to be used with heavy weights, one of the first reels, and a protractor for measuring vertical angles, were sent to W. E. Dickinson for trial on a Colorado River type of cable car.[209]

[209] Water Resources Bulletin, Jan. 10, 1929, p. 10.

As the Lee-Au reel was hand operated, and its use on large rivers, with 100-pound or heavier weights, involved great manual labor, a train of gears with a ratio of 2:1 and an inertia wheel were introduced in order to reduce this labor. This reel was known as Lee-Au No. 2 reel.

Although the Lee-Au reel functioned satisfactorily, it was relatively heavy (weight, 45 pounds) and expensive (cost about $165). Its cost prevented its use in some districts. The need for reels was increasing, however, particularly in small sit-down cable cars, for which use a lighter reel was desirable. To meet the need for a lighter and less expensive reel, the Columbus office early in 1932 designed a small aluminum reel for handling weights up to 75 pounds, which would meet general needs, except on a few large rivers. The drum had a circumference of 1 foot, a capacity of 80 feet of cable, and was equipped with a Veeder counter for indicating depths. The reel had a threading sheave and a shaft similar to that on the Lee-Au reel. Its weight was 14 pounds and cost about $50.[210] This reel was known

[210] Water-Resources Bulletin, Mar. 10, 1932, p. 14.

as the Lee-Cox No. 1 reel. A year or so later, a special counter was designed for the Lee-Cox reel which then became known as type A. The sturdiness and durability of this type of reel led to its use on large rivers where longer cables and heavier weights were required, and types B and C were developed. Type B had a drum circumference of 18 inches and was 8 inches long, with a capacity of 120 feet of cable. It likewise was equipped with the threading sheave and shaft. Type C was the same as type B except that its length was 16 inches and its capacity, 240 feet of cable. It was found that the special counter did not stand up under high speed, and a type B indicator similar to the Au depth indicator except that it was more rugged and had a positive drive, and cost about half as much, was developed for use on types B and C reels.[211]

211/ Letter from H. E. Cox to author.

In connection with the reels, Lee stated:[212]

212/ Water Resources Bulletin, Oct. 10, 1934, p. 18.

> The three new reels, A, B, and C, seem to meet the general requirements better than the Lee-Au reels. As future orders must be filled by contracts in the open market, we should standardize on as few types as possible of the most useful reels and booms.

The A and B reels were later placed on the Schedule of Supplies with Leupold, Volpel & Co. as the successful bidder for several years.

At a regional meeting of district engineers held in Birmingham in 1936, the need for a reel to handle heavy weights in measuring the lower Mississippi River was discussed, and as a result the Columbus office developed the type D reel the following year. It had a drum $2\frac{1}{2}$ feet in circumference and $10\frac{1}{2}$ inches long with a capacity of 200 feet of cable. It was equipped with a dial indicator. A. H. Frazier was detailed from the Washington office to assist in the design, fabrication, and trial of the type D reel which was designed for operation either by hand or by gasoline engine. For trial, a 2-horsepower air-cooled gasoline engine borrowed from a centrifugal pump, and a motorcycle transmission, were used.[213]

213/ Water-Resources Bulletin, Aug. 10, 1937, p. 143.

Survey engineers, like other engineers, are individualists, and some districts have preferred reels of their own design. A number of those are worthy of mention. About the beginning of the period the Texas district solved the problem of laying the cable in parallel rows by devising a reel having a grooved drum which had a circumference of 18 inches and sufficient length to carry 93 feet of .125 inch Ellsworth cable which was developed at that time.[214] It was

214/ p. 62, 1919-1928.

equipped with a Veeder counter for indicating depths. The Boise office, in 1934, had a number of inexpensive reels made locally, usually from material found in small machine shops. The cost per reel was about

$15.[215] That same year, the San Francisco office devised a small reel

[215] Water-Resources Bulletin, Feb. 10, 1934, p. 4.

weighing 5½ pounds, with cable for use in making boat measurements.[216]

[216] Op. cit., Aug. 10, 1934, p. 31.

The Helena office designed a small reel for a cable car using the single-wire circuit.[217] Canfield, in 1937, worked with Leupold, Volpel & Co.

[217] Op. Cit., Apr. 10, 1935, p. 31.

in the design of a compact reel to be attached to the side of a cable car, and used with the single-wire system, which was manufactured under the name of the Canfield reel.

Booms.[218] A satisfactory boom for use on bridges was the next

[218] The 1938 conference of district engineers decided that "crane" was a more appropriate term than "boom."

requirement. While Au was designing his reel, W. R. King sent to Columbus for study the "bridge crane" developed in the Chattanooga office some years previously. Au designed a boom for use with his new reel, capable of handling 50-pound weights. This boom had two straight angles rigidly fastened together, from which a hinged cantilever arm, with a pulley at the end, extended from the boom and served to keep the meter at a distance from the bridge. The lower ends of the angles were attached to a horizontal base mounted on large castors on which the boom, with meter and weight attached, was rolled along the bridge. This boom was called the Universal boom. The castors were soon replaced by two rubber-tired wheels about 6 inches in diameter and the boom then was known as the No. 1 boom. This boom proved to be unstable when being moved from one measuring point to the next. This instability caused Mr. Cox to be hit on the head by the weight, and not relishing the prospect of a repetition of the blow, he suggested that a change be made in the base to provide greater stability while the boom was being moved. In accordance with the tradition of the Branch that he who sticks his neck out has something hung on it, he was instructed to prepare a design which could meet his objective. The then popular toy "mecanno" gave him an idea for experimentation, and working with that toy he designed a model of a boom having a cantilever arm extending from the upper end of the short supporting member. The boom was mounted on a 3-wheel base.[219] In use, the cantilever arm was extended

[219] Statement to author.

and the base was tipped against the bridge rail, resting on two wheels. That design was adopted as the No. 2 boom.

The new equipment was discussed at the 1930 conference and a committee consisting of McCashin, Au, and Lee, was appointed to develop a boom for 100-pound weights. A sturdier design similar to the No. 2 boom was adopted, with a longer cantilever arm, and mounted on a 4-wheel base. When in use the boom remained on its 4-wheel base,

the side opposite the cantilever arm being weighted to prevent tipping. That boom was known as the No. 3 boom.

These booms were quite bulky and when transported by truck it was necessary to take them down. The assembling and knocking down was a very considerable job requiring perhaps a half hour. Engineers in the Columbus office suggested a folding boom which could be transported without being taken down but Lee thought such a boom could not be given sufficient stiffness to be practicable in use. At that time he apparently had not personally faced the necessity of hurriedly assembling the existing booms to make a flood measurement. In 1935, however, the need arose for a flood measurement on the Muskingum River and he made it himself. After struggling to assemble the boom on the job and take it down afterward, he was forcibly impressed with the need for a folding model. On his return to the office he held a consultation with the engineers then in the office, Youngquist, Cox, and Brooks. They adjourned to the machine shop and after 5 hours spent in discussion and experimentation, evolved the folding boom,[220] which was an adaptation

220/ Statement of H. E. Cox to author.

of the existing types whereby the structural members were joined by hooks and hinges.

After a few years' use it was found that the type A (No. 2) boom met practically all requirements. With the 3-wheel base it could be used with weights up to 100 pounds, and for heavier weights it was equipped with the 4-wheel base with counterweight. The term "boom" was later discarded for the original term "crane" as being more applicable to the structural members comprising it. The type A crane was placed on the General Schedule of Supplies. The No. 3 boom later was replaced by a piece of sturdier equipment on a 4-wheel base capable of handling weights up to 200 pounds, and designated as the type D crane. This type was made only on order as there was not sufficient demand for it to justify quantity production.[221]

221/ Letter from C. V. Youngquist to author.

With reference to the improvements made, Youngquist writes:[222]

222/ Op. cit.

> The new cranes are about as superior to the originals as a current model automobile is to a 1920 model. We have and will continue to make improvements as the experience of our field men in all our districts find it advisable.

The Ocala district had use for a boom lighter than those described, and in 1933 designed a light folding boom which could be used on either a bridge or a boat.[223]

223/ Water-Resources Bulletin, Dec. 10, 1935, p. 32.

Power-driven booms: The installation of the Vicksburg station on the Mississippi River in 1930, involved equipment to handle meters with 200-pound or greater weights, which could raise and lower these weights

quickly through distances of 100 feet or more. Therefore, power-driven booms were needed. The bridge company specified that measurements must be made from a 3-foot walkway on the railroad side of the bridge. An experimental hand-operated boom having a width of 29 inches was made in Columbus, and in September 1930, C. H. Au and C. E. McCashin took it to Vicksburg for trial. Mr. McCashin graphically describes that event as follows:[224]

224/ Letter to author.

> We set it up on the railway bridge and then lay in wait for a train to come by. Mr. Au was to take pictures with a movie camera, and I was to take still pictures to see how much clearance we had. We lay flat on the walkway and the first train that came by, we started taking pictures but lost our nerve and crawled to cover. However, we decided that there wasn't enough clearance because when we got the over-all dimensions of the largest I. C. R. R. equipment, we found there was only 4-inch clearance, not counting the sway of the freight cars.

In their dilemma the engineers again went to officials of the bridge company, who, when they saw the small size of the boom, gave permission to use the highway section of the bridge, provided the equipment to be used should not have a greater width than that of the experimental boom (29 inches).

That completed the investigation and Mr. Au was instructed to meet Grover in Columbus and make his report. He started work on a power driven boom, using the ubiquitous Ford engine (without which many human activities would have been curtailed). Mr. Au remained in Columbus until November 1930, returned the following January, and finished the power-driven boom in April. Au and Cox did much of the work on the boom themselves. The final equipment consisted of a Ford-engine which operated and propelled the sounding apparatus that was mounted on a framework 2 feet 8 inches wide (3 inches wider than specified but evidently not objected to) and 9 feet long. The reel which held 230 feet of 1/8-inch cable was operated by one lever, and a special 200-pound weight made especially narrow to pass through the small space between the highway and railroad sections of the bridge. The power was sufficient to raise the meter and weight at a speed greater than 10 feet per second. To permit shifting of gears while raising the weight and to retard its descent, an inertia wheel was meshed with the engine gears.[225] Concerning the successful operation

225/ Proc. Conference Dist. Engrs., Oct. 12-17, 1931, p. 91.

of the Vicksburg boom, Mr. McCashin writes:[226]

226/ Letter to author.

> This equipment was designed by Carl Au and to my mind is a monument to his engineering ability because there were no major changes made in the equipment and it functioned satisfactorily until worn out. And it was operated continuously until 1937 when it was replaced.

The establishment of the Memphis station in 1934 involved a power-driven boom, and one was designed in the Columbus office in 1935. A Ford engine with a truck radiator to provide greater capacity was mounted on a chassis having an overall width of 42 inches to interfere with bridge traffic as little as possible. The boom was mounted on the river side of the chassis when facing traffic. The opposite side of the chassis was weighted with 1,000 pounds as a counter balance for the boom when in operation. The reel on the boom was power operated and was controlled by one lever. The cost of the complete equipment was $3,300, at Columbus. It was first placed in operation on August 1, 1935.[227]

227/ Water Resources Bulletin, Oct. 10, 1935, p. 17.

By 1937 the original Vicksburg boom began to wear out after 6 years of strenuous service, particularly during the flood of 1937, when it was used daily, and plans were made for a replacement. By this time the bridge authorities had become convinced of the little interference with traffic and D. H. Barber, then in charge of the district, obtained permission to use a standard truck chassis. This simplified the problem for the Columbus office and a Ford 1½-ton truck chassis was adopted for use with a boom and reel similar to the equipment at Memphis. Its cost was about $3,000.

Columbus-type weights.- During the previous period the elliptical weight had been developed to offer less resistance to the current than the torpedo weight then in general use.[228] Although the elliptical

228/ p. 63, 1919-1928.

weight met that requirement, field use demonstrated two points of inferiority to the torpedo weight: (1) it was not as steady in swift, turbulent water, weaving from side to side, and (2) it was so short that it did not extend as far from the point of suspension as the meter cups and so did not afford adequate protection to the meter during soundings.

In 1931, while Mr. Au was in Columbus, designing the Vicksburg power equipment, the subject of a new weight was considered and Mr. Cox suggested that it should be shaped like a fish. With this idea in mind, work was started on the design of a new weight. The most satisfactory shape was selected after several trials and by the spring of 1933, the 15- and 30-pound weights were developed. The 15-pound weight was constructed of bronze instead of the usual lead in order to obtain sufficient length and thickness. The 30-pound weight was made of lead. The 15-pound weight was tested at the Bureau of Standards and found to be much steadier than the elliptical weight, and was sufficiently long to afford full protection to the meter, thus meeting the requirements imposed upon it.

Tests of the new weight at the Bureau of Standards showed a third advantage of the C-type weight (as the Columbus-type weights were designated) in that the cable-suspension rating was very nearly the same as the rating for the standard round-rod rating for velocities greater than 0.5 foot per second. This indicated that the C-type weight had much less effect on the meter rating than the older types and hence reduced nearly to the vanishing point the necessity for using rating coefficients for various hookups of meter and weight.

Before the heavy weights were designed, the district engineers were asked[229] to express their views on the various sizes needed, and as a

229/ Instructions, May 12, 1933.

result designs were completed and production of 15-, 30-, 50-, 75-, 100-, and 150-pound weights was started in 1934. The 150-pound size was developed at Newell's request, for use on the Kootenai River. To defray the cost of that development, $100 of State Department funds were transferred to the Columbus office.[230] All sizes were made of lead except the 15-pound size, which was made of gun-metal bronze.

230/ Letter from T. R. Newell to author.

New hangers were designed for the C-type weights. Those for the 15- and 30-pound sizes were so arranged that the center of the meter cups could be suspended either 0.5 or 0.9 foot above the bottom of the weight without the meter coming in contact with the weight or weight vanes. Another hanger was designed for the heavier weights used at Memphis and Vicksburg.

In 1934, while the power equipment was being built for the Memphis station, the need for heavier weights was apparent, and 200- and 300-pound weights were designed.

Steel cable cars.- The need was growing for reels for use with heavy weights in making cable measurements, and as a step in meeting that need, Mr. Au designed a steel cable car of the stand-up V type. This design was nearly completed when he noticed in a mining journal a picture and description of a gondola of steel-lattice construction with V-shaped roller supports, for use on a cable tramway. This gondola suggested changes which Au made in his design.[231]

231/ Statement to author.

The steel cable car, and the reel and boom to be used in the car, were designed during Au's stay in Columbus. When the designs were completed, a dozen of each were constructed in Columbus to be sent to various districts for thorough trial before quantity production was undertaken.[232]

232/ Water Resources Bulletin, Mar. 11, 1929, p. 11.

Wire-weight gages.- The need of the Army Engineers for gaging stations on large rivers involved the installation of chain gages (or their equivalent) on high bridges. The great length of chain in these gages accentuated the principal defect of the chain gage--its progression lengthening with use. Also, the very considerable area of chain exposed to the wind when low stages were being measured, resulted in so much bowing of the chain that accurate gage-height records could not be obtained during high winds. The frequency of such winds appears to the field engineer to increase with the height of the bridge above the water surface.

During the previous period airplane wire which is practically non-extensible, had come into use for single-wire suspension of meter

and heavy weights and this use suggested its substitution for the commonly-used chain. W. A. Lamb, in the latter part of 1928, substituted a 1/16-inch diameter aircraft strand for the chain, and mounted it on a reel in a box which was attached to the bridge rail beyond the outer end of the gage scale. He found little stretch or deflection by the wind, and from the experience gained, suggested that a better gage would be made by combining his wire gage with the old Weather Bureau Mott tape gage which was enclosed in a small box and required no outside scale.233/ G. H. Canfield was having difficulties with long chain gages

233/ Water-Resources Bulletin, Jan. 1929, p. 16.

and when he learned of Mr. Lamb's experimental gage he went to Leupold, Volpel & Co. in Portland, and discussed the design of a wire-weight gage to be wholly contained in a box which could be locked and permanently bolted to a bridge member or other structure. Following this discussion, Leupold, Volpel & Co. constructed such a gage and called it the Canfield wire-weight gage. This gage was described in the Water-Resources Bulletin for July 1929.

As Mr. Canfield writes234/ other district engineers became interested

234/ Letter to author.

in the wire-weight gage and the Rolla District wished to purchase 40 Canfield gages. After considerable correspondence, designs and specifications were prepared which included improvements suggested by Messrs. Beckman and Bolon. These 40 gages were the only ones purchased on contract, as the Canfield gage was gradually superseded in the Survey by the Type A wire-weight gage developed by the Columbus office.

Wire-weight gages were discussed at some length at the 1931 conference and a new field-equipment committee, consisting of Messrs. Hoyt, Lee, Mangan, and McCashin, was instructed to develop within the next two years a new type of wire-weight gage.235/ The Columbus office in 1932 designed

235/ Proceedings of 1931 conference, p. 32.

a wire-weight gage which differed from the Canfield gage, chiefly in having a counting attachment which indicated the number of revolutions of the drum of 1-foot circumference on which the wire was wound. A graduated disc for reading tenths and hundredths was clamped to the drum. A few of these gages were constructed and tried in the field and the experience gained led to a revision of design in 1934. As the need for wire-weight gages was widespread, the Type A gage, as it had been designated, was placed on the Schedule of Supplies, and Leupold, Volpel & Co., who had manufactured the Canfield gage, was the successful bidder each year during the remainder of the period. The type-A gage has been used extensively not only by the Survey but also by the Army Engineers.

Electric gages.- Many recorder installations with deep wells were made during the period. It was necessary for someone to descend into such a well and read the gage by aid of a flashlight in order to obtain an accurate reading of the inside staff gage. The deeper the well the less the assurance that the observer actually read the inside gage. To remove the necessity for reading the inside staff gages, Au, in 1929,

devised an electric tape gage, which consisted of a tape and weight, a dry battery and a spinner. The latter set up an alternating current, and when the tape and weight were lowered the break in the circuit caused by the weight touching the water, was indicated by means of a headphone. The first electric gage was installed on Rock Creek in Washington. Following instructions by the 1930 conference, Lee manufactured and shipped a trial gage to each district. It was found that the gage operated satisfactorily but was relatively expensive to manufacture and it required the use of a headphone.

While the Columbus office was remodeling other items of equipment in 1932, attention was given to the electric gage in an attempt to reduce the cost. Instead of requiring a headphone to detect the point of contact with the water surface, a galvanometer consisting of a compass and coil of wire was used. The spinner also was eliminated. After considerable field use the design was revised in 1933 by improving the sensitivity of the galvanometer, and mounting it in a separate unit which could be placed in position for easy observation.

Float gages.- The float gage, like many other items of survey equipment, was developed to meet a particular need. The first float gage was devised by H. F. Hill, Jr. in August 1923, in connection with the construction of a recorder shelter on the Merrimack River at Franklin Junction, N. H. As the well at that station was dark, a direct, easy-to-read indicator in the shelter itself was needed to avoid the necessity of having the observer descend into the well to read the inside gage. Hill conceived the idea of attaching a standard steel tape to a Gurley float and so mounting it that the upper end operated over a laminated hardwood wheel set on a hardwood standard attached to a shelf below the recorder shelf. The counterweight was a short piece of lead pipe. The wheel and standard were made by a local cabinet maker and both were saturated with water-proof varnish. Despite this careful treatment, the laminated wheel warped badly because of moisture from the well and was later replaced by a one-piece wooden wheel boiled in oil.[236] This first float gage operated

236/ Letter from Chief Hydraulic Engineer to author.

satisfactorily.

When H. B. Kinnison took charge of the New England district in 1925, he recognized the advantages of the float gage over the staff gage in the well and he installed a similar float gage on the Connecticut River at Sunderland, Mass. The operation of these two float gages was so satisfactory that about 1927 Kinnison began the development of what has been called the Kinnison float gage. As cost was an essential factor, a local shop constructed a number of 10-inch floats of spun copper with a rather flat cross-section, and a local hardware store supplied 3-inch bronze pulleys, each supported on a standard. A staple set in the front of the recorder table was the index. The operation of this equipment proved to be unsatisfactory as the pulley was so small in diameter that the counterweight did not clear the float. To remedy that defect a local machine shop designed a pulley having sufficient diameter to allow the counterweight to clear the float. Later, the index point was made a part of the pulley support, and the float was redesigned and made of heavy spun copper with cones for the top and bottom sections, and a vertical cylinder for the middle section.

The float was so weighted that the water surface would be near the center of the middle section. These floats were made in diameters varying from 4 to 20 inches, the former for use in wells of small cross-section, and the latter for use in large wells where a high degree of accuracy was required. They were found to be very satisfactory and held to the datum for long periods. 237/ The Boston office furnished the float

237/ Letter from H. B. Kinnison to author.

gages by purchase under contracts until April 1, 1939, when the gages with floats ranging from 10 to 20 inches were placed on the general schedule of supplies.

Radio gages 237a/

237a/ This section prepared by G. C. Stevens.

The first use of radio in the automatic transmission of signals indicating water stages with which the Water Resources Branch had any connection was begun in California during 1931. During that year Mr. Irvin M. Ingerson, an employee of the State engineers office serving as water master on Pit River, devised and installed on a storage reservoir some apparatus which transmitted signals which he received by radio and converted into stages of the reservoir, thus saving considerable time and travel and providing him with information needed in the performance of his watermaster duties. The State engineer, Mr. Edward Hyatt, became interested in the device and proceeded to have it perfected and additional instruments built as he foresaw its usefulness in water distribution and flood warning problems.

The essential features of the apparatus were a float-operated mechanism, a low-powered radio transmitter, a keying device operating between the float mechanism and the transmitter, and a clock which turned on the transmitter at a selected hour and also put the keying device into operation. The signals from the transmitter consisted of groups of dashes. The listener, using a radio receiver tuned to the frequency of the transmitter, counted the dashes in each group and thus obtained the stage of water. After one or more repetitions of the signals the clock turned off the sending apparatus.

In October 1931, the State engineer, with the advice of the Federal supervisor of Radio in San Francisco, made application to the Federal Radio Commission for a license to operate such unattended radio transmitters. In February 1932 a hearing on the application was held before the Federal Commission at which some representatives of the Geological Survey appeared on behalf of the State engineer. No decision was made by the Commission at that time.

In the meantime the State engineer was advised by the Supervisor of Radio that by virtue of the legal cooperative agreement between the federal survey and the state for stream-gaging it was possible to obtain use of frequencies assigned for the use of federal agencies. On February 19, 1932, representatives of the Survey appeared before a subcommittee of the Interdepartment Radio Advisory Committee. The presentation of the problem at this meeting was successful and the subcommittee recommendations were approved by the full Committee on April 13, 1932. The result was authority for the Geological Survey to use two frequencies for experimental purposes with low-power portable transmitters.

The State engineer proceeded with the development of equipment and at the end of 1933 had three stations in successful operation. The assigned frequency was not wholly satisfactory, however, and four other frequencies were assigned in February 1934 for experimental use for six months. In July 1935 the FCC notified the State of California that the use of frequencies for the purpose was unauthorized. After explanations the FCC stated that the prior authorization for six months' use had expired and the Survey should make application to IRAC for renewal. A new application was made September 5, 1935, and was finally approved December 10, 1935. During 1935 Mr. Albert S. Fry of the Tennessee Valley Authority became interested in radio gages and borrowed some equipment from the State engineer of California for experimenting. Mr. Fry was satisfied with the experiments, and the authorization approved December 10, 1935, for the use by the Survey of four frequencies in California provided also for the use of the same frequencies in the area of the Tennessee Valley Authority.

In the spring of 1938 the office of the State engineer in California and other cooperating agencies in the state had 16 radio gage stations in operation. In the area of the Tennessee Valley Authority 9 such stations had been placed in operation.

Artificial controls

Allotments of PWA funds for the rehabilitation of existing stations and cooperation with the Soil Conservation Service gave an impetus to the construction of artificial controls and made it possible to install many more than previously. As an aid to the district engineers, the Washington office delegated to C. H. Pierce the task of assembling existing plans in use by various districts, so far as such plans had been standardized. These plans were published in 1933 under the title, "Structures for artificial controls," in the series of "Equipment for river measurements." In that year many artificial controls were installed and with the experience gained, the existing plans were improved and new ones developed. It was then decided to test at the National Hydraulic Laboratory several of the more practical types in order to determine the one or two best suited for general use, and in

1934 the first project undertaken by the laboratory for the Survey, was a study of artificial controls under the supervision of a Survey committee consisting of O. W. Hartwell, Lasley Lee, and C. H. Pierce.

Most of the controls developed were low dams conforming closely to the cross-sectional shape of the stream bed with various forms of overflow section in the low part of the dam. Models of the overflow sections developed by the Trenton, Asheville, Middle Atlantic, and Columbus districts, were selected for study in the laboratory. The Boston district had developed a section so nearly comparable with the Trenton type that it was not included. All but the Trenton type had sloping upstream and downstream faces, either straight or curved, with sharp or rounded crests. The Trenton type had a vertical upstream face and a sloping downstream face with a relatively broad, rounded crest. The Middle Atlantic type crest was similar to that of the Trenton type. All of these types had horizontal crests. Several districts had also developed notched overflow sections, and those of the Trenton, Albany, and Columbus districts were studied by models.

The results of these tests were published in 1935 as another in the series of "Equipment for river measurements," under the title, "Preliminary report on studies of artificial controls." The purpose of the tests was stated, as follows:

> Studies * * * have been made * * * for the purpose of ascertaining the relative merits of various designs * * * that have already been developed.

> The models * * * were investigated with respect to performance under conditions of free fall and of various degrees of submergence in order to ascertain the characteristics of the different designs.

It is not within the scope of this history to give the results of these tests, but one more quotation is pertinent:

> Considering the wide range in hydraulic conditions and materials of stream beds * * * it is probable that no one type or design of artificial control can be found which will be the best type or best design for universal use.

When the preliminary report was issued, the publication of a final report as a Water-Supply Paper was scheduled. Before that was done, however, an extension of the investigation to higher heads than could be obtained by the full-sized models, and an investigation of the new California type of artificial control appeared to be desirable.238/ These additional

238/ Statement of C. H. Pierce to author.

investigations had not been completed by the end of the period.

The types tested were continuous structures that had been developed in the eastern part of the country where the stream beds were relatively stable. At a very considerable number of stations in some districts it was possible to place concrete between scattered boulders and thus obtain an artificial control. This type of control had been used extensively in Southern California during previous periods, and where carried down to bed rock the controls generally withstood the severe floods of 1916. They were, however, destroyed by the greater floods of March 1938. Two controls constructed of reinforced concrete by use of PWA funds withstood the 1938 flood.239/

239/ Letter from F. C. Ebert to author.

About 1934, a new type of control was used, which was substantially a broad-crested weir having sufficient slope of upstream face to produce greater velocities there than in the channel above and below the control, in order to keep the control itself free from debris. The control was so designed that the critical section was at the upstream side, and as the stage was measured on the control itself, the slope was slightly greater than the critical slope in order to give the greatest sensitivity in rating. The profile across the stream consisted of a series of horizontal steps, conforming as nearly as practicable to the natural cross-section, with the lowest point, or notch, next to the recorder well.240/ Seventeen controls of this type were constructed.

240/ Statement of F. C. Troxell to author.

The Parshall flume filled a need of the Branch and 100 or more were constructed in eight districts. Sharp-crested weirs, both rectangular and cippoletti, were also used on small streams.

As 29 districts constructed artificial controls during the period, many special designs were made to fit local situations. Three in the Urbana district are described on page 1014. The Honolulu district

used a type of overflow section designed by a former employee. This section was a V-notch in which the angle was about 165 degrees. The Parshall flume was also used extensively, and two concrete flumes were installed at each of two stations, a small 6-inch flume for low flows and a 4-foot flume for flood flows.[241] The Austin district used tongue-

[241] Water-Resources Bulletin, Nov. 10, 1930, p. 26.

and-groove sheet-piling controls at four stations. In describing them, C. E. Ellsworth writes:[242]

[242] Letter to author.

> The crests of the controls varied from 1½ to 4 feet above the stream bed at the downstream side (and the sheet piling was driven into the stream bed for an average distance of about 5 feet). At the time of installation no apron or rip-rap was placed on the downstream side of the controls. The type of material in the stream beds ranged from a sandy clay to a fairly well compacted black soil. None of the controls were constructed across streams having a sand bed of loose sand. After two or more floods passed over these controls, considerable scour developed on the downstream side and at the point where the controls entered the banks as the material there was not of a firm and stable nature.

The Hartford district also constructed a control of that type.

By far the largest number of artificial controls were constructed by the Santa Fe district chiefly in connection with gaging stations on small ditches.[243] The 70 or more controls on ditches were concrete

[243] p. 86.

Parshall flumes, constructed as a part of the gage shelter. Some 30 concrete controls of various types were installed on natural streams. The Honolulu district constructed 50 controls, Trenton 38, Albany 28, San Francisco 26, and Boston 26. Other districts constructed a smaller number. In all, 426 artificial controls were constructed during the period.

Boat measurements

Until the present period boats had been used for making measurements at regular gaging stations only at rare intervals, chiefly in emergencies. The San Francisco district in 1922, inherited from the State engineer what McGlashan termed the "summer run" which meant the maintenance of records from May to October at summer stations on the navigable channels of the San Joaquin, Sacramento, and Feather Rivers to meet the needs of the State Water Supervisor. At that time the only facilities available were "one husky engineer with standard meter equipment and the privilege of renting rowboats locally." In the course of time less "husky" engineers were detailed to the summer run and they gradually developed equipment which enabled one man to make the measurements with less physical exertion, and in much less time. The boat was held in place by a cable, stretched across the river and marked at 10-foot

intervals. A special reel and boom made possible the use of 50-pound weights.[244]

244/ Water-Resources Bulletin, Aug. 10, 1934, p. 31.

With the beginning of Army cooperation in 1928, boat measurements were made regularly at a few stations. The Army Engineers had used boats extensively in their own river measurements, and looked with favor upon such measurements, particularly where no other support for the engineer was available. The first Survey measurements of this kind for the Army Engineers were apparently made in June 1928 by A. H. Frazier in the Madison district, on the upper Mississippi. The Army Engineers furnished a motor launch and a 14-foot flat-bottom boat, with a launchman and helper. Frazier constructed and mounted on the flat-bottom boat a 3-foot reel and a boom which suspended the meter about 18 inches in front of the bow. The boat was held in place by a 3/8-inch steel cable stretched across the river and marked at 10-foot intervals. The cable was attached to a large reel by means of which it could be lowered to permit river traffic to pass.[245]

245/ Letter from A. H. Frazier to author.

A month or so later the Rolla district began making measurements of the Missouri River at the Bonnots Mill and Hermann, Mo. stations. The Army Engineers furnished a large steel launch with an operating crew of four men. One of them was an engineer who measured the distances between measuring points by means of transit and stadia. The meter, which was operated by a Survey engineer, was suspended from a wooden A-frame extending upstream from the bow of the launch. The boat was held in place by a heavy anchor operated by three laborers on the boat. The Hermann measurements were discontinued in 1930 when a new bridge was completed, but the Bonnots Mill measurements were continued until 1936 when the station was discontinued.

The use of the Army Engineer launch on the Upper Mississippi was discontinued in the fall of 1930 and it became necessary for Frazier to develop equipment which could be used with rented boats, and with the help of one man to lower the cable when necessary. In place of the cumbersome cables used previously, a 3/32-inch airplane-cord cable with a harness snap at the end was substituted. This cable was sufficiently strong to hold the boat in position against a velocity of 6 feet per second in a channel 2,000 feet wide. Aluminum was used for the boom, and a light reel was devised. This light, portable equipment was very satisfactory. Equipment of this type was subsequently used by the Atlanta, Iowa City, Chattanooga, Rolla, Madison,[246] and possibly one or two other districts.

246/ Letter from P. R. Speer to author.

In 1937 the Madison district purchased a 12-foot steel boat with outboard motor for measuring the Wisconsin River at Muscoda, and also used boats for making measurements in the Manistique Basin. The St. Paul district used boats exclusively at several stations in northern Minnesota.

The Chattanooga district made considerable use of boats at regular stations and, as the TVA insisted on measurements at peak stages of floods, these measurements were occasionally made at night. As a result of experience a flat-bottom boat 15½ feet long with square bow and stern was designed and two were built locally. They were equipped with 9-horsepower outboard motors.[247] A special investigation was made,

247/ Water-Resources Bulletin May 10, 1939, p. 362.

during the early spring of 1939, of the various slope-stage-discharge relations at stations affected by variable slopes. As a part of the investigation, a few measurements, including vertical velocity curves, were made simultaneously from boats to bridges. The results indicated that velocities measured from boats were from 1 to 3 per cent less than those measured from bridges.[248]

248/ Letter from F. M. Bell to author.

The Iowa City district in 1936 designed a flat-bottom boat 11½ feet long and had it built in two sections for easy transportation. The purpose was to make boat measurements for checking the accuracy of measurements made at certain bridges where measuring conditions were poor. The boat was needed also for reaching recorder shelters and for measuring overflow sections during floods.

In connection with the use of boats in the Ocala district[249] a test

249/ p. 201.

of the accuracy of such measurements was made on the Withlacooche and Oklawaha Rivers. Vertical velocity curves were made from bridges and also from a 16-foot boat equipped with the light boom designed and built in that district. The results showed that the degree of accuracy depended very largely upon the up and down motion of the boom, that the boom should be made as short as possible in order to reduce a motion, and that the displacement effect of the boat itself was much less important.[250]

250/ Water-Resources Bulletin, Feb. 10, 1939, p. 295.

Measurement of tidal flow[251]

251/ Based chiefly on information furnished by F. F. Schrader.

After the conclusion of the measurement of the tides in the Golden Gate in 1914,[252] the Survey had no further experience in measuring tidal

252/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 390.

flow until 1931. Between 1931 and 1939, five investigations of tidal flow were carried on by the Virginia district in connection with Army-Engineer cooperation which was promoted by two former members of the Survey who were in positions of authority in Army-Engineer offices.

In 1931 the Army-Engineers' Beach Erosion Board was studying the possibility of routing shipping through Albermarle Sound to avoid that "graveyard of the Atlantic," Cape Hatteras, and wanted measurements made of the tidal flow through various inlets. G. H. Matthes, an early-day member of the Survey,[253] was the principal civilian engineer

[253] Op. cit., p. 84.

in the Army-Engineers' office at Norfolk, Virginia, which was the office designated to undertake the investigation. Matthes selected Oregon Inlet off the North Carolina Coast and made trial measurements on July 28 and 29.[254] The Norfolk office requested the Charlottesville

[254] Letter by Matthes to author.

district to cooperate in the investigation, and the first measurement was made on August 26. Oregon Inlet is about 3,000 feet wide with depths varying from 3 to 30 feet, and with velocities varying from zero to 5 feet per second. Six Coast Guard boats, each containing two men to operate the boat and a Survey engineer with meter equipment, were placed at intervals across the section selected. The boats were anchored fore and aft by means of anchor ropes drawn taut to prevent swinging, and the position of each was determined by means of range poles and transits on shore. Three boats, anchored where the depths were great, were equipped with reels and booms for handling 75-pound weights; the remaining boats had hand-line equipment. Vertical velocity curves were obtained by measuring the velocity at 2-foot intervals of depth. The vertical velocity curves were obtained every half hour during the complete tidal cycle from 6 a.m. to 6 p.m. Two complete sets of measurements were made in the summer of 1931, again in the summer of 1932, and a few in later years. The vertical velocity curves obtained at the deepest sections during high tide were practically straight lines except near the bottom, where the velocity decreased slightly.

In describing this investigation, Mr. Schrader writes:[255]

[255] Letter to author.

> At times mosquitos and beach flies were present in vast hordes, and the Survey was well bitten. Mosquito netting and ointments were stock equipment on these trips. Also one susceptible member carried a special concoction which was supposed to offset sea sickness, but he was sadly disillusioned.

In commenting on this investigation, G. H. Matthes writes:[256]

[256] Letter to author.

> Observations were not made without danger to the men and their equipment as the breakers along the ocean shore are of considerable magnitude and any boat swept out to sea would have capsized. Fortunately, the anchors held, and by exercising care the boats pivoted around the anchors as the tidal current changed from flood to ebb tide.

The next investigation was started in September 1931 and continued for a year and a half. It was made primarily for the Division of Parks, State Conservation Board, but the Army Engineers assisted in maintaining the four recording gages established in connection with their studies of tidal fluctuation. The Division of Parks wished to determine the effect of tides and winds on the parks and bathing beaches near Virginia Beach, and on coast erosion generally. The investigation was limited essentially to the installation and operation of four water-stage recorders on the bays and marshes that discharge through Lynnhaven Inlet. This investigation showed the effect of high winds on the tide in the bays, and the differences in effects of winds from various directions.

Another tidal investigation in cooperation with the Norfolk office of the Army Engineers was started in March 1933. Richmond in its efforts to become a seaport obtained authorization by Congress for a project to dredge a channel from the mouth of the James River to Richmond. This channel would shorten the river distance by 10 miles by means of three cut-offs. To study the effects of these changes in channel the Army Engineers requested the cooperation of the Survey. Four recorders were installed on piling in the vicinity of the three cut-offs, and measurements similar to those in Oregon Inlet, using three boats, were made on April 20 and 21, and May 24 and 25, 1933. These measurements were made in the river before the cut-offs were completed and during a flood on the James River. These observations showed a strong downstream velocity with only a slight decrease during flood tide. The measurements of May 20 and 21 were made at comparatively low water and indicated clearly the influence of the tide in reversing the flow during flood tide. Subsequent to 1933, observations were made for two-day or three-day periods in 1934, 1936, 1937, 1938, and 1939. After the cut-offs were completed simultaneous measurements in the cut-offs and in the bends of the river were made each year.

Another investigation of tidal flow was made in October 1933, apparently in connection with the study of an inland waterway along the Atlantic Ocean between the mainland and the barrier islands. The Baltimore office of the Army Engineers desired measurements of tidal flow through Wachapreague and Metomkin Inlets, Virginia, and through Ocean City Inlet, Maryland, all leading to the Atlantic Ocean. C. C. Babb, Newell's first assistant,257/ was in charge of

257/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 66.

the work for the Army Engineers, and requested the cooperation of the Charlottesville district. The latter furnished seven engineers who devoted their time to it for about three weeks. Three medium-sized fishing boats were hired by the Army Engineers. Two current-meter operators were available for each boat in addition to the boat's owner who operated it with some Army-Engineer assistance. The equipment, methods, and arrangements were similar to those used in measuring the Oregon Inlet. As considerable time was required to reach the measuring sections and place the boats in position, the measurements did not quite cover the entire tidal cycle, the period of observations being from 10 to 11 hours. Depths as great as 50 feet were found at Wachapreague Inlet and velocities as great as 7 feet per second were measured at Ocean City Inlet. Temporary staff gages were read at frequent intervals by Army-Engineer personnel who

also fixed the positions of the boats at the points of measurement. Three days were spent at each inlet and the field work of the entire investigation was done between October 7 and 20.

The fifth investigation was started in May 1939 near the end of the period. The Army-Engineers' Vicksburg experimental station was preparing a model of the proposed Richmond Harbor and desired knowledge of the distribution of velocities and flow entering the harbor at various stages of the river and through tidal cycles. The Norfolk office which had been designated as the agency to obtain this information requested the cooperation of the Charlottesville district. Unlike the previous tidal measurements which were made from boats, these were made from the Mayo Island bridge in Richmond, a few hundred feet downstream from the head of tide water in the James River. Seven Survey engineers working simultaneously measured the James River, beginning every even hour. The river is 1,000 feet wide at Mayo Island bridge and with .2- and .8-depth velocities measured every 10 feet, each measurement required an hour and a quarter for completion. Seven measurements were made May 23, 1939, during a period of comparatively low water and a tidal range of about 4 feet. Five gages located at various points in the river were read at 10-minute intervals by Army-Engineer personnel. A complete report of these observations, including map of harbor and bridge section, graphs of stage, discharge, velocity, cross-section, and tabulation of data was made at the Norfolk office. This was the only set of measurements made prior to June 30, 1939, but additional measurements were made August 20, and September 5, 6, 1939.

Annual reports

The annual reports present to the public the finished product of the Survey's stream-gaging program each year, and the changes in contents reflect the effects of close contact between the Survey and the users of the records. Such changes during this period emphasize those effects and explain the reason for the increasing support given to the Survey by engineers as these changes are designed to meet the increasingly intensive requirements of the profession. Perhaps the most important of the changes from the standpoint of cooperating agencies and other users, was the successful effort to speed up publication and thus reduce the arrearages which at the beginning of the period had caused a lag of several years between the close of the water year and the date of publication. At the meeting of the Association of Western State Engineers held in Denver in November 1930, Mr. Grover was authorized by the Director to state that he expected to transmit to the Public Printer by July 1, 1931, the reports for the climatic year 1929, those for 1930 soon afterward, and in the future to transmit all reports for any climatic year by the following July first.258/

258/ Letter to district engineers Mar. 4, 1931.

The most apparent change was the substitution of the photo-offset, for the ordinary type-setting method of publication. This change was made in the reports for 1934, as a result, in part, of the experience of the Harrisburg district in publishing the State reports by the photo-offset method. It had been found that the State reports were published at one-third the cost of that of the regular printing method

and the time involved was materially shortened. The Survey's experience agreed with that of the State as to reduction in cost, but not in the saving in time. The State of Pennsylvania had found that under the type-setting method it had been necessary to have as many as ten proofs in extreme cases, and this had involved long delays in publishing the reports.[259] The Survey had not had such delays in the printing and con-

259/ Statement of R. H. Hosmer to author.

sequently the great saving in time did not materialize. The saving in cost, however, had the same effect as an increase in the funds available for printing, thus making possible the publication of additional Survey reports.

Other changes involved the inclusion of additional data in the stream-flow reports, the first being the addition in the station description of the paragraph on average discharge for 10-year or longer records. This addition was made at the suggestion of H. D. McGlashan[260] and was

260/ Statement of B. J. Peterson to author.

first made in the 1933 reports.

The report for 1935 contained the greatest number of changes which were partly the result of recommendations of the Water Resources Committee of the National Resources Committee, of which Mr. Grover was a member.[261] Latitude and longitude were added to the station descrip-

261/ Deficiencies in basic hydrologic data, Sept. 1936, pp 56-57.

tion to facilitate the plotting of the station on maps which did not contain the public land system of townships and ranges. Gages were more generally referred to sea level datum than formerly. This was due partly to the request of the Army Engineers that their cooperative stations be so referred, and partly to the fact that the U. S. Coast and Geodetic Survey had run many secondary lines of levels about 1934, thus making available more bench marks than formerly. By the end of the period, 42 per cent of the gages had been referred to sea level datum. The elevations of the gage datums varied from sea level for those near the coast, to 9,617 feet for the Animas River station near Howardsville, Colo., in the San Juan Mountains. Skeleton rating tables were presented in order that the user of the records could reproduce the rating curve, and translate daily discharge into stage, as the increasing study of floods frequently made this procedure necessary. The yearly values for the calendar year were inserted between December and January in the monthly discharge table, in order that this information might be readily available for comparison with precipitation records published on the calendar-year basis. In the introduction to each part of the report, a list was presented of stream-flow records in that area collected by other agencies and not published by the Survey.

When the 1935 reports were published, the list of annual appropriations, which had been placed on the first page of the introduction since the reports for 1904, was omitted. To explain the appropriations for the year 1935 would have required complicated footnotes, and the

Survey editor suggested that the practice should be discontinued as the reports of no other Branch contained such information.[262] Another

262/ Letter from B. J. Peterson to author.

change was the substitution of photographs of actual gaging stations for the isometric drawing of a typical recorder shelter which had been used since 1929. Beginning with the 1937 report, the introduction to each report contained a list of all compilation reports related to the area published either by the Survey or by the States. This likewise was a suggestion of the Water Resources Committee.

The intensive use of stream-flow records during the period brought about the development of the so-called unit-hydrograph method of studying flows.[263] To enable the users of that method to construct more

263/ Proposed by L. K. Sherman in 1932. Engineering News Record Vol. 108, p. 501 (April 4, 1932).

accurately the discharge hydrograph from the published records, the Survey in the 1938 reports began the practice of publishing peak discharges of all peak flows which exceeded the mean for the 24-hour period by more than 10 per cent. This procedure had apparently first been suggested by Waldo E. Smith of the Muskingum Conservation District.

Beginning with the 1939 report, more comprehensive records of reservoir storage were published in accordance with the desire of the district engineers, as expressed at the 1931 conference. After the 1931 conference, that subject and the subject of records of regulated flow were referred to a committee for recommendation. On the latter subject there was such divergence of opinion that several years elapsed before the committee reported on both subjects and it was not until 1939 that the procedure for publishing reservoir records was adopted.[264] The 1939 report also contained summaries for all stations,

264/ Letter from B. J. Peterson to author.

active or discontinued, for which records of 10 years or longer were available. This suggestion had first been made by the Bureau of Reclamation in 1936, and it was the original intention to publish the summaries in the 1937 reports, but the districts found that the time required to prepare them prevented their completion for that year. The new PWA program in 1938 prevented their completion for that year, and it was not until 1939 that the summaries were ready for publication.

A minor change in computation rules which was first made in connection with the records published in the 1934 reports, modified the rule of three significant figures which had been in effect since 1906. Harrington suggested that the users of the records in New York State desired a greater degree of refinement in monthly discharge than that given by three significant figures. Accordingly the three-significant-figure rule was modified by requiring that monthly means in excess of 1,000 second-feet be carried to four significant figures, and that monthly values of acre-feet in excess of 10,000 be similarly expressed. The change rendered obsolete the hydraulic conversion table previously used, and a new table for converting second-foot days to acre-feet

was prepared. In line with the general procedure, drainage areas greater than 1,000 square miles were carried to four significant figures.

Flood reports

The Survey's status as the chief agency for the collection of flood data on a nation-wide scale was widely recognized during this period as a result of the occurrence of record-breaking floods in nearly all parts of the country, the availability of a personnel almost adequate to make the necessary investigation promptly, and the willingness of the Public Works Administration to allot funds for the study of some of the larger floods. The purpose of flood investigations was succinctly stated in Water-Supply Paper 838, as follows:

> A reliable record of floods is essential to a satisfactory solution of flood problems. The records of stage and discharge of streams, precipitation and other hydrologic features of the more critical floods of the past are necessary for studies of the influences of reservoirs and of such aspects of land use as terracing, cropping, and forestation in affecting flood stages and discharges.

All outstanding floods were investigated for the purpose of preparing and publishing reports, thereby making permanent record of all pertinent data on the meteorological and hydrological features. Not only were these reports useful in flood studies for the streams affected, but also for streams having similar characteristics. By the end of the period the Survey Water-Supply Papers contained information applicable to many sections of the United States that are subject to severe floods.

The floods investigated were of two general types:

(1) Floods caused by widespread storms of several days' duration over large areas in which Weather Bureau records of precipitation were numerous, and the streams in flood had numerous gaging stations. In this type, the official precipitation records were generally sufficient for a study of the storm, and peak discharges were obtained chiefly by extension of rating curves and computation of flow over dams.

(2) Floods caused by violent storms of short duration over limited areas, often in sparsely settled regions where Weather Bureau records were few or entirely lacking, and the resulting high floods on a few relatively small streams, were of even shorter duration than the storms which caused them and gaging stations were few or non-existent. For this type, it was necessary to scour the storm areas for records of rainfall obtained by local residents by the use of improvised rain gages. The flood peaks were far higher than ordinary high-water stages at which current-meter measurements, if any, had been made and it was necessary to compute the peak discharges from high-water marks. Dams were few or lacking in those areas and it was generally necessary to resort to slope-area determinations of peak discharges, and to statements of local residents regarding time and duration of peak and other pertinent information.

As precipitation does not follow exact patterns as to time, intensity or area involved, there are gradations from one type of flood to the other. So far as was practicable, the flood reports contained historical information as to previous floods. Although much of this latter information did not include quantities of discharge, it was of value in indicating the type, frequency, and relative heights of past floods. The resulting reports became therefore "handbooks" on floods in the areas covered.

Beginning in 1936, all flood reports were prepared under the general supervision of the Division of Water Utilization, and a general form of presentation was developed. The method of making slope-area determinations, based on the Manning instead of the Kutter formula, which had been generally used previously, was improved and standardized as much as possible. In connection with the flood studies, the district offices, as opportunity was afforded, made determinations of this value of "n" for various types of river channel and overflow sections. To meet a growing demand, studies of rainfall-runoff relations were included in the later flood reports. The following descriptions of the flood reports are arranged in order of flood occurrence:

Flood in La Canada Valley, California.- The first flood described in the period was that of January 1, 1934 in La Canada Valley, a small basin in Southern California. The flood which resulted from heavy rains on recently burned-over hillsides, caused the loss of more than 40 lives and property damage exceeding $5,000,000, destroyed gaging stations, and carried so much debris that it was impossible to measure accurately the mixture of water and debris forming the flood. It was, therefore, necessary to estimate the flood discharges from an intensive study of rainfall records. The debris from 1½ square miles was deposited in a gravel pit where its volume was measured as 28,500 cubic yards, and from this the entire amount of debris was estimated at 600,000 cubic yards. H. C. Troxell and J. Q. Peterson made the field investigation and prepared the report which contained a discussion of erosion and debris deposits in addition to the rainfall and run-off features. It was published as Water-Supply Paper 796-C.

Republican River flood.- A cloudburst storm on a small area chiefly in Colorado and Kansas during the night of May 30-31, 1935, put the peak on the greatest known flood in the Republican River, which caused the loss of 110 lives, and property damage in excess of $8,000,000. There was no Weather Bureau rainfall station in the area covered by the storm, but fortunately local residents measured in improvised rain gages the precipitation at 30 points. These records which were obtained by combing the areas of heavy precipitation, were so consistent that it was possible to draw isohyets of the storm. The storm was so outstanding that its pattern was subsequently transposed to other areas as a basis for studies of maximum possible floods in other river basins. The resulting flood was the greatest since the region was settled, and according to Indian tradition had not been equalled since about 1826. It was most severe in Colorado and Nebraska where the rainfall was heaviest. Although the general storm of May 26 to June 2 extended over the entire Republican-Kansas River Basin the rainfall decreased downstream and the flood crests flattened out. In the upper States the peak discharge was of such duration and was so much greater than any discharges recorded previously, that it was necessary to extend the rating curves by means of slope-area determinations. Discharges were

similarly determined at other points in the basin. Not only the Survey but the Army Engineers and Kansas officials investigated the flood. With each agency making slope-area determinations at various points, it was inevitable that the results would be discordant in some degree. A meeting of interested agencies was held in the Army-Engineer office at Kansas City to iron out differences, and to agree upon the most probable and consistent quantities which all interested agencies would use. In the lower valley the flood peaks were lower, and of longer duration, and it was possible to obtain flood measurements and thus obtain peak discharges from rating curves. J. B. Spiegel investigated the flood in Kansas, and the author in the upper basin in Colorado and Nebraska. The resulting reports were correlated by C. H. Pierce, and published as Water-Supply Paper 796-B.

Central New York floods.- Floods in central New York during July 1935 caused, according to newspaper reports, a loss of 43 lives and property damage of $25,000,000. During the period July 6-9, 1935, a succession of heavy thunderstorms occurred in an area extending from northern Steuben County eastward to northern Delaware County. Previous records of 24-, 48-, and 72-hour precipitation were exceeded at all Weather Bureau stations in that area. The maximum recorded rainfall during the period was in excess of 10 inches. As there were no gaging stations in the areas of most intense precipitation and hence greatest run-off, it was not possible to determine hourly or mean daily discharges during the flood period. Hollister Johnson investigated the flood, and made 55 determinations of peak discharges, 26 by slope-area measurements, 22 over dams, and the remainder by miscellaneous methods. The Weather Bureau prepared a statement on the meteorology of the storm. The report was published as Water-Supply Paper 773-E. Largely because of those floods, the Army Engineers made an intensive flood-control investigation.

Muskingum River flood.- In August 1935, heavy rainfall over the entire Muskingum River Basin, Ohio, with intense rainfall of more than 8 inches over an area of 400 square miles, caused the greatest summer flood in that basin. No lives were lost but the property damage was reported at about $6,000,000. The Weather Bureau records of rainfall were supplemented by private records and the Weather Bureau prepared a statement concerning the meteorology of the storm, which was included in the Survey report. The Muskingum Watershed Conservancy District prepared a statement which was also included, on the meteorologic and hydrologic conditions. Records of the flood were compiled at 20 regular gaging stations and at six flood-control dam sites where construction by the Army Engineers was under way. Records of stage at locks and dams on the Muskingum River, furnished by the Army Engineers, were also included. A study of rainfall-run-off relations was made by W. B. Langbein. Lasley Lee was in charge of the investigation until his death. He was succeeded by C. V. Youngquist. The results were published as Water-Supply Paper 869.

Floods in Texas.- Texas lived up to its well-established reputation for having "bigger and better" floods, by the floods which occurred during 1935, 1936, 1938, and 1939. In 1935, exceptional floods occurred on Seco Creek during May, on the Colorado and Nueces Rivers during June, and on Buffalo Bayou during December. During the May and June floods, 50,000 square miles contributed extraordinarily high run-off,

and 16,000 square miles yielded run-off greater than had been reported previously. The toll of the 1935 floods was 30 lives lost, and estimated property damage of $28,500,000. During 1936, more than 20 inches of rain fell on the Guadalupe River Basin June 30 to July 1, and as much as 30 inches of rain fell on the Concho, San Saba, and North Llano River Basins from September 13 to 18, resulting in record-breaking floods. An area of 20,000 square miles yielded the greatest floods recorded, and 50,000 square miles yielded extraordinarily high floods. In January, June, and July 1938, and June 1939, floods occurred in Texas that exceeded previously-recorded stages at many places. These floods were caused by heavy rainstorms on an area of about 30,000 square miles in the Panhandle-plains region and Upper Colorado River (of Texas) Basin. On June 15, 1938, a cloudburst rain of 14 inches at one point caused a peak discharge of 945 second-feet per square mile from 68.5 square miles. From July 16 to 25, 1938, heavy rains fell on an area of 5,700 square miles in the Upper Colorado River Basin, with recorded rainfall ranging from 15 to 30 inches. San Saba River had a peak discharge of 843 second-feet per square mile from 72.4 square miles. In June 1939, 1,000 square miles in the Upper Colorado River Basin had a rainfall ranging from 4 to 19 inches in from 4 to 10 hours.

In making the flood investigations except those for the 1938 and 1939 floods, it was necessary to supplement the rainfall records of the relatively few Weather Bureau stations by non-standard private records. It was also necessary to measure many peak discharges by slope-area methods. At regular gaging stations the stage and discharge were given for the flood periods and records at intervals of a few hours for the times of unusual discharge. The reports on the 1935 floods, published as Water-Supply Paper 796-G, and on the 1936 floods, as Water-Supply Paper 816, were prepared chiefly by Tate Dalrymple. The report on the 1938 and 1939 floods was prepared by S. D. Breeding and Tate Dalrymple and contained studies of rainfall-run-off relations, and records of sediment transported by the Colorado River during the flood. It was published as Water-Supply Paper 914. An allotment of $10,000 from PWA funds was made for this investigation.

Floods of March 1936.- From March 9 to 22, 1936, there occurred in close succession in the region extending from the James and Upper Ohio River Basins to the river basins in Maine, two extraordinarily heavy storms, which caused the greatest concentration of precipitation, chiefly in the form of rain, recorded in that region. With the large accumulated snow cover, the total quantity of water ranged from 10 to 30 inches in depth over the region. The resulting floods were the greatest known, the Connecticut at Hartford being 8.6 feet higher than in any other flood during the 300 years of white occupancy, the Susquehanna at Harrisburg, 3.5 feet higher than any known floods during 200 years, and the Ohio at Pittsburgh, 6.1 feet higher than any flood since 1762. The magnitudes of the floods, the great areas affected by the storm, and the necessity for compiling the field data before flood debris were removed made the investigation of these floods a major task for the districts affected. The importance of a thorough investigation was so great that a PWA allotment of $125,000 was made. Each district affected investigated its floods, with the result that peak discharges at 470 regular gaging stations and crest stages along 7,100 miles of river were obtained. In presenting the flood data bi-hourly records of stage and discharge were tabulated. W. G. Hoyt

collected data on rainfall and made studies of rainfall-runoff relations. The results were published as Water-Supply Papers 798, 799, and 800. Other details of the field operation are given in summaries of operations for the Boston, Hartford, Harrisburg, Middle Atlantic, Charlottesville, and Charleston districts.

Floods in the Ohio and Mississippi Rivers.- A succession of heavy storms, chiefly in the form of rain and heaviest in the middle and lower portions of the Ohio Valley, started late in December 1936, continued through January 1937, and caused floods from Point Pleasant, W. Va., on the Ohio to a point below Helena, Ark., on the Mississippi, a distance of more than 1,000 miles in which the crests were the greatest known since the first white settlements. The Ohio at Louisville exceeded its previous record stage by about 10 feet, an excess over previous floods that was greater than at any other place. So great was this catastrophe that a thorough investigation was ordered, and a PWA allotment of $78,000 was made. Like those of 1936, the Ohio and Mississippi River floods extended through several districts, each of which made the investigation in its boundaries.

Flood discharges at 250 gaging stations, crest stages along 5,000 miles of rivers, and records of storage in many reservoirs were collected. An unusual feature of this investigation was the use of an airplane to determine the feasibility of obtaining pictures from which reliable estimates of flood discharges could be made when gaging stations were isolated by high water. The TVA offered the use of an airplane and photographic equipment if the Survey desired to make the experiment. This offer was accepted and A. H. Frazier spent January 30 and 31 in flights over the flooded portion of the Ohio and Mississippi Rivers from Evansville, Indiana, to Memphis, Tennessee. The object of the flights was to obtain pictures of drift in the river at recognized points, which could be identified in successive pictures that were accurately timed, for use in computing velocity of current. Pictures were taken from an elevation of 6,000 feet, and in one section of river drift was found to have a velocity of 8.2 feet per second. Owing to the great difficulty in identifying the drift in the various pictures, no other determinations of velocity were made.[265] W. G. Hoyt made studies of

[265] Water-Resources Bulletin, Feb. 10, 1937, p. 4.

the meteorologic features, rainfall-runoff relations, and effects of channel storage. The sediment deposited by the floods was studied by G. R. Mansfield of the Geologic Branch, and an abstract of his findings was included in the report which was entitled Floods of the Ohio and Mississippi Rivers, January-February 1937, Water-Supply Paper 838. The magnitude of this report is indicated by its 736 pages. Further details of field operations are given under summary of operations for the Indianapolis district.

Eastern New Mexico floods.- Heavy cloudburst rains which occurred over the eastern part of New Mexico from May 23 to June 4, 1937, caused floods in the Canadian and Pecos River Basins, that were record-breaking in many places and resulted in the loss of nine lives and property damage reported at $2,000,000. Tate Dalrymple directed the investigation and obtained flood records at 23 regular gaging stations and 14 miscellaneous points. The Weather Bureau prepared a statement on

the climatologic features. The resulting report published as Water-Supply Paper 842, contained a list of all previous known flood peaks in New Mexico.

Northern California floods.- An exceptionally intense rainstorm accompanied by warm temperatures, occurred in the northern part of California during the period December 9 to 12, 1937. The precipitation was in the form of rain up to high altitudes in the Sierras, where December precipitation is normally in the form of snow. The maximum precipitation recorded during a 48-hour period was more than 18 inches in the Feather River Basin. Floods occurred from the Kaweah River Basin in the south to the Pit and Trinity River Basins in the north, and from the Sierras to the Pacific Ocean. At 80 gaging stations the floods reached peaks greater than any previously recorded. Since 1867 no other major floods have occurred so early in the season. The property damage was estimated at $15,000,000. So essential was a comprehensive report that the Governor of California allotted $10,000 for that purpose and that amount was matched by Survey funds. The Bureau of Reclamation furnished about $14,000 for the report, and the WPA organized an office project to assist in compiling the data. The investigation was made by H. D. McGlashan and R. C. Briggs. Flood discharges were obtained at the 185 regular gaging stations within the flood area. W. G. Hoyt compiled precipitation and other climatological data and made studies of rainfall-runoff relations. The report was published as Water-Supply Paper 843. The Army Engineers spent $12,500 to repair damages to Survey gaging stations in the Sacramento Basin.[266]

266/ Letter from H. D. McGlashan to author.

Southern California floods.- A series of heavy rainstorms between February 27 and March 4, 1938, in the coastal area extending from San Diego on the south to San Luis Obispo on the north and inland to parts of the Mojave Desert, produced floods which were apparently the greatest in 70 years. Eighty-seven lives were lost and the estimated property damage was $78,600,000. The storm center was apparently in the San Gabriel and San Bernardino Mountain areas in the basins of the Santa Ana, San Gabriel, and Los Angeles Rivers. Many rainfall records indicated from 20 to 30 inches of rain during the 6-day period. Much detritus in the mountain channels was carried into mountain reservoirs and reduced their capacities by as much as 78 per cent.

A comprehensive report was so important that the PWA allotted $21,000 and set up an office project to assist in computing the data. H. C. Troxell, under F. C. Ebert's supervision, had charge of the investigation and made the special studies. One of these was concerned with the influence of intervening mountains on the distribution of precipitation and was made possible by the many rainfall records furnished by various agencies.

Of the 165 peak discharges presented, 20 were determined by extension of rating curves, 70 by slope-area measurements 19 by reservoir records, 14 estimated, and the remainder by other methods. Daily discharges at 117 gaging stations were included and for the more important stations, hourly discharges were shown. Studies of rainfall, run-off, and detention were also made. The resulting report was published as Water-Supply Paper 844. So great was the damage to

Survey gaging stations that the PWA allotted $43,000 and the Army $23,000 for their rebuilding.

Hurricane floods.- The outstanding and unique character of the hurricane floods of September 1938 is well described in Water-Supply Paper 867, as follows: 267

267 p. 1, Water-Supply Paper 867.

> During the brief interval of 6 hours on September 21, 1938, a West Indian hurricane passed over Long Island and New England. The hurricane as it struck New England was the climax of a 4-day period of rainfall which in itself was of outstanding amount and character and which produced river stages that inundated and damaged nearly everything on the river flood plains. When measured by the appalling loss of life and property by the combined forces of the hurricane winds and the associated ocean storm waves and river floods, these events constituted the greatest catastrophe in New England since its settlement by the white man.

Hurricane storms in New England have been recorded since the early days of the Colonies, the first of record being that of August 15, (old style; August 26 of present calendar) 1635. But apparently none of the earlier storms were accompanied by such intense rainfall as that of the 1938 storm during which at some points the rainfall was 17 inches, with an average of 11.5 inches over an area of 10,000 square miles. The resulting floods on many streams were the greatest known, and the ocean crests were as high as 17 feet above mean high-water level. About 500 lives were lost, chiefly along the coast, and the property damage was $300,000,000 or more. The floods occurred in several Survey districts, and each district made its own investigation. PWA allotted $38,000 for the investigation and report. Flood records of stage and discharge at some 240 regular gaging stations were collected, also crest stages along 1,450 miles of rivers, ocean heights at about 230 points along the coast, and records from 31 observation wells on Long Island where the storm caused a rise of about 7 inches in ground water level. W. B. Langbein studied the meteorologic features which included 750 precipitation records. Of these, 111 were obtained by recording gages, making it possible to present for the first time hourly records during the storm period. Langbein also made rainfall-runoff and storage studies. R. M. Leggette prepared a statement on ground-water recharge on Long Island. The resulting report was published as Water-Supply Paper 867. Details of field operations during the investigation are given in summary of operations for the Boston and Hartford districts.

Floods in Colorado.- In July 1938, an allocation of $3,000 of PWA funds was made to the Denver district for a study of floods in Colorado, where the topography is favorable to the occurrence of violent floods of the cloudburst type, and of floods of the more conventional pattern. As no very recent outstanding floods had occurred, it was decided after consultation with local engineers to make a search for all records of past floods, and bring the results together in one report which would be a handbook on Colorado floods. L. R. Sawyer was detailed to that search. He was aided very materially by the extensive file of Colorado

newspapers in the State Historical Society's library, and by the writings of early explorers and travellers in Colorado before actual settlement began. For some of the later floods, leads furnished by newspapers were followed up by visits to the localities indicated in order to obtain additional information from local residents, some of whom had witnessed the particular floods that were being investigated. Also, through a few historically-minded individuals who had collected "hearsay" evidence of floods that occurred before white settlement, accounts of floods of as long ago as 1826 and 1859 were compiled. Although these early accounts were very sketchy they indicated the occurrence of severe floods under natural conditions. The earliest account of a cloudburst flood in Colorado related to a "water spout" which occurred in Golden Gate Gulch near Golden on July 14, 1872. In another flood of that type in May 1878, a standard-gage locomotive went into Kiowa Creek and as the bed consisted of 50 feet of sand overlying bed rock, the locomotive was never recovered. The intensity of cloudburst rainfall was shown by two incidents--one in which a horseback rider was nearly drowned or smothered from inability to breathe, and another in which a horse was drowned in an open field. The effect of erosion on stream channels has been traced through the studies of successive floods; the width of the Purgatoire River at Trinidad has increased from 30 to 200 feet, Fountain Creek from 40 to 200 feet, and Cherry Creek in Denver, from 14 to 100 feet. Descriptions of more recent floods published in Water-Supply Papers were condensed and included in the handbook, "Floods in Colorado" which was published as Water-Supply Paper 997.

Cloudburst floods in Utah.- A PWA allotment of $3,000 was made for a study of floods in Utah. R. R. Woolley received the allotment and decided to concentrate on cloudburst floods for the following reasons:268/

268/ Letter to author.

> (a) I was not convinced that the cows and sheep made all the gullies, as we were being led to believe by the vigorous propaganda of the Forest Service and the Soil Conservation Service.
>
> (b) I found in Mr. Stabler as a result of his "Then and Now" studies, and his experiences with the officials of these two bureaus who would chalk up all erosion to overgrazing, an inspiration to search out some real substantial information on floods that antedated the immigration of man and his destructive herds.
>
> (c) With Stabler's encouragement and my initial success in finding actual records of floods in the early days of the State, I dug in, so to speak, and compiled a great amount of historical material on cloudburst floods.

For this purpose the most comprehensive source of information was the newspaper files. This source was particularly good as the file of the Deseret News was complete since 1850, three years after the Mormon pioneers settled Salt Lake City. As the Deseret News had a wide circulation throughout the State, it published weekly statements sent to headquarters from each settlement, and as nearly all of the important towns of the State antedated 1860, the weekly reports were, as Woolley phrases it, "unique in their simultaneous coverage

of a long period of time."

As the report was devoted to cloudburst floods, Woolley gave the following definition:

> The term "cloudburst" is here used, as commonly, to designate a sudden flood of rain which in the course of a very short time tears up the ground, fills up gulleys and water courses, and not infrequently produces devastating floods. These downpours are noted for their high intensity of rainfall (generally only over localized areas) which suggests the bursting and discharge of a whole cloud at once.

Reports of several hundred outstanding floods indicate that the western and southern fronts of the Wasatch Mountains, below an elevation of about 8,000 feet, are especially subject to cloudbursts. Relative to the frequency of cloudburst floods, it was found that

> a stream course susceptible to cloudburst floods may pass unscathed through a succession of years climatically conducive to cloudbursts and then receive a cataclysmic downpour during a year of generally feeble thunderstorm activity.

A manifestation of the cloudburst floods is the mudflows which, as Woolley phrases it, are

> a lubricated mass of alluvium which is spewed from the canyon in a fan-shaped deposit like a huge sheet of mortar or concrete.

The momentum and carrying capacity of a mudflow are tremendous and one incident is cited where a large dairy barn was carried for half a mile and finally came to rest on a main highway.

By means of PWA funds, a number of assistants were employed to make detailed studies of two widely differing areas, both subject to cloudburst floods. These areas were mapped topographically and studies, which included volumetric determinations of recent mudflows, were made of the alluvial fans at the mouths of the canyons. The purpose of these studies was to make a rough estimate of the volume of debris added to the alluvial fans during the floods of 1923 and 1930, and knowing these volumes, to make an estimate of the volume of water required to liquify the debris. With this information and the approximate time required to deposit the debris, it was possible to make a rough estimate of the maximum discharge. This was done for three small streams. The streams were so steep and winding that it was impossible to use slope-area methods for that purpose.

In addition to descriptions of physiographic features by R. E. Marsell, and of climatic factors influencing storms, the report contains a list of some 650 cloudburst floods including date, location, and brief description of each, but does not attempt to give estimates of peak discharges. It also presents results of a study of the relation of man's occupancy and use of the lands to the magnitude and devastating character of the floods. Contrary to a widely-held view, Woolley believes that man's activities have had a minor effect on

the magnitude and effect of cloudburst floods, and presents facts supporting his views.

The report was published as Water-Supply Paper 994.

Flood Runoff in the Willamette Valley, Oreg.- An allocation of PWA funds was made to the Portland District for a flood study, and the Willamette Valley was selected for that study, which was made by M. D. Brands. That valley is subject to severe floods, that of 1861 being the greatest known, and as the Army Engineers were investigating multiple-purpose projects, including flood control, there was need for a better understanding of the flood characteristics. The floods are caused by rainfall in the valley itself and usually, in addition, by melting snow in the high mountains bordering the valley. All available rainfall and runoff data were assembled and in making the study, the discharge from the entire basin was divided into two parts, one in which rainfall was the sole cause of the flood, and the other in which both rain and melting snow were factors. For the part of the basin solely affected by rainfall, unit hydrographs were defined from the flood discharges, and for the section where melting snow plays an important part, various relations between temperature, altitude, and snow runoff were determined. The results of the study were published as Water-Supply Paper 968-A.

Floods of the Puyallup and Chehalis River Basins, Wash.- An allocation of PWA funds was made to the Tacoma District. A study was made of the floods in two basins comparable in size and shape, but unlike in other characteristics. Puyallup River rises in the glaciers of Mt. Ranier and flows through mountainous foot hill, and delta topography, with a range in altitude from sea level to 14,408 feet; Chehalis River rises in the Willapa Hills and the western foot hills of the Cascades, the range of altitude in the basin being from sea level to about 4,000 feet. Rainfall and runoff studies were made for the mountains, and for the valley sections of the Puyallup Basin. Floods to be studied were selected for two purposes: (1) to show differences between flood behavior between the mountainous and valley parts of the Puyallup River, and (2) between the valley part of the Puyallup River and the Chehelis River. The study, which was made by I. E. Anderson, indicated that the flood characteristics of the Chehalis River and of the valley part of the Puyallup River did not differ greatly. The results were published as Water-Supply Paper 968-B.

Drought reports

Serious droughts occurred over wide areas in the United States in 5 out of the 7 years, 1930-36, which might be likened to the 7 lean years of the Pharaohs. In 1930 the humid States except the Gulf Coast States and Maine and Vermont, and to a lesser extent North Dakota, Montana, and the Pacific Coast States were seriously affected. In 1931, a large block of States in the northwestern part of the country, east of the Pacific Coast States, and four States in the southeastern corner of the country which had escaped the 1930 drought, were affected. The 1933 drought which was relatively light affected 11 States scattered throughout the country. The 1934 drought was the most severe and covered the vast area from the Canadian border to the southern border of New Mexico, Oklahoma, Missouri, and Kentucky, and from Ohio to the Pacific Coast with the exception of Washington, Oregon, Idaho, and

Nevada. The 1936 drought covered the entire Mississippi Valley except Wyoming, Colorado, and New Mexico. It also covered parts of Oregon and Washington, and in a part of that area was more severe than the drought of 1934.

Little information regarding earlier droughts is available because, in comparison with the present time, water supplies had not then been developed so fully, droughts did not affect the country so vitally, and less attention was paid to them by the general public. However, the meager available information, including particularly the long-time records of stream flow, indicates that the droughts during the present period were the most severe of record and covered the largest areas. In the humid States, the longest stream-flow record, that of Lake Cochituate Outlet at Cochituate, Mass., is continuous since 1863 and shows that the lowest runoff since that year occurred in 1930. Other records extending back to the seventies and eighties show similar conditions. In a few isolated areas the run-off during 1931 was slightly less than during 1930.

The deficiency in precipitation was greatest in Virginia and West Virginia, and to the author's personal knowledge of conditions in the "Blue Ridge Mountains of Virginia," springs which had never before been known to fail, either dried up entirely or were reduced to the merest trickle.

In the semiarid States, which are in general the States bisected by the 100th meridian and constitute the Great Plains, so severe were the droughts of 1934 and 1936 that a large part of that area became known as the "dust bowl." In the most sorely stricken part of that area the Federal Government purchased cattle which were either diseased or would die for lack of feed. The Great Plains Committee stated in its report,269/ that the Federal Government took emergency steps to

269/ The future of the Great Plains, G.P.O. Dec. 1936.

rescue dying cattle, relieve destitute families, and safeguard human life. That report referred to the period from 1886 to 1895 also as one of disastrous drought in the Great Plains. Prof. A. E. Douglass, the pioneer in tree-ring studies in Arizona and New Mexico, states that his studies indicated a period of drought from 1880 to 1904. The records of the elevation of Great Salt Lake also indicate deficient rainfall from 1886 to 1906, with the years 1902 to 1905 showing the lowest levels. It is therefore evident that intermittent droughts were widespread throughout the semiarid and arid regions during the period from the eighties to the early years in the present century. However, the available information, including stream flow records of Red River at Grand Forks, N. D., and elevations of Great Salt Lake, indicate that the droughts during that period were not as severe as during 1934 and 1936. It may not be out of place to add that the tree-ring studies indicated a severe drought period in the southwest extending from 1276 to 1299, with particularly severe droughts during 1288, 1294, 1295, and 1297. It is probable that during these years, failing water supplies caused the cliff-dwellers to leave the Mesa Verde in Colorado.

J. C. Hoyt writes [270] that in earlier years droughts were judged

270/ Water-Supply Paper 680, p. 5.

largely by the extent of their damage to agriculture, but in recent years, as demands for and uses of water have increased, more consideration is given to the effect of droughts on surface and ground-water supplies in their relation to other normal activities. Because of present-day development, future droughts will have a wider and more disastrous effect than those of the past.

Early in 1931, Mr. Hoyt, having been interested in the drought of the previous year, requested each district engineer to furnish information relative to 1930 precipitation, run-off at selected stations, crop failures, condition of livestock ranges, water supplies for irrigation where applicable, ground-water levels, domestic and municipal water supplies, and effects on water-power plants. Again in 1934, similar information was requested, with comparisons between the drought years of 1930, 1931, and 1934. With these various reports as a basis, augmented by data from many other sources, Mr. Hoyt prepared the first drought report to be published by the Survey.[271]

271/ Water-Supply Paper 680.

Similar data were obtained from the districts affected by the drought of 1936, and he made a second drought report,[272] including a discussion

272/ Water-Supply Paper 820.

of the significance of droughts in relation to climate.

Conferences

The program of biennial conferences which had been started soon after Mr. Grover became chief of the Branch in 1913, continued through 1931. When the time for the 1933 conference arrived, the economy program of the New Deal was in full swing, and it was felt that a conference involving as it would a very considerable expense in bringing the district engineers to Washington, would not be justified, and this feeling continued for several years. By the spring of 1937 a number of new districts had been created, the work of all districts had been expanded greatly, and many new problems confronted the Branch. It was therefore decided to hold a conference in the following October. Unfortunately, the next year's appropriation act effective July 1, reduced drastically the limit on salaries for services in the District of Columbia,[273] and as the salaries of all field men while in Washington

273/ p. 8.

would be included within that limitation, although actually paid from allotments to the various districts, it was not possible to hold the conference in 1937. The limitation on D. C. salaries was substantially increased, however, in the next year's appropriation act and the long-postponed conference was held in the fall of 1938.

The first conference during the period, scheduled for October 1929, was postponed until the following January as several engineers, particularly J. C. Hoyt, chief of the Surface-Water Division, wished to attend the World Engineering Congress in Japan in October. The conference was therefore set for January 20-25, 1930, and a committee consisting of C. G. Paulsen, W. R. King, and A. W. Harrington, chairman, was appointed to arrange the program which, as usual, was based largely on suggestions made by the district engineers. In the letter transmitting the program in advance of the conference, the committee stressed the need for discussing the various papers, stating:

> Everything is to be gained by discussion, provided it is to the point and conducted in an orderly fashion * * *. The purpose of prepared papers is primarily to evoke discussion. They should therefore be short and pertinent.

This admonition to conserve time was reflected in one of the first acts of the opening session, when the motion to read the minutes of the 1927 conference was lost. The usual fine of 25 cents for tardiness at subsequent sessions was assessed, and the delinquent fines for failure to contribute to the Water-Resources Bulletin ordered collected by the sergeant-at-arms and turned over to the entertainment committee. One member of the conference absented himself for an entire day and was promptly fined $2.25 upon his reappearance. J. W. Mangan was conference secretary.

New equipment which had been developed since the 1927 conference, chiefly the Lee-Au reel and boom for 50-pound weights, and the improved current meter, were perhaps of greatest interest. The committee on field equipment was instructed to develop heavier booms for use with 100-pound weights. Several papers were devoted to new or improved methods for computing records at slope stations which were coming to be of great importance in stream gaging. The committee on rating curves called attention to the methods devised by Grosbach, King, McCashin, and Harrington, and requested each to furnish a complete description of his method in order that they might be compared and reviewed for presentation at the next conference. The perennial subject of a field manual was again discussed and the committee on field methods was instructed to proceed with its preparation, the stipulation being that the manual should be concise, brief, and thorough--somewhat conflicting and paradoxical requirements. The committee on an office manual stated that the five parts of the manual discussed at the 1927 conference had been issued in mimeograph form. For the first time no entertainment feature was provided. The proceedings of the conference were mimeographed.[274/]

274/ Proceedings of the Conference of district engineers * * * Jan. 20-25, 1930.

The next conference was held October 12-17, 1931. In announcing that date, Mr. Grover stated:

> You are hereby directed to attend the * * * conference * * * and to arrive in Washington several days prior to the conference and/or remain several days after the conference in order that there may be sufficient opportunity to discuss * * * the many problems related to your technical, fiscal, and general duties.

A program committee consisting of G. H. Canfield, A. W. Harrington, and G. L. Parker, chairman, was appointed and in transmitting the program to the district engineers, the committee stated:

> The program committee suggests that papers be prepared by each one who has been assigned a topic. As the main purpose of the papers is to preserve for reference many valuable ideas, suggestions and opinions, it may be desirable to include * * * more details than would be desirable to read * * *. Most engineers will talk * * * using prepared papers only as a guide * * *.

The entertainment committee made reservations for the conferees at the Lee House.

In opening the conference Mr. Grover said:

> The biennial conferences are now well established and are accepted by all as well worth their cost. These conferences are high spots in our work, at which four principal objects are accomplished:
>
> (a) Improvements in our field and office methods, and in our instrumental and other equipment;
>
> (b) Development in esprit de corps;
>
> (c) Contacts with Survey and other officials in Washington;
>
> (d) Development of the district engineers as interpreters. The district engineers must interpret the Survey to the public as well as interpret the public to the Survey. They live throughout 103 weeks of the 104 weeks in 2 years in their districts, in close contact with cooperating officials and the public. During that time they must represent and interpret the Survey. They must also keep us in Washington advised of State and public needs and opinions.

The conferee was welcomed to Washington by Acting Director (later Director) W. C. Mendenhall, who was a former member of the Branch, in charge of ground-water investigations. In the course of his remarks, Dr. Mendenhall stated:

> You represent in one sense one of the oldest of the problems of the Geological Survey, perhaps one of the oldest problems of government, the problem of centralization versus decentralization. When the Survey began its existence it was a decentralized organization, having three great districts. * * * After a number of years' experience * * * Major Powell deliberately abandoned it as the least wise of the two plans of organization.
>
> You <u>necessarily</u> represent something of a flareback of that abandoned plan. * * * We must have these district offices. That is * * * an established policy. It does not represent, of course, a complete abandonment of the old centralization

idea--only a partial abandonment. You are in a sense but not completely autonomous.

The increased responsibilities and opportunities of the Branch brought about by the increase in available funds through the adoption by Congress of the 50-50 cooperative principle was stressed by both speakers. It was perhaps the keynote of the conference.

As usual, improvement in equipment since the previous conference was given considerable attention, as was the measurement of large rivers--the Mississippi, Columbia, and Colorado. A paper on the three-dimension method of computing records at slope stations was presented. The early availability of a national hydraulic laboratory promised to afford opportunity for scientific research and it was urged that such research be given a definite place in the program of the Branch. It was further pointed out that unless the Branch should take advantage of opportunities to contribute to the science of river hydraulics within the field of its activities, others would do so, perhaps less satisfactorily and less efficiently.

E. D. Burchard, chairman of the committee on a field manual, read parts of a first draft to give an idea of its scope. The conference voted that the manuscript be mimeographed and a copy sent to each district for comment. Afterward, the committee was to take whatever action it desired. Later, D. M. Corbett was detailed to complete the draft of the field manual.

F. H. Newell was a most-welcome visitor, and gave a sketch of the early days of stream gaging. Dr. Newell's appearance at the conference gave many of the young men of the Branch their only opportunity to see and hear the man to whom the Survey owes so much for his vision, courage and perseverence in initiating and putting on a sound basis the study and recording of the Nation's water resources. His brief address at this time was perhaps Dr. Newell's final tribute to his first love--systematic stream gaging. He died July 5, 1932.

One afternoon was devoted to an inspection of the Bureau of Standards meter rating station, and of the hydraulic laboratory that was then under construction. The entertainment feature was a dinner dance at the Columbia Country Club. H. F. Hill, Jr. was secretary of the conference. The proceedings were mimeographed.[27]

27/ Proceedings of the Conference of district engineers * * * Oct. 12-17, 1931.

The last conference in the period was the postponed 1937 conference held October 24-29, 1938, and the program committee was G. H. Canfield, H. B. Kinnison, and H. C. Beckman, chairman. In its announcement regarding the conference the Committee stated:

> The conference * * * will be one of extraordinary importance on account of (1) the long time since the preceding conference, (2) the many new problems which have arisen as a result of the large expansion of our work, and (3) the many additions and changes in our personnel. It is also significant in that it comes almost exactly 50 years after

the establishment of the Geological Survey camp on the Rio Grande at Embudo, N. Mex., in December 1888.

In connection with the program the writers of papers were instructed to send them to the district engineers at least a month in advance of the conference in order that they might be studied preparatory to discussion. To conserve time, the papers were to be presented in summary form for the purpose of opening the discussions. The committee arranged five half-day executive sessions, a greater number than at previous conferences, and as those were to be attended only by the district engineers, a separate program of technical subjects was arranged for the younger engineers of the Branch of whom about 40 were in attendance from the Washington office and neighboring districts, including one each from Hawaii and California. The total attendance at the conference, including personnel of the Washington office, Ground Water, and Quality of Water divisions, and representatives of other governmental agencies and of manufacturers, was 135. For the first time it was found desirable to have name buttons for each participant.

Emphasizing the 50th anniversary, Mr. Grover, in his opening address, read a letter he had written to Prof. A. C. Lane,[276] the only surviving

276/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 47.

member of the original Embudo party, inviting him to attend the conference. He also read Prof. Lane's letter of regrets. A letter from W. C. Price, describing the genesis of the Price meter was also read,[277] as a fitting

277/ Op. cit., p. 80.

sequence to the historic beginnings at Embudo.

Following the precedent set by the 1931 conference, the reports of standing committees were considered first. The committee on field methods considered that it had been discharged when the work of completing the preliminary draft was assigned to D. M. Corbett. He completed such a draft which was mimeographed and circulated throughout the Branch with requests for criticisms and suggestions. Many of great value were received. Before they could be incorporated, however, Mr. Corbett was transferred to a new field assignment which made it impracticable for him to follow through the final stages. The draft and suggestions were, therefore, turned over to C. H. Pierce in May 1938 for completion and editing. The conference voted to have the manual made an official publication of the Survey. Thus ended the effort to obtain a field manual, which had resulted in the appointment of a committee on field methods at the 1927 conference.[278] The

278/ p. 90, 1919-1928.

manual, entitled Stream Gaging Procedure, was published in the autumn of 1943 as Water-Supply Paper 888.

B. J. Peterson, chairman of the committee on rating curves, called attention to the method for extending rating curves beyond the highest measurement by computations of discharge made by use of slope-area, contracted openings, and dams, and stated:

> Even though the results obtained by the use of such methods are not as accurate as those obtained with a current meter, the Committee strongly recommends that those districts which have not been making measurements of flood discharges by the slope-area method, or other special methods, should plan to do so in the future in order to provide a more substantial basis for the rating-curve extensions.

Attention was also called to the recently-improved method for computing records affected by variable slope, and the statement was made that further improvement in technique was necessary to solve the problem at many stations.

C. V. Youngquist, chairman of the committee on field equipment, described the new equipment developed since the 1931 conference, chiefly wire-weight gage, type-A sounding reel, type-B boom, and C-type sounding weights. The committees on rating curves and field equipment were continued.

Because of the record-breaking floods in the Ohio and Mississippi Rivers which occurred during January and February 1937, and floods in other parts of the country in 1938, flood measurements were the principal topic discussed during the conference; five papers were presented. Variable slope was a close second in interest and two papers were presented on that subject. The exhibit of new equipment was larger than usual, and the various pieces were so numerous that the overflow was placed in the corridor.

The entertainment features included a dinner-smoker at the Columbia Country Club given by the Director, Chief Hydraulic Engineer, and the chiefs of the Divisions of Ground Water, Quality of Water, and Water Utilization. At this dinner the district engineers presented Mr. Grover with a signet ring and a travelling bag in recognition of his twenty-five years' service as Chief of the Branch. A dinner at the Chevy Chase Country Club was given the district engineers by J. C. Hoyt. The regular subscription dinner-dance was held at the Columbia Country Club. Julian P. Friez and Sons were hosts at a buffet supper at the Carlton Hotel, at which time a demonstration of a new method of recording stage by means of dots instead of a continuous line was given. W. S. Eisenlohr, Jr. was conference Secretary. Proceedings of the conference were not issued.

Water Resources Bulletin

In previous periods matters pertaining to the Bulletin were decided by the district engineers at the biennial conferences. But with no conference between 1931 and 1938, the Washington office ascertained the wishes of the district engineers on several occasions by means of questionnaires. The Bulletin was rated as an official memorandum, and not a publication, and so continued to be mimeographed in the Department at no expense to the Branch.

From its revival, January 10, 1926, to and including the issue for February 10, 1937, the Bulletin was issued bimonthly--until 1933, in January, March, May, July, September and November--and thereafter, at the suggestion of J. B. Spiegel, to avoid "the difficult months of January and July", in February, April, June, August, October and

December. Because of the 1930 conference, the issue for January 10, 1930, was omitted; because of the great amount of work incident to starting the first PWA program, the issue of October 10, 1933, was also omitted.

At the 1930 conference, J. B. Spiegel stated that the value and use of the Bulletin, and its predecessor, the News Letter, would be increased if they were indexed, and he offered to prepare an index of all issues since 1918. This offer was enthusiastically accepted. Spiegel continued to prepare indexes of succeeding issues through the calendar year 1935. Thereafter, C. T. Pynchon, clerk-stenographer in the Tucson district, performed that work until 1938, when the reviewer in the Washington office took over that duty at the end of each calendar year.

After Doctor Mendenhall became acting director December 22, 1930, he decided that as the Bulletin was an official memorandum it should be edited by the Survey's editorial section and as that section was overworked, very considerable delay ensued before the Bulletin could be issued. This delay was increased by the necessity of sending all contributions to the appraiser and became so protracted that contributions for each issue had to be prepared before the previous issue had been delivered, thus making it impossible to discuss the contents of one issue in the next. To remedy this situation, several district engineers suggested that the Bulletin be issued quarterly. This suggestion met with general approval and beginning with February 10, 1937, the Bulletin became a quarterly memorandum. With the increase in size of each issue, the work entailed on the editorial section became so great that in November 1937, the requirement for official editing was terminated.

When the Bulletin was started in 1926, it was with the warning that future contributions to the Bulletin were to be on the basis that it was an official medium for the exchange of ideas, and subjects not directly pertinent to official work were to be avoided.[279] The deadly

279/ p. 94, 1919-1928.

parallel afforded by the list of each district's record of contributions published in each issue proved to be more effective than a small fine in causing the district engineers to contribute with a fair degree of regularity, but oftentimes such contributions consisted of relatively brief and unimportant statements regarding weather conditions, changes of personnel, etc. In the issue of May 16, 1932, A. H. Horton called attention to this state of affairs, and suggested that a contribution made up of unimportant items be counted as no contribution, and that a district engineer be appointed by the Chief of the Branch to appraise each contribution. As no objections were made to this suggestion, such an appraiser was appointed, and his work began with the July 1932 issue. In making this announcement, Mr. Grover stated that a district engineer outside Washington, whose identity would never be disclosed, had been appointed, and in passing it may be stated that so far as the author is informed such identity never has been disclosed.

The appointment of an appraiser was looked upon as an experiment, and in November 1934 the Washington office called for an expression

of opinion as to whether the appraiser should be continued and, if not, what substitute procedure should be followed to insure high quality of contributions. There was a practically unanimous desire to continue the appraiser, perhaps for the reason that no one could suggest a better substitute. Early in 1938, the duties of the unknown appraiser were taken over by a reviewer in the Washington office. This action was taken as a result of the new form in which contributions were presented beginning with the issue of May 10, 1938. As a further spur to keeping a high standard of contributions, the Washington office, beginning in January 1935, appointed soon after the close of each calendar year, a committee of three district engineers to select for special mention the best contribution during the year.

The system of fines for failure to contribute to the Bulletin, first ordered by the 1925 conference,280/ and reaffirmed by the 1930 and

280/ p. 90, 1919-1928.

1931 conferences, remained in effect until the calendar year 1935. In one instance the failure to contribute should not have been made the reason for a fine, because one contribution sent by air mail from the Tucson district, was destroyed when the plane crashed and burned.281/

281/ Water-Resources Bulletin, Nov. 10, 1932, p. 49.

As the result of a questionnaire sent out in December 1934, it was decided to cancel all fines prior to January 1, 1935, which for some districts totalled a not inconsiderable amount, and that subsequently the fine should be a flat rate of 25 cents for each failure to contribute. Also, each district could omit two contributions per year without being penalized. This was done in recognition of the fact that the personnel of the smaller districts were so driven by a multitude of duties that time for the adequate preparation of articles every two months was lacking. This action on fines was approved by the 1938 conference.

From almost the first issue of the News Letter the contributions from the relatively few districts had been arranged geographically beginning with the New England States. With the increasing number of districts the geographical arrangement became unsatisfactory, and beginning with the issue of March 10, 1932, the arrangement was alphabetical under the place name of the district office. Along in the middle thirties, the contributions began to change from descriptions of equipment and specific construction jobs to more or less theoretical studies of various problems affecting the accuracy of the stream-gaging records. These studies frequently represented a very considerable amount of labor on the part of the contributor, and in many instances the resulting discussions in subsequent issues were disappointing and were not sufficient to reach any definite conclusions. Thus important questions were left undecided. The first engineer to call attention to this state of affairs was H. D. McGlashan, in whose district many of the theoretical studies originated. In the issue of October 10, 1935, he wrote:

> * * * far too few discussions of important problems are presented in these pages. * * * It is very desirable that all districts join in these discussions.

In subsequent issues several other district engineers suggested that a plan of organized discussion similar to that followed by the American Society of Civil Engineers in its Proceedings be adopted. The Washington office appointed a committee on December 7, 1937, to study and make recommendations regarding organized discussion in the Bulletin. Recognizing the probability that the younger men would take a more active part in discussions than would the district engineers, the committee, of which M. T. Thomson was chairman, consisted of assistant and associate engineers. The committee's recommendations appeared in the issue of February 10, 1938, and were put into effect with the issue of May 10, 1938. The chief effect on the Bulletin's make-up was to substitute for district office headings a few broad subject headings under which the contributions were grouped by the reviewer in Washington. Subsequent discussions were to bear the heading of the original paper and discussions were to be closed after three succeeding issues. If considerable discussion was evoked by a contribution, the author was to present a summary of the discussions, and the author's new ideas gained from the discussions, and his comments upon them.

National Hydraulic Laboratory[282]

282/ Based chiefly on information furnished by C. H. Pierce.

The creation of the National Hydraulic Laboratory by Act of Congress, approved May 14, 1930,[283] was the culmination of several years' effort

283/ 46 Stat. L 328.

by engineers and scientists interested in hydraulic research. John R. Freeman took a leading part in this effort; for many years he had studied engineering methods and procedures in the principal countries of the world, and had been impressed with the work being done at hydraulic laboratories in one or two countries. In his address as President of the American Society of Civil Engineers, delivered June 21, 1922,[284] Mr. Freeman said that for the past 10 years he had been thinking

284/ Trans. Am. Soc. C. E., vol. 85, pp. 1601-30, 1922.

about the benefits to be derived from a hydraulic laboratory, and on several occasions had suggested the value of such a laboratory somewhere in the United States, and that he believed now to be the time to urge the immediate construction of a national hydraulic laboratory, on a large scale, which should be at the service of those branches of the Government having need for it. Among the government agencies he listed the Hydrographic Branch of the Geological Survey, (Mr. Freeman had become interested in the Survey's work in the days of the Hydrographic Branch[285] and continued the use of that name) and later in his

285/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 240.

address, said:

> There is abundant proof that some supposedly accurate measurements made by ordinary current meters in streams having deeply disturbed currents, have been seriously in error, and the use of such an experimental channel, it is believed, would be of great advantage to the Hydrographic Department of the U. S. Geological Survey, and to many other institutions, in educating its young men in the avoidance of errors in gauging, in addition to other uses in developing new and accurate methods.

It may not be out of place to state here that subsequent studies made at the National Hydraulic Laboratory showed conclusively that the results obtained by methods then in use were much more accurate than was generally believed. Mr. Freeman worked long and earnestly for the laboratory and it was largely through his efforts that the National Hydraulic Laboratory came into existence. It was placed in the Bureau of Standards.

When the laboratory was opened in 1932, Director Burgess stated:

> One basic function of the laboratory is basic research to make more exact our knowledge of the flow of water, to seek out new facts, and to determine more accurately values for the many coefficients involved in hydraulic design.

The Branch was quick to avail itself of the laboratory's facilities. A committee consisting of J. C. Hoyt, chairman, R. W. Davenport, and C. H. Pierce, was appointed to study the situation, to develop plans for research in the order of needed priority and to recommend action. In announcing this appointment,[286] the Branch personnel were called

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286/ Letter from Chief Hydraulic Engineer, Dec. 9, 1931.

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upon for suggestions. On June 2, 1932, Dr. L. J. Briggs of the Bureau of Standards wrote Mr. Grover requesting information regarding the investigations in which the Survey would be interested. Based on the suggestions already received, the Survey listed the following specific projects:

1. Methods and appliances used in making determinations of depths of deep, swift rivers and in placing the current meter with certainty in the positions where the velocity observations are desired in the vertical sections.

2. An investigation of the relations of still-water and flowing-water ratings of the current meter.

3. An investigation of the effects of slopes and rapidly changing stages in the determination of discharge in open channels.

4. Rating of the deep-well current meter used for exploring wells.

5. Velocity with which particles of sand of different sizes are transported by streams.

6. The drag load of streams.

Of these, the fourth was for the Ground Water Division and the last two for the Quality of Water Division. These projects were considered of major importance but the laboratory facilities did not permit all of them to be undertaken at that time and the list was changed to include projects which could be investigated.[287]

287/ Letter from C. H. Pierce to author.

The first project undertaken was a study of artificial controls, and a committee consisting of C. H. Pierce, Lasley Lee, and O. W. Hartwell was selected to supervise it for the Survey. This committee supervised succeeding projects until the death of Lasley Lee, November 15, 1937, when H. C. Beckman and C. V. Youngquist were added to it. The study of artificial controls was undertaken as a Bureau of Standards project in cooperation with the Survey. The personnel of the Laboratory assumed responsibility for the conduct of the project and for preparing the final report. The Survey contributed the services of an assistant engineer, W. S. Eisenlohr, Jr., and a laborer, also materials for the construction of full-size models. Eisenlohr performed a large part of the laboratory work related to this project which is briefly described on pages 793 to 798.

Under a similar cooperative arrangement, a minor project, "Performance characteristics of a water current meter in water and in air" was investigated. The results of this investigation were published by the Bureau of Standards.[288]

288/ Research Paper RP 981, March 1937.

The next project, "The performance of current meters in water of shallow depth" was undertaken during 1936 and 1937. No member of the laboratory staff had the necessary practical knowledge of, and experience with, a current meter to take charge of the project and prepare the report, and as the Survey personnel had by this time gained the necessary laboratory experience, the project was conducted as a Survey project. The Survey furnished two assistant engineers, Eisenlohr with either Frazier, Cox or Ash, and the laboratory furnished its facilities. About 475 measurements were made with a standard meter, and 198 with Pygmy meters. A preliminary report on the results was released to the Survey engineers in October 1937, and the final report published as Water-Supply Paper 868-A.

So successful had been the cooperative agreement for the current meter tests that when the next project was undertaken during the period July 1937 to July 1938, it also was a Survey project, in direct charge of a Survey committee, assisted by W. S. Eisenlohr, Jr. and A. D. Ash. This project tested about 90 different devices and arrangements of intakes, used by various districts to eliminate the draw-down in gage wells caused by the current passing the intakes.[289] The results of this

289/ pp. 108-9.

investigation, showing the superiority of several devices, particularly the static tube, were published as Water-Supply Paper 868-B.

The three projects described were the only major ones undertaken prior to June 30, 1939. There were, however, a number of minor projects and studies of stream-gaging methods and equipment, the results of which appeared in various issues of the Water Resources Bulletin. Thus during the period, the National Hydraulic Laboratory proved its value to the Survey in making researches on an adequate scale, and in allaying some of the fears expressed by John R. Freeman in the previous decade.

International gaging stations

The joint operation of gaging stations on international streams at the Canadian boundary began in 1913 as a result of conflicting claims to the waters of the St. Mary and Milk Rivers for irrigation.[290]

290/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, pp. 347-350.

Although at first voluntary and informal, this arrangement was brought about by the international problems involved. Independently of the action with respect to St. Mary and Milk Rivers, although perhaps influenced by it, the Washington district and the British Columbia Hydrometric Survey in 1915 began the joint operation of two gaging stations on international streams on the Washington-British Columbia boundary.[291] No problems had then arisen on these streams and the

291/ Op. cit., p. 351.

arrangement was merely one of obtaining economically one record on each stream which would be acceptable to both countries. The satisfactory working of the arrangements for the gaging stations mentioned was doubtless the primary reason for the conference in Washington between J. T. Johnston, Director of the Dominion Water Power and Reclamation Service and Director Smith, held on November 15, 1928, when a basis of cooperation on streams crossing the International Boundary west of the Great Lakes[292] was arranged.

292/ Water Resources Bulletin, Jan. 10, 1929, p. 4.

When the Kootenai River investigation was started in 1928, the American and Canadian organizations made independent studies, each on its own side of the boundary. Mindful of the satisfactory results that were being obtained at jointly-operated stations, and of the conference in Washington on November 15, 1928, it seemed advisable to increase that program and C. E. Webb of the Dominion Water Power and Reclamation Service, visited the Boise office in January 1929 to discuss a proposed program of operating jointly all gaging stations on international streams west of the Rocky Mountains.[293] Semi-final

293/ Water-Resources Bulletin, Sept. 10, 1929, p. 15.

arrangements appear to have been made in the following September. These arrangements do not appear to have been effective immediately, however, as during 1930 the only extension of the previous program was the making of a few discharge measurements by the Canadian engineers at the Survey station on the Kootenai River near Rexford, Mont. However, by 1931 it appeared that international problems on the various

boundary waters would arise in the future, and base data acceptable to both governments were desirable. Therefore, at that time, the 17 stations on boundary streams west of the Rocky Mountains were designated international gaging stations and were jointly operated. The 25 stations in the St. Mary and Milk River Basins in Montana, which had been jointly operated for many years, were also designated international gaging stations. The next year, 1932, the program was extended east of the Rockies to the Great Lakes and five stations on boundary streams in North Dakota and Minnesota were designated international gaging stations. The Army Engineers, in connection with the "308" investigations had established and operated a number of stations in northern Minnesota. After the discontinuance of those investigations, the Army Engineers desired additional records at two of the stations on boundary waters, and these two stations were designated international gaging stations in 1935. At the same time three Canadian stations, which had been maintained for several years by the Canadian engineers, were also designated international gaging stations and an additional station on Souris River in North Dakota was added to the list.

At the end of the period 53 international gaging stations were being operated by State Department funds. During the period of cooperation with the International Boundary Commission, United States and Mexico, the gaging stations on the Rio Grande were not jointly operated, and were not designated international gaging stations.

The procedure at the international gaging stations on the Canadian boundary was generally as follows: The stations south of the boundary were operated by the Survey with occasional measurements made by Canadian engineers. The records were computed by the Survey after consultation with the Canadians in order that the final records would be mutually satisfactory. The reverse procedure was followed at stations north of the boundary.

The gaging stations related to the division of the waters of the Milk and St. Mary Rivers are considered to be "international" because of this relation and the language pertinent to maintenance of such stations in the Order of the International Joint Commission of October 4, 1921. Other international gaging stations were agreed upon by formal diplomatic exchanges between the United States and Canada. The abandonment of such stations is considered to require similar exchanges.294/

294/ Statement to R. W. Davenport to author.

Operations for State Department

The operations for the State Department along the Canadian border were for the International Joint Commission, and those along the Mexican border for the International Boundary Commission, United States and Mexico.

International Joint Commission: The work during this period for the International Joint Commission, which under the Waterways Treaty of 1909 had jurisdiction over the boundary waters between the United States and Canada, included not only a continuation of the division of waters of the St. Mary and Milk Rivers in Montana, but an increase

caused by three new projects related to the Kootenai River in Idaho, the Roseau River in Minnesota and the Souris River in North Dakota. A number of stations were also maintained near the International Boundary in the Columbia River Basin.

St. Mary and Milk Rivers: Operations required in the division of the waters of the St. Mary and Milk Rivers which were described during the previous period [295] were continued substantially unchanged. The

295/ pp. 54-55, 1919-1928.

annual allotments of State Department funds for that work were:

1929	$8,900	1933	$9,500	1937	$9,550
1930	9,500	1934	8,000	1938	9,000
1931	11,500	1935	8,900	1939	7,900
1932	10,012	1936	9,500		

Kootenai River: The Kootenai valley in both Canada and the United States is so flat that during high water the river overflows its banks. On October 26, 1927, the Creston Reclamation Company of Canada made application to the Commission for approval of the construction of dikes along the Kootenai River in Canada to protect adjacent land from overflow. The construction of the proposed dikes would constrict the river channel and increase the stages of the river on the upstream or United States side of the boundary, thus requiring prior approval by the Commission. That agency held a hearing on the project on November 29, 1927, at which time the Secretary of State requested that proceedings on the application be postponed for a period of one year to afford time for the collection and study of the necessary hydrographic and topographic data.[296] At that hearing, representatives of the West Kootenay

296/ International Joint Commission: Papers relating to the work of, Ottawa, 1929.

(note the Canadian spelling) Power and Light Co. of Nelson, B. C., stated that at some time in the future that company would apply for a permit to store water to a depth of 6 feet above average low-water level of Kootenai Lake, the outlet of which is situated 68 miles north of the boundary. Thus it appeared that the effect of this future application should also be investigated, and as it would be greater than the effect of the proposed Creston diking, owing to the flatness of the slope of the Kootenai River which in a distance of 34 miles south of the boundary has a fall of about 0.4 foot, the investigations were planned almost wholly in anticipation of the expected storage application.[297]

297/ Statement of R. W. Davenport.

To finance the needed investigations, the item for cooperation with the Geological Survey in the State Department's 1929 appropriation act which had appeared first in 1928 for the Milk and St. Mary Rivers, was increased to provide for the new work. This item read: [298]

298/ 45 Stat. L, 72, 73.

> For an additional amount for the waterways treaty, United States and Great Britain; International Joint Commission, United States and Great Britain, including personal services, procurement of technical and scientific equipment, and the hire, maintenance, repair, and operation of motor-propelled and horse-drawn passenger-carrying vehicles, $75,000 to be immediately available, which amount may be transferred * * * to the United States Geological Survey for direct expenditures.

The provision that the appropriation be made immediately available indicated the need for an early start of the investigation. In March 1928, a reconnaissance trip along Kootenai River between Bonners Ferry, Ida. and Nelson, B. C., was made by C. G. Paulsen, G. L. Parker, an engineer of the Dominion Water Power and Reclamation Service, and the Idaho State Commissioner of Reclamation. Tentative arrangements were agreed upon for the investigational work to be done on both sides of the boundary.299/ At that time the plan was that the engineers of each

299/ Water-Resources Bulletin, Mar. 10, 1928, p. 13.

country were to carry on their investigations independently of the investigations in the other country. The program provided for records of discharge at controlling points on the Kootenai River and for records of stage at still other points to be used to determine slope, and to furnish data for backwater studies.

The Canadian government had evidently foreseen several years earlier that problems related to the development of Kootenai Valley would arise, because engineers of the Dominion Water Power and Reclamation Service had already established staff gages and obtained daily records of stage at three points on the Kootenai River in Idaho, one starting in October 1924 and the others in April 1925. When the State Department funds became available in the spring of 1928, the Idaho District took over the operation of two of these stations. Water-stage recorders were installed and discharge measurements started. The third station which was not taken over until December 1929, was continued as a stage station. Field work was commenced in March 1928 when field headquarters were established at Bonners Ferry with a force of three engineers. Three regular gaging stations were installed on the Kootenai River, measurements were made at the two stage stations taken over from the Canadian engineers, and stage stations were established at five points on the Kootenai. Gaging stations were also established on 14 tributaries of the Kootenai. Subsequently a gaging station was established on the Kootenai River near the point where it enters Canada from the United States, and one was established at the boundary line on a tributary stream which rises in Canada and flows into the United States. The Canadian engineers previously and thereafter established a number of stations on the Kootenai River and tributaries in Canada. Measurements at the river stations were made weekly, and at the tributary stations fortnightly. Because of the very light slope, below Bonners Ferry, the velocities during low water were so small, about .3 foot per second, that it was necessary to reduce the friction in the meters by removing the penta mechanism. A special low-velocity meter was used for which the rating table had a longer interval than the standard 70-seconds limit. This meter served merely as a palliative

and out of the situation grew the movement for more sensitive meters.300/

300/ p. 100.

In computing the records it was necessary to use the method for variable slope. The creston project was not constructed immediately, and the investigations were continued on account of the proposed storage on Kootenai Lake.

In June 1929 the expected application for storage materialized and the Water Board of the Province of British Columbia held a hearing which was attended by C. G. Paulsen as an observer. It was evident that the proposed storage project would raise the water level of the Kootenai River in the United States and hence was an international matter. The application was made to the International Joint Commission on September 6, 1929, and the Commission held a hearing on November 6, 1929, at Bonners Ferry, Idaho, at which time it was contended that the proposed dam, in addition to raising the water level of the river itself, would raise the ground-water level under some 30,000 acres of adjacent overflow land in Idaho, the greater part of which was protected by dikes in nine reclamation districts. Further hearings were postponed to permit the United States interests to investigate the effects of the storage dam. At this hearing it appeared that plans for the storage project were much farther advanced than had been anticipated, and that it was necessary to revise the investigations to obtain additional data, particularly with respect to the inflow and outflow from the reclamation districts, and to the effects on the agricultural use of diked lands in Idaho that would be caused by the higher water levels to be expected in the Kootenai River.

To meet the new situation the Kootenai River program was enlarged in the following spring (1930) by the installation of 300 special test wells which were measured weekly thereafter. In addition, water-stage recorders were installed on two of the larger wells. The drainage of the lands in the reclamation districts, which had been increased from 9 to 13 in the meantime, was accomplished by pumping during high river stages; at low stages the drains discharged into the river by gravity. As it was necessary to record such seepage returns to the river, frequent measurements were made of them. When the seepage was pumped, records of the hours pumped and the rates of pumpage were kept, and the pumpage was checked by current meter measurements.

With the designation of international gaging stations in 1931,301/

301/ p. 154.

four stations on the Kootenai and two on boundary tributaries were included in that classification. That same year the Bureau of Agricultural Engineering was brought into the program to consider questions as to the relation of agricultural productivity to the position of the water table. Field data were collected and special studies were made largely by the Idaho district, with the advice of the Ground Water Division as to ground-water features. The investigation was generally supervised and coordinated by R. W. Davenport, Chief of the Water Utilization Division.

A hearing on the storage application was held by the International Joint Commission at Nelson, B. C., in August 1933, at which results of the investigations were presented by Messrs. Davenport, Newell, and Jessup (of the Bureau of Agricultural Engineering). Results of investigations were also presented by the Canadian Government and the applicant power company. At a subsequent hearing at Ottawa, Ont., the power company withdrew its application. The application was renewed in 1938 and in November of that year after further hearings the Commission issued an order authorizing the power company to store water as proposed. The order of approval included provision for increasing the capacity of Kootenai Lake outlet by removal of several hundred thousand cubic yards of rock at Grohman Narrows. This improvement was designed to reduce the river levels in Idaho substantially during flood periods.

After 1934, the investigation has been continued on a considerably reduced scope with view to meeting the international problems which are expected to arise in connection with further development of Kootenai Valley.

The annual allotments of State Department funds for the Kootenai River investigations were:

1929	$30,309	1933	$22,622	1937	$14,050
1930	23,500	1934	19,074	1938	12,000
1931	24,000	1935	16,021	1939	10,400
1932	21,002	1936	13,000		

Roseau River: For many years the drainage of the peat bogs of northern Minnesota had been carried on actively. Whenever heavy rain occurred there were floods in the streams of that region. This situation was particularly serious on the Roseau River which rises in Minnesota and after receiving two tributaries which rise in Canada, flows into Canada and empties into the Red River. To protect their lands from overflow, landowners in Canada proposed to construct dikes which it was feared would constrict the channel and aggravate flood conditions upstream in Minnesota. Informal protests were made to the International Joint Commission, and in June 1928 Mr. Grover and Mr. Davenport went to Winnipeg to confer with the Canadians and formulate questions for the Commission to decide.[302] It was evident that facts

302/ Statement of R. W. Davenport.

must be developed for the consideration of the Commission, and a program of investigation in Minnesota was arranged which included the obtaining of records of flow of the Roseau River and its tributaries, the slope of the river, a large scale topographic map of the basin, a detailed survey of the river channel to determine the work necessary to enlarge it, and borings in the channel to hard-pan to determine the cost of such work.

The State Department's appropriation of $75,000 for 1929 [303] had been

303/ p. 156.

increased sufficiently to provide for both the Roseau and the Kootenai investigations. At that time the small amount of stream-gaging in

Minnesota was being handled by the Madison office. For the intensive work contemplated, C. L. Batchelder was reinstated in the Survey in July 1928 and made his headquarters temporarily at Roseau. In September a separate district was created with headquarters at Thief River Falls, with Batchelder in charge. Mr. Davenport had general supervision over the Roseau River work. One station was being maintained on Roseau River near the International Boundary, and four more stations were established on the Roseau and three on tributaries. During 1932 and 1933, four additional stations were established on Roseau River at which stage observations only were made. The Topographic Branch made a large-scale map of the Roseau Basin and, under Batchelder's direction, a detailed map of about 50 miles of the Roseau River channel. In that connection Batchelder stated:304/

304/ Water Resources Bulletin, Nov. 10, 1929, p. 10.

> Although no one is anxious for winter to set in, yet it will be appreciated when the river freezes over so as to expedite cross-sectioning.

The soundings to determine the depth of the muck, which were an important part of the field work, were made by means of half-inch metal rods. A hole similar to a shallow post hole was dug and filled with water. A short length of pointed rod with a detachable handle was worked up and down and water added as necessary. By this means the rods were worked down to hardpan which was from 50 to 20 feet below the stream bed.305/

305/ Letter from Frank Stermitz to author.

While the Survey was carrying on this investigation, Canadian engineers, working independently, were doing similar work north of the boundary. In 1931 the station on the Roseau at the International Boundary and those on the two international tributaries were made international gaging stations.

The investigations along the northern border related to numerous schemes for flood control. Several reports were made to the International Joint Commission showing the results of the studies. Because of the freedom from serious floods during the thirties there was little popular pressure for the solution of the international flood problems and nothing tangible resulted at that time. However, the data collected by the Geological Survey have been utilized by the Army Engineers in connection with their studies of flood control in the region.

Among the investigations that had to do with international problems, present and prospective, was one involving the utilization of the waters of Souris River in North Dakota, Saskatchewan, and Manitoba; another involved the determination of natural flow conditions of Columbia River in the vicinity of the international boundary in connection with the possible prospective backwater from the Grand Coulee Dam; and still another involved similar problems with respect to Skagit River.

The annual allotments of State Department funds for use in Minnesota and North Dakota were:

1929	$ 9,838 1/	1933	$10,400	1937	$11,550
1930	10,000	1934	8,500	1938	11,000
1931	12,602 1/	1935	10,500	1939	8,000
1932	9,469	1936	12,000		

1/ Expenditures.

Upper Columbia River Basin: The informal agreement made in 1916, 306/ whereby the Canadian engineers would operate the station on the

306/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 351.

Columbia River near Trail, B. C., and the Survey would operate the station on the Pend d'Oreille River near Metaline Falls, Wash., and the records would be exchanged, was in effect at the beginning of the period. In the fiscal year 1929 State Department funds became available for the maintenance of stations on international streams and the station on the Pend d'Oreille River was moved to a better site below Z Canyon, and two additional stations were established. During the next fiscal year two more stations were installed, making a total of five stations maintained by the Survey. Of the 17 stations on the boundary streams west of the Rocky Mountains which were designated as international gaging stations in 1931, 307/ 11 were in the upper Columbia River

307/ p. 155.

Basin, 6 being in British Columbia, operated chiefly by Canadian engineers, and the 5 described above, in Washington operated by the Geological Survey.

In 1937, the gaging station on the Columbia River at Trail, B. C., which had been jointly operated since 1916, was moved 7 miles upstream to a better site at Birchbank, B. C. The Dominion Water Power and Hydrometric Bureau installed a recorder in a standard Survey concrete shelter equipped with four intakes and having an overall height of 63 feet, and installed a cable of 1,038-foot span. The total cost was about $12,000. As the Grand Coulee Dam when completed would cause backwater at the International Boundary, and as Birchbank was 17 miles upstream, the International Joint Commission desired a station at the Boundary in order to determine the amount of such backwater. The Survey accordingly established a station there in 1939. As the Bureau of Reclamation was greatly interested in the record to be obtained from that station, it paid for the cableway. 308/

308/ p. 83.

Annual expenditures or allotment from State Department funds were:

1929	$ 6,627	1933	$4,672	1937	$5,400
1930	11,999	1934	4,200	1938	5,500
1931	5,649	1935	4,700	1939	14,200
1932	5,800	1936	5,500		

International Boundary Commission.- The International Boundary Commission, United States and Mexico, unlike the International Joint Commission which acts as one body, consisted of an American Commissioner

and a Mexican Commissioner, each with his own organization. The gaging stations were not jointly operated except in one instance, but were divided between the American and Mexican sections by mutual agreement. The Survey operated those assigned to the American section.309/

309/ p. 225.

At the end of the previous period, in 1928, State Department funds were provided for an enlarged program which was started in 1928. This program provided not only for the continuation of the Langtry, Del Rio, and Eagle Pass stations on the Rio Grande, and Del Rio station on Del Rio, but also for taking over (a) from the Bureau of Reclamation the stations on the Rio Grande at San Marcial, near El Paso, and at Tornillo Bridge near Fabens, (b) from the State engineer of Colorado the station on the Rio Grande below Fort Quitman, (c) from the Mexican Section the station on the Rio Grande at Roma, and (d) from the Texas district of the Survey the station on the Pecos River near Comstock, and also for the establishment of additional stations on the Rio Grande at Boquillas, the Rio Grande at Hidalgo, Pinto Creek near Del Rio, and Goodenough Spring which enters the Pecos below the Comstock station. For the operation of these stations resident engineers were stationed at San Marcial, El Paso, Boquillas, Del Rio, and McAllen (Hidalgo), beginning in the fall of 1928. Recorders were installed at the Langtry, Del Rio, Roma, and Eagle Pass stations, and a cable was installed at the latter station.

Of the new stations, that at Boquillas was located in the Big Bend area, an uninhabited region about 90 miles from the railroad, reached by a road which Ellsworth describes as "terrible."310/ Added to the

310/ Statement to author.

anticipated difficulty in finding a suitable site was evidence that the extreme range in stage of the Rio Grande in that general region was 100 feet.311/ However, this was evidently an exaggeration as a site was found

311/ Water Resources Bulletin, Mar. 10, 1928, p. 12.

where a 40-foot corrugated-iron well with a timber house attached to the canyon wall was sufficient. A cable was also erected. Recorders in corrugated-iron wells were installed at the Hidalgo, Pinto Creek, and Goodenough Spring stations.

The station on the Rio Grande below Presidio was operated in co-operation with the Mexican section, which had its own equipment. Occasional measurements were made at the Mexican section's Laredo station for the purpose of giving the Mexican engineers the benefit of the Survey's experience in making measurements. Several canals in the lower Rio Grande Valley were also measured. Along the lower Rio Grande the summers were hot and in the Big Bend area the temperature was well above 100 degrees in the shade all summer long. Most of the main river stations were at international bridges and it was necessary for the engineers to show their identification cards whenever they crossed to the Mexican side.

The Rio Grande is subject to sharp floods, and during one of these

a Survey engineer spent the night on the roof of the Harvey House at San Marcial. His automobile was buried so deeply in the mud deposited by the flood that the cost of digging it out and rehabilitating it was $150.[312]

312/ Statement of C. E. Ellsworth to author.

Cooperation continued until August 1931, when the American Commissioner, L M. Lawson, decided to operate the American section's stations with his own organization. He evidently believed that the cordial relations existing between himself and the Mexican Commissioner would be further strengthened if the American stations were operated directly by the American section, which would be in closer touch with the actual work. As a former project manager of the Rio Grande project of the Bureau of Reclamation, Lawson had been accustomed to operating gaging stations with his own organization.

The annual allotments of State Department funds during the cooperative period were:

1929	$18,440	1931	$18,440
1930	18,440	1932	2,131

Gaging stations on the Lower Mississippi River[313]

313/ Stations in the vicinity of St. Louis below the mouth of the Ohio River are described under Summary of operations for the Rolla, Mo. district.

During the previous period the Survey had begun a comprehensive stream-gaging program on the lower Colorado River,[314] and by so doing

314/ pp. 104-110, 1919-1928.

had extended its investigations to all the principal streams of the country except the Ohio River and the lower Mississippi River--the largest river in the United States and the fourth in size of the world, being exceeded by the Amazon, Congo, and LaPlata in that order. The cost of installing and operating stations on such large streams with the special measuring equipment needed, had been beyond the previous slender resources of the Survey.

The Army Engineers and Weather Bureau were recording daily gage heights at various points on the lower Mississippi River. Although the Army Engineers and the Mississippi River Commission were making low-water measurements in the interest of navigation, and flood measurements in the interest of flood protection, systematic measurements were not being made, and daily discharges throughout the year were not being computed. The "308" investigations started in 1928 showed, however, the need for records of daily discharge at various points and the Army Engineers and the Mississippi River Commission began to make more frequent discharge measurements and to compute daily discharges. The measurements were made from a boat by means of two large Price meters supported on a rod 1 foot apart horizontally held near .6 depth, or by means of floats. Soundings were made by a sounding lead in a manner similar to that used by ships when approaching shallow water. Positions in the cross-section were determined by sextant readings

from the boat to range poles.

The beginning of the Survey's work on the lower Mississippi River was made possible by the allotment of funds for Federal-type stations, and was brought about by the opportunity of installing a recorder at relatively small expense in a hollow pier of the Vicksburg bridge which was opened to traffic about May 1, 1930. Three years later, during the summer of 1933, the Mississippi Valley Committee[315] was studying

315/ p. 74.

proposed projects on the Mississippi River and decided that two additional stations were needed, one nearer the mouth of the Ohio than Vicksburg, and one near New Orleans. The Committee obtained a PWA grant to the Survey for the installation of the two stations.

Vicksburg, Miss.- The completion in 1930 of a combined railroad and highway bridge across the Mississippi River 3 miles below Vicksburg afforded the Survey an opportunity to determine whether its standard type of gaging stations, with measurements from a bridge, was suitable for the lower Mississippi River, where depths of 100 feet or more, and velocities of 12 feet or more per second, would be encountered at flood stage and where the bridge is about 100 feet above ordinary stage. McCashin, whose district included the State of Mississippi, was instructed to contact the Army Engineers with a view to possible cooperation. At that time the Army Engineers were making discharge measurements from a boat in their customary manner and stated that they did not believe satisfactory bridge measurements could be made, particularly as it would be impossible to remove the meter from the water in time to escape drift during flood stage. However, McCashin was convinced that with special equipment, such measurements could be made, and recommended the establishment of the station.

The hollow bridge piers 120 feet high were capped with concrete 31 feet thick and the bridge company gave permission to the Survey to cast a 3-foot well through this cap and erect a shelter on top of the pier. This was done chiefly at Survey expense.[316] The well was connected

316/ Letter from C. E. McCashin to author.

with the river by three inclined intakes making an angle of 30 degrees with the vertical. Regarding this unusual arrangement, McCashin writes:[317]

317/ Op. cit.

> The intake pipes being inclined 30 degrees with the vertical were my idea in order to make them self-cleaning. This 30-degree angle was selected for the same reason that I had previously selected that angle for the sides of the cones on pipe wells. * * * Moderately wet concrete would always slide in a chute if the angle was not greater than 30 degrees with the vertical. I figured that silt would slide on the same angle, especially where the water entering the cavity was confined only to the intake openings.

As a further precaution against silt troubles, several 6-inch capped pipe openings were installed horizontally and of such design that Army Engineer dredge-boat pumps could be connected with the pipes and suction hose used to remove silt. As yet (1940) this has not been necessary as very little silt has accumulated in the well. A water-stage recorder was installed April 19, 1930, and records of stage started. Discharge measurements were not made, however, until July 13, 1931, when specially designed power equipment for handling the meter and 200- and 300-pound weights were available.[318] It had

318/ p. 119.

been thought that the rating curve developed from the discharge measurements could be used later in computing the daily discharge for the period beginning with the installation of the recorder.[319]

319/ Letter from E. B. Rice to author.

A resident engineer, with the help of a laborer to watch the angle measuring device and detect drift, made an average of three measurements a week. At bank-full stage the width is 2,830 feet, and at flood stage, as much as 8,200 feet. Vicksburg is in the tornado belt and a high bridge like that at Vicksburg is particularly exposed to the full force of the tornado. In the spring of 1933, C. H. Prior and helper were making a measurement with the special equipment and 200-pound weight and observed a storm approaching. As it was not customary to stop for "rain squalls" work was continued, but the wind reached such a high velocity that it overturned the self-propelling reel and boom, and the two men were compelled to lie flat on the pavement in lee of the guardrail.

During the 1937 flood the Mississippi River Commission, which by that time was using the Survey's Vicksburg records, requested the Survey to make daily measurements of the Mississippi at Vicksburg, and of the Atchafalaya River at Krotz Springs, La. S. C. Moore who made the measurements at Vicksburg, stated that the total of his daily discharge measurements during February was about 50,000,000 second-feet. The maximum measured discharge was 2,080,000 second-feet. The maximum depth was 107 feet and the maximum mean velocity in any vertical was 10 feet per second. Three engineers and two helpers were employed, two engineers operated the reel and boom with the 300-pound weight and the helpers watched for drift. So heavy was the drift on the rising stage that at times it was necessary to wait as long as 15 minutes for the stream of drift to pass. Forty-five sections were used in the main channel and 33 in the overflow channel. In the latter the velocity was about 0.9 foot per second and the measurement was made by the third engineer who made the observations at the 33 sections in the overflow area. About 7 hours were required for each flood measurement. This station was operated by the Montgomery office.

These daily measurements during the flood showed the value of the station, and thereafter the Mississippi River Commission paid half the cost of maintaining it. The Army Engineers continued to make boat measurements and subsequently adopted the small Price meter but retained the mechanical counter.

The two-table method, first devised by the Survey in connection with the stations on the lower Colorado River[320], was used in making

320/ p. 77, 1919-1928.

soundings and setting the meter at the desired depths. As the depths were much greater than those measured previously, and the angles greater, G. C. Stevens extended the two tables to cover depths as great as 150 feet and angles as great as 50 degrees. The Army Engineers were not convinced that these great extensions of the tables would give correct results, and tested the results from those extensions at one of their stations in Arkansas, by comparisons with results obtained by using 700 pounds of weight to eliminate the angle corrections. The Survey was naturally interested in these tests, and had an observer who reported that the correctness of the table extensions was proven.[321]

321/ Letter from C. E. McCashin to author.

Memphis, Tenn.- When the PWA grant was available in the fall of 1933, C. G. Paulsen and others, made a reconnaissance of the river between the mouth of the Ohio River and Helena, Ark. The Army Engineers were maintaining staff gages at Columbus, Ky., just below the Ohio, and at Helena, and had made sufficient discharge measurements by means of boats to enable them to publish records of daily discharge at both stations since January 1, 1928. The Survey would have preferred ro install recorders at either of those sites, but as there was no bridge at either, boat equipment would have been required. This equipment would have been expensive not only to purchase but also to operate, as a crew of several men would have been needed. The operation of the Vicksburg station had shown the feasibility of maintaining bridge stations on the lower Mississippi River, and it was decided to establish a gaging station at Memphis and make the measurements from one of the two bridges at that city. The Army Engineers and Weather Bureau had maintained since 1871 a daily record of stage by means of a staff gage at Beale Street. As extensive changes to the river bank in that vicinity were being made by the city, a recorder site was selected between the two bridges which were 200 feet apart, and in line with the piers of the two bridges, where there was protection from drift during floods.[322]

322/ Letter from J. L. Saunders to author.

Construction by the caisson method of a concrete structure having a cross-section 6 feet square and an overall height of 66 feet was started in February 1934 by the Chattanooga office. The work was halted by high water and resumed in June and completed in the late summer. The well was equipped with four 2½-inch intakes, three of which were connected with the city water system for flushing. The total cost was about $5,500. As measurements were started on April 16, before the completion of the shelter, the Weather Bureau staff gage was used until December 21, 1934, when the recorder was installed. One of the few instances noted when an engineer did not use his head occurred during the construction of the outside gage. This gage was to be equipped with the Weather Bureau type of numerals at the foot marks to permit passing boats to read the stage. The required numerals were

packed by the St. Louis office and shipped to the engineer. As soon as they were received the aforesaid engineer frantically telegraphed that he had too many nines, but no sixes. The reply he received was to turn the nines upside down.323/ The St. Louis office had been given the

323/ Letter from F. M. Bell to author.

task of constructing and operating the station as a Federal-type station. For administrative reasons the station was transferred to the Fort Smith office in 1935.

Unlike the situation at Vicksburg, the width of truck used was not limited, and a specially designed self-propelling reel and boom was used for operating the meter and weight which varied with the stage from 100 to 300 pounds. An engineer was stationed at Memphis to make several measurements a week, with a helper to watch for drift and river traffic. The river is 2,100 feet wide at bank-full stage. During the 1937 flood, the width of the main channel was 4,700 feet and that of three relief openings was 4,430 feet. At that time, vertical angles of 45 degrees were observed while using a 300-pound weight, maximum depths were 135 feet, and maximum velocities were 13 feet per second.

About the time the Survey established the Memphis station, the Army Engineers began to make almost daily measurements by means of a launch. As a matter of interest, a description of the Army-Engineer procedure in measuring the Mississippi River during the 1937 flood has been obtained from J. C. Cannon, a civilian engineer of the War Department who assisted in the measurements at Hickman, Ky. A launch equipped with derricks for handling the weights was manned by a crew of five, one being an expert boatman whose duty it was to keep the launch in position on the range line, the exact location being determined by sextant readings on established markers on the bank. Two leadsmen were used who took turns in measuring the depths, which were in excess of 100 feet, by means of 24-pound weights on sounding lines. After the depth was determined, two large Price meters on separate cables, placed a few feet apart horizontally, were lowered by means of derrick and winch and held at the 0.6 depth by 150-pound Columbus-type weights. The use of two meters was deemed necessary as the revolutions were mechanically recorder by "counters," and with no audible sounds it was not easy to detect stoppage of the meter or counter, which sometimes occurred. Velocity determinations were made for periods of 100 seconds. At Hickman, the section was about 1 mile wide, and observations were made at average distances of about 75 feet across the stream, the distance depending on variations in depth.

New Orleans, La.- The Mississippi Valley Committee's need for a station near New Orleans related to river stages in a study of the protection of New Orleans from floods, and of the effect of the Bonnet Carre spillway, one of the main features of the plan to protect the city.

The recently constructed Huey P. Long Bridge 5 miles above New Orleans and 121 miles from the mouth of the river afforded a suitable site for a recorder installation. In 1934 arrangements were made to have a concrete well and shelter cast on the side of one of the piers. As the range of stage is about 30 feet, a high structure was not required. Inclined intakes somewhat similar to those used at Vicksburg

were placed in the well, and although not equipped with a flushing device, they have been fairly satisfactory in keeping silt out of the well. As the piers are 150 feet high, the bridge engineers objected to the use of a ladder of that length for reaching the station, and it is necessary to use a boat for that purpose. The datum of the gage is mean Gulf level. The station was placed in operation November 22, 1934. The tide which has a range of about 2 feet at the site, prevented the obtaining of a record of discharge, even with several measurements a week.324/

324/ Letter from E. B. Rice to author.

Gaging stations on the Ohio River

The Ohio River was not included in the Survey's field of operations prior to the present period except for the maintenance of a station at Wheeling, W. Va., during 1905-6. The Ohio is one of the most important rivers in the country from the viewpoint of navigation, and the Army Engineers had collected such records as they considered necessary for their operations.

By 1933, however, the picture changed, as the Mississippi Valley Committee in its study of water problems in the Mississippi Valley found that gaging stations at which daily discharges would be obtained were needed on the Ohio. To make it possible for the Survey to establish such stations the Committee recommended a PWA allotment which was granted.325/ It was necessary to operate these gaging stations as slope

325/ p. 71.

stations with two gages each because navigation dams caused variable slopes during periods of low water, and floods on the Mississippi caused serious backwater in the lower reaches of the Ohio. As the Ohio, except at its upper end, has a range in stage of 50 feet or more, the installation of recorders involved structures of at least that height in order to put the recorders above flood stages.

The first station was installed, however, by use of Army-Engineer funds, and not by the PWA grant. The Army Engineers had recorded staff-gage readings made just below the mouth of the Tennessee River at Paducah, Ky., since 1874, and in January 1934 funds were furnished by them for installing a recorder and operating the station by the Survey. During the next two years a study was made for gage sites that would yield the best possible slope determinations; recorders were tried at six different sites and staff gages at three sites. Permanent sites for the gages were finally selected in 1936, and the installations were made with recorders set well above previous flood levels. PWA funds were used for these installations. One recorder was installed in a concrete shelter having an overall height of 59 feet half a mile above Dam 53, 18.2 miles above the mouth of the Ohio. The concrete shelter was equipped with two intakes, one 125 feet long and the other 135 feet long. A standard flush tank of 47 gallons capacity filled by means of a pump in the well was used to flush the intakes.326/ The second

326/ Letter from J. V. B. Wells to author.

recorder was installed in an 18-inch spiral welded pipe well, 68 feet high, on a pier of the Metropolis railroad bridge 18 miles upstream from Dam 53.[327] The fall in this 18-mile reach varies from 0.25 foot

327/ Veatch, F. M., Measuring discharges of the Ohio River at Metropolis, Ill., during the flood of January-February 1937; Min. Conference of Dist. Engineers, Oct. 24-29, 1938.

to 8.5 feet. It may be noted that with that range in slope, the discharge for a given gage height might vary from 40,000 to 200,000 second-feet.[328] The record-breaking 1937 flood washed away the Metropolis

328/ Statement of R. D. Schmickle.

installation and submerged the recorder at Dam 53. The Metropolis recorder was later replaced, and the shelter above Dam 53 raised 7 feet to allow the recorder to operate at a stage 4 feet higher than that of the 1937 flood.[329] Measurements were made from the Metropolis

329/ Letter from F. N. Hansen to author.

bridge of 3,500-foot span, exclusive of deck approach spans. The Metropolis station, including the two recorders, was operated by the St. Louis office until April 1938, when it was transferred to the newly-established Louisville district.

The next station was established in October 1933 at Sewickley, Pa., near the upper end of the Ohio. A concrete structure, having an overall height of 41 feet, was built 200 feet upstream from the highway bridge. The well was equipped with two intakes, 145 feet and 150 feet long, and a standard flush tank of 35 gallons capacity filled by means of a pump in the well was used to flush the intakes. Unlike the other Ohio River stations, the Sewickley station was not operated as a slope station because the fall between the station and Dashields Dam, a fixed crest navigation dam 1.5 miles downstream, was reasonably constant except at extremely high stages. The cost of the station which was installed and operated by the Harrisburg district, was about $3,900. Discharge measurements were made from the highway bridge except during extreme low stages when a boat was used.

The station at Huntington, W. Va., a few miles below the mouth of the Kanawha River, and in the middle third of the distance from Pittsburgh to the Mississippi, was constructed by the Columbus district and placed in operation in August 1934 by the South Charleston district. One recorder was installed at the Huntington Water Works in a concrete structure having an overall height of 72 feet of which 35 feet was underground. Two 3-inch intakes each about 120 feet long were provided. To flush these intakes the tops of the riser pipes of the standard flushing device had connections for a fire hose, and once a month the fire hose was connected and water flushed through the intakes for about 15 minutes.[330] A second recorder was placed 4.7 miles

330/ Letter from Wm. Kessler to author.

downstream at Dam 28 where the Army Engineers had obtained a gage-height record for 20 years. The concrete shelter was 81 feet high of which 47

feet was under ground. One 3-inch intake 140 feet long was provided and a tank of 60-gallons capacity was installed to flush it. The tank is connected with the water supply line at the back and is filled in about 25 minutes. Three fillings of the tank are required for complete flushing. Construction was accomplished by means of the open-caisson method.331/ The total cost of the two shelters was about $5,500. Discharge

331/ Water-Resources Bulletin, Apr. 10, 1934, p. 22.

measurements were made from the highway bridge. The slope in the 4.7 miles between the gages varies from .04 foot at pool stages to 2.7 feet at intermediate stages, and decreases to about 1.3 feet at extremely high stages. There is no definite relation between stage and fall as the latter depends on the type of rise and also upon the rate of rise or fall of the river.332/

332/ Letter from Wm. Kessler to author.

The Weather Bureau had maintained a staff gage at Evansville, Ind. for some 20 years, and when the PWA allotment for Weather Bureau stations was made,333/ that agency selected the Evansville station as one to

333/ p. 92.

be equipped with a recorder. In the fall of 1934 the Indianapolis office started construction by the open-caisson method of a concrete structure 55 feet high, of which 45 feet was underground. Unexpected difficulty in jacking through the intakes increased the cost greatly and delayed the work until high water when operations were suspended. At that time available funds were exhausted and the work was not resumed until 1936, when additional funds became available. The recorder was finally placed in operation in December 1936. The upper intake was 220 feet and the lower 240 feet long, and a flushing system connected with the city water supply was used. The cost of the station was about $9,000. Gage-height record obtained from the recorder was sufficient for the Weather Bureau, but the Survey desired to obtain daily discharges, and readings from the Army-Engineers' staff gage at Lock 48, 17.3 miles downstream were used to determine the variable slope. In this stretch the total fall varies from about .2 foot to 13 feet. After the establishment of the Louisville district, the operation of the Evansville station was transferred to it. As the Evansville station was primarily a flood-warning station, it was not operated during low-water periods. Therefore, it was not necessary to use the auxiliary gage readings in computing the records.

No additional stations were established by the Survey on the Ohio until 1938. The 1937 flood caused severe damages in the vicinity of Louisville, and in connection with plans for flood control, the Army Engineers had need for more adequate records at Louisville than had been obtained by readings from two staff gages and some discharge measurements started by that agency in 1935. When the Louisville district was established on April 18, 1938, a state-wide WPA program was set up for the installation of gaging stations. The Survey as sponsor for the Louisville work contributed about $10,000 of which $6,200 was furnished by the Army Engineers. Two recorders were installed, one at Louisville, and the other near Kosmosdale, 16 miles

downstream. Temporary staff gages were installed by the Army Engineers at those sites in September 1938 and construction work on the recorder installations was started in November. The Louisville structure had an overall height of 91 feet of which 41 feet was underground. It was equipped with one intake 130 feet long which was flushed by means of a standard flush tank placed at ground level and filled by a lift pump. The Kosmosdale structure had a height of 87 feet of which 37 feet was underground. It was equipped with two intakes, the upper 120 feet, and the lower 130 feet long. A standard flush tank connected with an outside water supply was installed to flush the intakes. Owing to the heavy ground-water flow which made the lowest material excavated at both sites an extremely fluid sand, it was necessary to substitute the pneumatic-caisson method for the open-caisson method which was first tried.334/ The work was performed by the WPA under the general supervision

334/ Water-Resources Bulletin, May 10, 1940, p. 83.

of the Louisville district. Because of the many difficulties experienced and the interruptions caused by high water, work was not completed on the Kosmosdale shelter until March 1940, and on the Louisville shelter until September 1940. The total cost of the Louisville shelter was about $35,000 and of the Kosmosdale shelter, about $20,000. The fall in the 16 miles between the gages varied from .2 foot at pool stage to 6 feet at high stages. Discharge measurements during low stages are made by boat either below Dam 41, or opposite the Louisville gage. At higher stages measurements are made from the Louisville municipal bridge 7.5 miles upstream.

The Army Engineers established stations at Cincinnati in December 1936 and at Golconda, Ill. in October 1937, each equipped with two staff gages. Under the cooperative agreement with the Army Engineers, that agency furnished the staff-gage records and made most of the discharge measurements at all Ohio River stations, and the Survey computed all records of daily discharge.

St. Louis Office

The expansion of the stream-gaging work on the Mississippi River and especially the establishment of stations on the lower river, involved the maintenance of stations in one river system by several Survey districts. The Army Engineers who used many of the resulting records, were making extensive studies in connection with navigation and flood-control problems, and for these studies they wanted consistency not only in the monthly but also in the daily records of discharge. The discharges dealt with were very much greater than those of streams heretofore measured and although the percentage of error of the records might not be greater, actual errors were greater, and adjustments were required in order to make the various records consistent.

The idea of a central office was apparently suggested by C. E. McCashin who had observed that results on the lower Mississippi River obtained by different agencies had shown serious inconsistencies requiring later revision of records. To prevent similar occurrences in future he suggested a central office whose chief function would be to coordinate the records for the stations in the Mississippi River

basin operated by the several Survey districts.

St. Louis was selected for the central office which was established early in March 1934. In announcing this action, the Washington office stated:335/

335/ Letter of Feb. 23, 1934.

> * * * establishing a Survey office in St. Louis, Mo. * * * primarily for the two purposes of aiding the present district offices in coordinating the river measurement program and the records collected at the (Federal-type) base stations on the Mississippi River and its principal tributaries and of creating a Survey agency in the basin to which the interested parties will look for all such unpublished records.

F. M. Veatch was placed in direct charge of the office, under H. C. Beckman's general supervision. Veatch continued in charge until April 1938 when he was transferred to the position of district engineer of the newly-established Louisville, Ky. district. He was succeeded at St. Louis by R. D. Schmickle. The St. Louis office was financed by Federal-station and Army-Engineer funds.

When the St. Louis office was established, the Survey was maintaining through five districts, eleven stations on the Mississippi River from St. Paul, Minn. to Vicksburg, Miss., and the records for these 11 stations were to be analyzed and coordinated by the St. Louis office. The general plan was to add to the record at a station the measured inflow between it and the next station downstream, and the unmeasured flow estimated by means of unit run-off per square mile applied to its drainage area. This total was then compared with the record at the lower station. These comparisons were made for the entire year, and then successively for the low-water period of fall and winter, the high-water period of spring and early summer, and the low-water period of late summer. Discrepancies were further studied by means of hydrographs of daily discharge at the gaging stations. The periods of discordant records were called to the attention of the districts furnishing the records, and by means of additional study, the records were revised.336/

336/ Beckman, H. C., The coordination of discharge records of the Mississippi and Missouri Rivers: Minutes of Conference of district engineers, Oct. 24-29, 1938, pp. 179-180.

For the purpose of keeping on file in St. Louis information relative to unpublished records, those districts that maintained gaging stations in the Mississippi River Basin, a goodly portion of the United States, furnished at 6-month intervals list of stations that were being maintained. Another duty of the St. Louis office was the coordination of requests from the various districts for additional Federal-type stations.

In addition to the duties described, the St. Louis office operated the stations on the Mississippi at Alton, Ill., St. Louis and Cape Girardeau, Mo., and a station on the Kaskaskia River at Carlyle, Ill. The latter was an old station reestablished for the Army Engineers in connection with their Carlyle project. The Army Engineers desired

frequent measurements and as Carlyle is much nearer to St. Louis than to Urbana, the station was operated by the former office. It was the only Army-Engineer station in Illinois.

Beginning in March 1938, the Army Engineer office in St. Louis required daily information whenever the flow at any of the 11 stations on the principal tributaries above the Ohio exceeded 1,000 second-feet. The observers phoned or wired the stages to the Survey office where the discharges were computed and furnished the Army Engineers for use in forecasting flows in the middle and lower reaches of the Mississippi River.

The St. Louis office can probably substantiate the claim that it has measured the largest volume of water that has been measured under complete ice cover. On February 21, 1936, a measurement of the Mississippi River at St. Louis was made under an ice cover 1 foot thick. Eighteen sections were used in a width of 1,340 feet and the discharge found to be 50,500 second-feet. Messrs. Veatch, Bell, and Schmickle made the measurement in 4 hours. Subsequently, the latter two made 4 other ice measurements.

An incident worthy of note occurred during the latter part of the period. R. D. Goodrich, Jr., while measuring the Mississippi River at Alton from a steel boat equipped with outboard motor, suddenly found himself in the water as the boat had been struck and sunk. Grabbing the meter case with tools, the only article of value he could reach, he started to swim for the shore, 200 feet distant. In order to make the last 50 feet, he was obliged to drop the meter case, and on finally reaching the shore, apologized for not being able to save the meter case.

The personnel of the St. Louis office were:

F. M. Veatch	Mar. 6, 1934 to Apr. 18, 1938
F. M. Bell	Mar. 1, 1934 to Feb. 24, 1937
C. J. Eyberg	July 2, 1934 to Nov. 18, 1935
F. S. Anderson	Nov. 6, 1934 to Nov. 13, 1935
R. D. Schmickle	Feb. 1, 1935 to June 30, 1939
R. D. Goodrich, Jr.	Oct. 16, 1936 to Sept. 21, 1937
F. N. Hansen	Apr. 21, 1937 to Apr. 1, 1938
E. R. Leeson	July 1, 1937 to Mar. 3, 1938
A. L. Reed	June 22, 1937 to Apr. 11, 1938
John Herndon, Jr.	July 26, 1937 to Nov. 1937
J. C. Berkenbosch	Jan. 26, 1938 to Apr. 3, 1939
Milburn Hassler	Aug. 1, 1938 to June 30, 1939
G. A. LaRocque, Jr.	Aug. 15, 1937 to Nov. 1, 1937

The Columbia River at The Dalles

With the beginning of the "308" investigations, the long-time records of the Columbia River at The Dalles[337] assumed added importance. From

337/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, pp. 281-283.

1907 to 1927, 32 current-meter discharge measurements of the Columbia River had been made and referred to the gage at The Dalles. Low-water

measurements were made from boats at The Dalles, medium and high-water measurements to 750,000 second-feet, from bridges 24 and 100 miles downstream and 138 miles upstream, corrections having been made for intervening inflow. The low-water slope at The Dalles was so small, 4 feet in 40 miles, that the effect of changing stage on the discharge was significant. The Weather Bureau was collecting daily gage-height records.

To check and improve the accuracy of the discharge records that were being obtained by use of a rating curve based on the measurements made prior to 1927, the Army Engineers desired that regular measurements be made near the gage at all stages. They suggested that low-water measurements be made from boat at The Dalles and higher measurements from boat held by a line about 250 feet from the bridge at Hood River, 24 miles downstream. However, willing to be shown, Capt. Copeland accompanied G. H. Canfield and G. L. Parker on a reconnaissance trip in September 1928. Because of an excellent section for measurements at any stage, the Survey engineers recommended the erection of a 1,250-foot gaging cable supported by steel towers half a mile downstream from the gage at The Dalles. The Army Engineers were not convinced of the economy and desirability of the proposed cable, but authorized the making of surveys, estimates, and application for permit for proposed overhead crossing of a navigable river. In September 1929, Col. G. R. Lukesh authorized an allotment to the Survey for the cableway which was completed in the spring of 1930 at a cost of about $7,000. To meet the War Department's requirement for clearance on this navigable stream, the center of the unloaded cableway of 1,237 feet clear span had to be 75 feet above low water, requiring steel towers 54 feet high to saddle supports of cableway. The cableway was completed on May 6, 1930. The War Department permit required that an Airways red obstruction beacon be mounted on each tower and four 100-watt white lights be suspended above the main cableway, all lights to be flashing 60 times per minute. The lights were operated by a mercury contact sign-flasher and an astronomical dial time switch which turned the lights on at sunset and off at sunrise.338/

338/ Water Resources Bulletin, May 10, 1930, p. 20.

The life of The Dalles cableway, although a useful one in checking and slightly revising rating between 50,000 and 700,000 second-feet, was only about 3 years, as it was wrecked on June 17, 1933, during a period of unusually high water. An unloaded steamer bound downstream struck the cableway with the top of its towing mast which was reinforced four ways with heavy diagonal steel rods. Both steel towers were overturned and the cableway pulled into the river. Towers and cables were a total loss.

In the meantime the Bonneville Project had been authorized, which contemplated the use of the Columbia River by ocean-going vessels as far upstream as The Dalles. As such navigation would require a clearance of 125 feet or more with correspondingly high towers, and as low-water stage would be increased 27 feet resulting in very sluggish current, The Dalles site was not considered for a new cableway.

Since 1916, the Army Engineers had obtained systematic readings of stage at its gage at the head of Celilo Canal just above Celilo Falls, 11 miles above The Dalles. As the control for this gage was

the head of the Celilo Falls rapids, the stage-discharge relation was not affected by changing stage, nor by ice. The Celilo Falls gage appeared to have a permanent control where a more satisfactory record could be obtained than at The Dalles, after the construction of the Bonneville Dam which was begun in the fall of 1933. The Army Engineers desired as accurate a record as possible of the inflow into the Bonneville Reservoir. Accordingly, funds were provided for the installation of a water-stage recorder above Celilo Falls, which began operation in May 1935. That agency provided funds also for recorders on the principal tributaries between Celilo and Bonneville. The best measuring site for rating the Celilo Falls gage was 9 miles upstream between Grant, Oreg., and Maryhill, Wash., where a cableway with clear span of 1,727 feet was required, a longer span than any previously installed by the Survey. By study, it was found that the formulae previously used to determine the amount of change in sag with varying conditions of temperature and load gave inconsistent results. An original analysis of the problem was, therefore, made by the Portland district.339/

339/ Water-Resources Bulletin, Dec. 10, 1935, p. 33.

Funds for the cableway were allotted by the Army Engineers, and erection was completed in the fall of 1936. As the 1894 flood had submerged the tower site on the Oregon side to a depth of 11 feet, concrete piers extending 13 feet above the ground were constructed for supports of a steel tower which would thus be set above flood stages. On each bank, square steel towers 100 feet high were erected which provived 80-foot navigation clearance of unloaded cableway at low water, as required by permit of the War Department.

Galvanized improved plow steel tramway cable 1-3/8 inches in diameter was used, from which was suspended a Columbus-type duralumin car. To comply with air traffic regulations, the steel towers were painted in alternate bands of white and international orange, and on each tower were placed five airway obstruction lights with red globes. At The Dalles, electric service for the lights had been furnished by a public utility, but at the Maryhill cableway commercial service was not available, so it was necessary to install a gasoline-electric plant in a small power house built near the Oregon end of the cable. A storehouse with small living quarters for use of engineers while working there was erected nearby. The cost of cableway and accessories was about $17,000.

The cable car was hand operated, and as the loaded sag, with two engineers and equipment, including a 100-pound weight in the car, was about 46 feet, the effort required to pull the car toward either support was conservatively stated to be very considerable. Survey ingenuity reduced the effort by means of a gravity pull-back consisting of a concrete block supported by a sheave which moves along a separate cable from top of tower to deadman back of the main cable anchorage. A light cable 200 feet long is attached at one end to a concrete block, passes through sheave at top of tower; the other end may be attached to car on main cableway. This block is disconnected from the car at a point 200 feet from the tower on the descent, and picked up at that point on the return.340/

340/ Water-Resources Bulletin, May 10, 1938, p. 150.

At certain seasons of the year, possible all seasons, a strong wind blows during the daytime, the effect of which on water surface and on the cable car in mid span is so great that accurate measurements cannot be made. The author can vouch for the velocity of the wind as at the time of his visit to the station in May 1937 the wind was so strong that it was difficult to stand against it on the ground. As the wind does not attain its full force until some time during the forenoon, it is customary to start the measurement from the cableway at dawn in order to finish by the middle of the forenoon. On such occasions the engineers stay over night in the living quarters in the storehouse. The time required for two men to make a complete 0.2 and 0.8 depth discharge measurement varies from 3½ hours for a discharge of less than 100,000 second-feet to 8 hours for a discharge of 600,000 second-feet. For the longer measurements the men take drinking water and food with them in the cable car.

Accuracy of stream-gaging records

Having described the development of stream-gaging methods during the 50 years covered by this history, it is appropriate to discuss the accuracy of the methods as determined by comparing the results with those obtained by other methods recognized as having a high degree of accuracy.

Although the volumetric method gives the most accurate results, this method can generally be used for very small quantities only, and is unsuited for practical comparisons. However, the Albany district, about 1939, began the volumetric measurement of low discharges at its gaging station on the Mongaup River near Mongaup. The control is a weir, and at low stages the flow at from 20 to 25 points along the crest is deflected into containers of 2 cubic feet capacity by means of special troughs .17 and .33 foot in width, respectively, and the time of filling recorded. The river discharges thus determined, when compared with the station rating curve based on current-meter measurements, showed deviations ranging from -3.7 to +3.3 per cent for volumes between 17 and 106 second-feet.341/

341/ Water Resources Bulletin, Feb. 10, 1944, p. 58.

In general, other methods must be used for practical comparisons. One of the most accurate methods of measuring water, is by means of a standard sharp-crested weir. The Survey's first determination of the accuracy of a current-meter measurement was made in 1902, by E. C. Murphy at the Cornell hydraulic laboratory canal, having a capacity in excess of 200 second-feet. These tests showed that the small Price meter gave results well within 2 per cent of those by the weir, and in some series within 1 per cent.342/

342/ Water-Supply Paper 95, p. 98.

In 1923, the Portland district began the comparison of its records on the Hood River near Hood River, Oreg., with the Pacific Power and Light Co's. records of flow through its conduit and penstock, based on pitometer measurements, and, later, on the manometer readings of a Venturi meter. During the first few years the discharge measured by current-meter was about 8 per cent less than that indicated by pitometer, but in later years the current-meter measurements have generally

checked Venturi meter discharge within 5 per cent, the plus and minus deviations being about equally divided.[343]

[343] Letter from G. H. Canfield to author.

Three accurate methods, the salt-titration,[344], the Allen salt-velocity,[345], and the Gibson,[346], have been devised to determine the flow

[344] Water-Supply Paper 888, p. 89.
[345] Water-Supply Paper 888, p. 88.
[346] Grover, N. C., and Harrington, A. W.; Stream flow: John Wiley & Sons, Inc., N. Y., p. 104, 1943.

through penstocks, and comparisons have been made with each method. In 1926, the Tacoma district participated in the determination by the Gibson method of the flow through two power plants of the Washington Water Power Co. and compared the results of those tests with the corresponding records at the Survey gaging stations located a mile or more below the power plants. The comparison between the Survey and power plant records showed that the Survey records were about 3 per cent larger. However, as both gaging stations were a mile or more below the power plants, unmeasured inflow was estimated to account for at least one-third of the difference.[347] In December 1934, the Madison district made a

[347] Letter from G. L. Parker to author.

comparison between meter measurements and records at the Ford power plant on the Mississippi River at St. Paul, computed by the salt-velocity method. In this comparison the flow was varied to cover the range of use, and the resulting rating curves based on the two methods crossed each other and at no point were more than 2 per cent apart.[348] In 1939,

[348] News Letter, Feb. 10, 1925.

the Albany district compared the results obtained by the station rating curve with those obtained by the salt-velocity method, at the Rio power plant of the Rockland Light and Power Co., and found that the deviation between the two ranged from +6.7 to -10.2 per cent, the deviation for 37 of the 46 comparisons presented being within ± 5 per cent.[349]

[349] Water Resources Bulletin, Aug. 10, 1940, pp. 150-151.

The foregoing comparisons have dealt with single measurements or series of measurements, but a more severe test is made by a comparison of daily or monthly discharges computed by the standard Survey methods, and those computed at power plants. Such comparisons not only test the accuracy of meter measurements, but also that of the stage-discharge relation, and that of the recorder charts. The results of three such comparisons are available, the first covering an 18-month period in 1928 and 1929. The Washington Water Power Co. had a power plant at each end of a 15-mile stretch of the Spokane River near Spokane. Records at each plant were computed by the Gibson method, and although there was no surface inflow, an increase of some 500 second-feet was indicated at the lower plant. The Tacoma district was called upon to establish and maintain a station near each plant, and make

measurements at more than the usual number of points, spaced both vertically and horizontally, at the measuring section at each station. The resulting records checked those at the power plants within 1½ per cent.350/

350/ Statement of G. L. Parker to author.

The longest comparison covers the period from August 1932 to September 1942, and is between the records of the Albany district's station on the Sacandaga River at Conklingville, and the record computed by the Gibson method at the E. J. West power plant at Conklingville dam. The agreement was generally well within 5 per cent, the range of deviation being from -7.6 per cent to +5.6 per cent. The agreement between the yearly mean values was closer, with a range of from -3.7 per cent to +0.4 per cent. The mean deviation of the power plant records from those of the Survey for the entire period amounted to -1.2 per cent.351/

351/ Letter from F. F. LeFever to author.

During June and July 1925, the Northern States Power Co. rated the flow through its St. Croix Falls, Wisc. plant by means of the salt-titration method and subsequently computed the flow. In 1940, the Madison district installed a gaging station a short distance below the power plant. A comparison between the power house and Survey records for the period April 1940 to September 1943 shows an agreement well within 5 per cent. Below 2,000 second-feet the Survey records were larger, but above that value the power plant records were larger.352/

352/ Letter from F. C. Christopherson to author.

Summary of district operations

Previously, the various districts were designated by the names of the States comprising them, but in the present period they came to be designated by the names of the cities in which the district offices were located. The only exception was the Middle Atlantic States district, the headquarters of which was in Washington, D. C.

Augusta, Me.- September 1, 1928, Army engineer funds, together with State funds, warranted the creation of a separate district and M. R. Stackpole, who had been in charge of the Maine stations under the Boston office, was made district engineer.

The district started with 19 gaging stations, which were increased to 38 in 1939. Power companies also furnished six records computed through their plants. The number of recorders was increased from 7 to 37, all being installed in concrete structures. Twenty-one cableways were erected, the longest having a span of 920 feet. In addition to the gaging stations, 2 evaporation stations were maintained and the snow surveys started in 1920 were continued.

Requests for data were increasing and about 1934, it was estimated that before many years, not less than 70 stations would be required. About that same time, the preparation of duration tables on the basis of runoff per square mile and percent of time was resumed, after a lapse of several years.353/

353/ Sixth Bien. Rept., Public Utilities Com., 1933-34.

Soon after the record-breaking floods of March 1936 [354] in the south-

354/ p. 135-136.

western part of the state, all important streams were visited and the high-water marks at points at which there were no stations, the high-water marks were referenced; at a later date, bronze tablets were set at some 50 permanent points to "serve as reminders in the future to parties occupying those areas."[355] Many old wooden shelters were damaged by the

355/ Seventh Bien. Rept. 1935-36.

floods, and those were later replaced by concrete structures, through the use of PWA funds.

Compartments in the cable cars had their drawbacks as they formed convenient nests for hornets. On one occasion, Mr. Stackpole stepped into a car on the St. Croix River and immediately released it to ride to the other side where he was to start his measurement. Before the car came to rest near the center of the 350-foot span, a large swarm of hornets appeared from the compartment and attacked the "intruder" stinging him many times before they were driven off and the nest cleaned out.[356] Stackpole did not state whether he made the measurement.

356/ Letter to author.

Mr. Stackpole continued as district engineer and had the following Civil Service engineering assistants:

C. E. Aspen	Sept. 1, 1928 to Nov. 10, 1928
J. H. Foster	Sept. 1, 1928 to Jan. 7, 1929
G. K. Wood	Nov. 11, 1928 to May 3, 1929
L. W. Furness	May 16, 1929 to Nov. 9, 1934
W. A. Bowmaster	June 30, 1930 to Sept. 20, 1930
A. O. Patterson, Jr.	Sept. 26, 1930 to Aug. 21, 1932
R. O. Martin	Nov. 17, 1934 to July 26, 1938
C. H. Hardison	Nov. 16, 1936 to Mar. 31, 1937
P. J. Sheehy	July 22, 1938 to June 30, 1939

Boston, Mass.- The area of the Boston district was materially reduced when the Augusta district was created on September 1, 1928, and again when the Hartford district was created on June 16, 1929.

During this period, the floods of March 1936, and the hurricane floods of September 1938, occurred and brought about substantial increases in State cooperation, particularly in Massachusetts, with corresponding increases in the number of gaging stations. On July 1, 1928, 64 gaging stations were being operated, of which 19 Maine stations were transferred to the Augusta district. Nine stations were installed in Connecticut and eight of these with two existing stations were transferred to the Hartford district. The station on the Connecticut River at Thompsonville, Conn., which was maintained in cooperation with the Boston Metropolitan District Commission, was retained. Despite these transfers, the number of stations steadily increased, and 97 were in operation on June 30, 1939, of which 92 were equipped with recorders. Thirty-eight stations were located in Massachusetts,

and 29 each in New Hampshire and Vermont. Ninety-five recorder installations, (part of which were transferred to the August and Hartford districts) chiefly concrete structures, were made, and 49 cableways and 25 artificial controls were constructed. The controls were of the Trenton type.

Outstanding features of the district operations related to the construction and rehabilitation of gaging stations and the flood studies made after the floods of March 1936 and September 1938. After the floods in the fall of 1927, a construction program had been started, which had been almost completed when the two floods of March 1936 occurred. At that time trained personnel were available not only in the Boston office, but also in Hartford and Augusta, and an "all out" investigation of those floods was made. During the later flood which was the greater, some of the engineers became isolated because of submerged highways and washed-out bridges. As soon as travel could be resumed, all were engaged in making flood measurements and in inspecting and cleaning the eight recorders which had been submerged. The water-tight lids on the Au recorders enabled them to operate through the flood. All possible data that had a bearing on the flood and its causes were obtained in the field as soon as possible. All known methods of computing flood flows were used, and in this work Hollister Johnson, borrowed from the Albany district, checked methods and values of coefficients by means of a field examination. The results of the flood studies were published as Water-Supply Paper 798. Referring to that report H. B. Kinnison writes:357/

357/ Letter to author.

> Old methods of publishing the data appeared satisfactory so this office prepared sample station descriptions with their essential data and a sample of Form 9-216 showing the bi-hourly stage and discharge. With slight changes, these were adopted as standard by the Washington office and have been used for most of the flood reports since that time.

After the 1936 flood, an attempt was made to assemble data on the water content of the snow mantle which produced much of the flood water. There were practically no data of this type available. In order to obtain these data for future use for flood analysis and for use of operators of reservoirs, this district began to make snow surveys during the winter of 1937-38. About 50 snow courses were established throughout the district and measurements were made at each course at least 3 times each winter.

As a result of the flood investigations and subsequent studies, the regular program, which included very considerable rehabilitation, had fallen behind and had not become current when the hurricane floods of September 1938 occurred. These floods had been preceded by several days of heavy rain and several engineers were in the field when the hurricane passed over the area. They likewise were isolated as high water and fallen trees blocked all means of transportation and communication. It was not possible to make measurements at or near peak stages and the peak discharges were later determined by other methods. Again all available data were obtained under the direction of Hollister Johnson, and the results published in Water-Supply Paper 867.

The last month of the period was one of intense activity. Early in June, with practically no warning, the Army Engineers stated that they had WPA funds for the installation of 9 stations providing the money could be used by June 30. The district selected 9 of its best engineers, gave each brief instructions and a set of standard plans, and held each responsible for the completion of his station by June 30; the Army Engineers furnished each engineer unlimited purchase orders. Large construction crews of local labor were employed; standard forms for the concrete structures were used, one set for two stations. The structures were completed by the deadline date, although the recorders were not available for installation until several months later.[358]

[358] Letter from H. B. Kinnison to author.

Mr. Kinnison continued as district engineer and had the following Civil Service engineering personnel:

J. H. Morgan	July 1, 1928 to Aug. 7, 1930
O. D. Mussey	July 1, 1928 to Aug. 16, 1928
D. S. Wallace	July 1, 1928 to July 4, 1929
W. S. Eisenlohr, Jr.	July 1, 1928 to Dec. 6, 1928
G. K. Wood	July 1, 1928 to June 30, 1939
G. S. Rowe	Aug. 8, 1928 to Nov. 27, 1928
J. H. Foster	July 27, 1928 to Aug. 31, 1934
R. A. Hovey	Nov. 1, 1928 to May 9, 1929
E. H. Curtis	July 1, 1929 to July 30, 1934
A. A. Fischback, Jr.	Aug. 2, 1929 to Jan. 17, 1932
G. R. Williams	Oct. 27, 1930 to Mar. 26, 1934
LeRoy Engstrom	Sept.17, 1931 to Jan. 6, 1933
D. M. Corbett	June 20, 1932 to Apr. 23, 1938
C. L. Muntz	Sept.10, 1934 to June 30, 1939
J. S. Sweet	Sept.29, 1934 to Sept.19, 1938
V. W. Rupp	Dec. 2, 1935 to Dec. 31, 1937
C. E. Knox	May 27, 1936 to June 30, 1939
W. L. Isherwood, Jr.	Nov. 8, 1936 to June 30, 1939
M. A. Patch	Apr. 28, 1938 to June 30, 1939
J. W. Gurry	July 11, 1938 to June 30, 1939
M. T. Thomson	July 13, 1938 to June 30, 1939
M. A. Benson	Oct. 1, 1938 to June 30, 1939
F. J. Flynn	Oct. 24, 1938 to June 30, 1939
A. M. Moore	Nov. 1, 1938 to June 30, 1939
D. L. Milliken	Nov. 28, 1938 to June 30, 1939
P. D. Kelly	Dec. 30, 1938 to June 30, 1939
A. F. McVarish	Dec. 30, 1938 to June 30, 1939
R. S. Pease	Dec. 30, 1938 to June 6, 1939
R. J. Greer	Mar. 8, 1939 to June 30, 1939

Hartford, Conn.- When the district office was established in Hartford on June 16, 1929, with B. L. Bigwood as district engineer, the Boston office which had previously maintained the Connecticut stations, transferred 10 stations, of which 8 had been established within a few months. Of the other 2, the station on the Housatonic River at Falls Village had been maintained since 1912 and that on the Quinebaug River at Jewett City since 1918, both with the assistance of power companies. In keeping with the New England tradition of accuracy and permanence, the stations were equipped with water-stage recorders, chiefly in concrete shelters.

The goal toward which the district progressed contemplated a total of 35 gaging stations which, at the time cooperation was first considered, appeared to be the minimum number needed to provide the State with essential basic stream-flow data.[359] The number of stations was increased

359/ Seventh Bien. Rept. State Water Com., 1936-38, Pub. Doc. 78.

gradually until in 1938, 35 stations were in operation. The next year two temporary stations were discontinued, leaving 33 permanent stations. Thus the goal was reached within 6 per cent. All but two of the stations were equipped with recorders, 22 in all-concrete structures and 9 in concrete wells with brick or timber shelters. Eighteen stations were equipped with cableways, and three with artificial controls.

Describing the operations of the district, Mr. Bigwood writes:[360]

360/ Letter to author.

> During the life of the Connecticut district, Nature has run the entire gamut. Around 1930 it was the drought, * * * In March 1936, came the great Connecticut River flood, and many another local stream too was raised to record-breaking levels. However, the Climax came in 1938 when the regular procession of floods was produced one after another, topped by the hurricane, and accompanying record-shattering floods of September 21, 1938.

During March 1936 there were two distinct floods a week apart, in the second of which, the Connecticut River reached its highest stage in the 300 years that the valley had been occupied by whites. The district personnel was in the field, day and night, during that time obtaining all possible information relative to the flood. As Mr. Bigwood phrased it,[361]

361/ Op. cit.

> It was apparent that a new yardstick for hydraulic design had been provided and it was up to the Survey personnel to see that comprehensive information was made available.

Several weeks were spent in gathering and analyzing the flood data which were published in Water-Supply Paper 798.

The hurricane flood of September 1938 was one of rare occurrence in New England. Heavy rains which preceded the West Indies hurricane caused all streams in Connecticut as well as in much of New England, to reach high flood stages. When the hurricane struck, the violent wind piled up a storm wave from 10 to 15 feet above ordinary high tide along the sea coast, and miles of shore line were swept clean with the loss of hundreds of lives. In the interior the coincidence of the hurricane and an extraordinary flood proved nearly as devastating, but the loss of life was very much less than on the coast.[362]

362/ Op. cit.

As soon as the highways were reopened, the gaging stations were visited and many were found to have been submerged. Profiting by the experience of the March 1936 flood, several spare recorders had been added to the equipment and these were substituted for the submerged instruments in order that the latter might be cleaned as soon as possible. The force of the hurricane is indicated by the fact that at several gaging stations as far distant from the coast as 40 miles, the submerged clocks were seriously damaged by salt water blown in from the sea. The southern side of evergreen trees in the same areas were blasted and made brown by the salty spray driven through the air during the hurricane. In addition to obtaining the usual data on the floods, Bigwood spent considerable time obtaining data on maximum ocean storm-wave heights. The results of the flood study were published in Water-Supply Paper 867.

A feature worthy of note was the district stream-gaging exhibit at the fiftieth anniversary meeting of the Connecticut Society of Civil Engineers held at Yale University in February 1934. This exhibit consisted of stream-gaging equipment then in use. To show the development in equipment some museum pieces were borrowed from the Washington office. The equipment was set on a table at the rear of the booth. To set the exhibit off, a large map of the State showing the gaging stations was hung on the rear wall. The Survey's booth was directly opposite that used for the Gurley Company's exhibit which was in charge of C. C. Covert, formerly in charge of the New York district.363/

363/ Letter from E. B. Rice to author.

Mr. Bigwood continued as district engineer and had the following Civil Service engineering assistants:

E. B. Rice	Aug. 5, 1929 to Nov. 11, 1934
L. W. Furness	Nov. 10, 1934 to June 30, 1939
K. M. Kelley	(June 10, 1935 to Aug. 14, 1935
	(May 17, 1936 to July 16, 1936
M. P. Thomas	Oct. 12, 1936 to June 30, 1939
W. L. Isherwood, Jr.	June 8, 1938 to July 18, 1938
J. H. Ehrich	Jan. 5, 1939 to June 30, 1939

Albany, N. Y.- During the period the Albany district increased its technical personnel from 5 to 18, and the number of gaging stations from 83 to 154. Of these, 141 were equipped with recorders and 31 with artificial controls. The increase occurred chiefly during the latter part of the period, beginning in 1936, when the floods of 1935 and 1936 had shown the need for additional stations.

The "308" work, started at the end of the previous period, resulted in the establishment of 13 gaging stations which were maintained in cooperation with the Army Engineers until 1932. Thereafter most of the stations were continued as a part of the State cooperative program.

In 1932 an investigation of the effect of reforestation on stream flow was started. 1/ The program which was to cover a 20-year period

1/ p. 22

contemplated the installation of about 15 gaging stations in different parts of the State. Four stations were established on streams draining from 1 to 3 square miles of abandoned farm land which had just been reforested. Each station was equipped with a natural-scale recorder and an artificial control having a standardized V-notch for measuring low flows. This was more than a study of surface run-off as the investigation required also records of ground-water elevations, temperatures, snowfall, rainfall, and sediment movement.[365] To obtain ground-

365/ Water-Resources Bulletin, Oct. 10, 1934, p. 12.

water levels in rather remote areas unaffected by withdrawals, three observation wells equipped with recorders were established in Courtland, Chenango, and Delaware Counties.

In 1933, in cooperation with the City of Ossining[366], three stations

366/ p. 22.

equipped with artificial controls were constructed on Croton River.

Prior to 1935, except for one local flood in 1928, New York State had not experienced a disastrous flood for more than 20 years, but the flood of July 7, 1935, in central and southern New York, showed clearly that the number of gaging stations in that part of the State, at least, was inadequate. In the following March, streams in that area were again subjected to severe floods. The passage of the flood-control bill of 1936 made it possible for the Army Engineers to make an intensive study of flood control on the headwaters of the Susquehanna River. The Army Engineers established an office at Binghamton in the fall of 1936, and during the ensuing winter installed 16 gaging stations and maintained them until the State could so increase its allotment as to permit taking them into the cooperative program. The additional funds became available on July 1, 1937, and the Survey established a sub-office at Binghamton with three, and later four, engineers detailed to it. In 1938 the Army Engineers furnished funds for the installation and operation of 18 additional stations. About 60 stations, both State-cooperative and Army, were subsequently operated by the Binghamton office. This was not the extent of Army Engineer cooperation as flood-control studies in the western part of the State required the installation and operation of six stations by the Survey at Army-Engineer expense.

In 1936, cooperation with New York City's Board of Water Supply[367]

367/ p. 22.

resulted in the establishment of additional stations. For economy of operation not only of those stations but of other stations in that section, a sub-office was opened at Kingston on July 1, 1937 with three Survey engineers. On December 1, 1937, the sub-office was moved to Ellenville in order to maintain close contact with New York City's Board of Water Supply, which moved its office to Ellenville in order to be near its construction work.

The Army Engineers, through the U. S. Lake Survey, were maintaining gaging stations on the Niagara River at Buffalo, N. Y., and on the

St. Lawrence River at Ogdensburg, N. Y. At the former site they were making measurements by means of large Price meters suspended from a boom on a specially-constructed catamaran. Nearby, was the International Peace Bridge about 100 feet above the water. J. C. Hoyt, while on a trip through New York State with A. W. Harrington, felt that here was an opportunity to compare the results of measurements from a high bridge, using the new, heavy reels and booms and 100-pound weights with the results obtained by Lake Survey methods. Accordingly, in November 1931, Lasley Lee brought his equipment to Niagara River and with little difficulty made a measurement from the bridge. On the previous day two measurements had been made from the catamaran using the Lake Survey equipment and methods. Unfortunately for the success of the investigation, the wind on Lake Erie shifted between the measurements, and so affected the flow of the Niagara that the results were not comparable. This was, to use the words of an ex-President in referring to another effort which finally failed, "a noble experiment."

Water-power interests assisted in the operation of many of the stations, and during 1932 such assistance resulted in a critical, comparative study of records obtained at power plants carefully rated by the Gibson method, and records at the Survey's nearby stations. The comparison of mean monthly discharges obtained at the gaging station on Sacandaga River below Conklingville Dam, at Conklingville, with those at the E. J. West power plant at Conklingville Dam, obtained by the Gibson method, indicated very close agreement in the two methods.

The dry year of 1931 made the people of New York State more water-conscious than previously and in order to be able to answer questions regarding up-to-the-minute stream flow, Mr. Harrington, beginning in 1933, made it a practice to keep current the hydrographs for selected base stations. By comparison with hydrographs for previous years the desired information could usually be given. Similar comparison of current ground-water levels obtained by the Ground-Water Division, with the levels of previous years, helped to complete the picture of current water conditions.

Cooperation with Nassau County, Long Island, which was started in 1936, required records of the highest degree of accuracy as the records were to be used intensively in correlating the surface flow with the many ground-water records in that region, and in connection with the known withdrawals for water-supply purposes to show, as Harrington phrases it,368/ "what became of the rainfall on Long Island." In addition

368/ Letter to author.

to equipping the six gaging stations with recorders and artificial controls, hook-gage readings were used, and the mean daily gage heights were carried to thousandths of a foot. When the discharge was very small it was measured by pygmy meter. Another group of three stations was maintained primarily for the benefit of ground-water studies in the Croton River Basin, in cooperation with the City of Ossining.

As a result of the floods of March 1936, which had shown what an important factor the snow melt was in causing spring floods, the Survey was instrumental in organizing the New York State Cooperative Snow Survey.

Power companies and other agencies made most of the observations with some by Survey personnel. The observations were made three times during the winter, ending about the middle of March, and the records were assembled by the Survey and made available.

Taking advantage of the opportunity offered by the Civil Works Administration to furnish clerical workers for statistical work, Mr. Harrington in 1934 sponsored a project to assemble and publish in a compact and comprehensive manner stream-flow records for New York State, some of which had been started near the turn of the century. Hollister Johnson, for many years principal assistant engineer of the Black River Regulating District, was selected to direct this work,[369] which began

[369] Water Resources Bulletin, Feb. 10, 1934, pp. 11-12. For account of project, see p. 725.

December 7, 1933, and ended April 28, 1934, when the CWA funds became exhausted. As the project was not completed, the results were not published.

Mr. Harrington continued as district engineer and Miss Agnes D. Buchanan, district clerk, during the period. The Civil Service engineering personnel were:

H. F. Hill, Jr.	July 1, 1928 to Aug. 15, 1930
B. L. Bigwood	July 1, 1928 to June 15, 1929
A. E. Johnson	July 1, 1928 to Jan. 15, 1929
H. W. Palm	Aug. 1, 1928 to June 15, 1929
F. C. Christopherson	Feb. 25, 1929 to Jan. 5, 1932
J. L. Lamson	May 24, 1929 to Apr. 5, 1935
J. V. B. Wells	Oct. 3, 1929 to Apr. 23, 1932
W. B. Hanlon	(July 1, 1930 to Apr. 29, 1935
	(Aug. 12, 1937 to June 30, 1939
Kyle Forrest	Sept. 15, 1930 to Jan. 4, 1932
R. H. Brigham	Aug. 15, 1931 to Apr. 23, 1932
A. A. Fischback, Jr.	Jan. 18, 1932 to June 7, 1934
W. P. Cross	Feb. 1, 1932 to June 30, 1939
LeRoy Engstrom	Jan. 6, 1933 to May 21, 1934
Verne Alexander	Aug. 20, 1934 to Mar. 23, 1937
N. W. Herzberg	Oct. 6, 1934 to Oct. 16, 1938
K. M. Kelley	Apr. 11, 1935 to June 30, 1939
Hollister Johnson	May 1, 1935 to June 30, 1939
P. R. Speer	May 17, 1935 to May 20, 1939
W. B. Langbein	June 3, 1935 to Nov. 2, 1936
N. J. Lusczynski	Aug. 10, 1936 to June 30, 1939
C. C. McDonald	Sept. 29, 1936 to June 30, 1939
A. O. Waananen	Nov. 16, 1936 to June 30, 1939
J. R. Throckmorton	Mar. 22, 1937 to Apr. 30, 1938
A. H. Williams	Sept. 7, 1937 to Aug. 31, 1938
G. D. Freeman	Mar. 2, 1938 to June 30, 1939
J. J. Molloy	May 2, 1938 to June 30, 1939
C. P. Parkinson	Apr. 14, 1938 to June 30, 1939
R. O. Martin	July 1, 1938 to June 30, 1939
D. K. Serby	Oct. 17, 1938 to June 30, 1939
Vincent Shamamian	Oct. 19, 1938 to June 30, 1939
G. L. Oakland	Nov. 15, 1938 to June 30, 1939
L. A. Wiard	Jan. 4, 1939 to June 30, 1939
T. Briganti	Mar. 27, 1939 to June 30, 1939
H. W. Fear	May 1, 1939 to June 30, 1939

Trenton, N. J.- Additional cooperation in New Jersey caused O. W. Hartwell to revise somewhat his earlier practice of maintaining a comparatively few stations in New Jersey in first-class shape, and the number was increased from 39 to 80 stations. Of these, 13 stations were on the Delaware River at bridges operated by the Delaware River Joint Toll Bridge Commission, where records of stage only were obtained.370/

370/ p. 24.

One of these stations was at Washington Crossing of Revolutionary fame, and another was at Lambertville where a regular station had been maintained from 1897 to 1908. The Lambertville station had been the first equipped with a chain gage, window weight, and copper rivet marker.371/

371/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 89.

Until the creation of the Pennsylvania district on June 1, 1931, the New Jersey district operated three stations in Pennsylvania, two for the Army Engineers and one for a permittee of the Federal Power Commission.

Not only was the number of stations in New Jersey doubled but every station was equipped with a recorder in a standard concrete shelter except the 13 Delaware River stage stations, which had wire-weight gages. Of the 30 recorders added during the period, 13 were installed during the first year.

Three stations established in 1932 were used in the ground-water investigation of the Runyan area which supplied the water for Perth Amboy. The object was to compare the run-off from three adjoining drainage basins, and to determine whether Tennant Brook Basin was contributing an unusually large amount to the ground-water reservoir, and whether it was losing water by percolation to the Matawan Creek Basin.

In 1933, Hartwell installed on the Passaic River at Paterson a recorder visible to the public. The shelter consisted of a bronze box with one glass side, placed on a concrete base at a suitable height for examination. It was located at the side of a memorial plaza at the end of a new highway bridge.372/ When first installed shatterproof glass was

372/ Water-Resources Bulletin, Jan. 10, 1933, p. 54.

used on the advice of those familiar with the neighborhood. The aspersions thus cast on the local residents were found to be unwarranted as after several years there had been no molestation and the shatterproof glass had become so discolored that it was necessary to replace it. Plate glass was substituted and this was not molested.373/ To the best

373/ Letter from O. W. Hartwell to author.

of the author's knowledge this was the first "open-face" recorder installation made since those installed in Yosemite National Park and in Yellowstone National Park in 1916, and in Glacier National Park in 1918.

Keeping pace with the installation of recorders, was the installation of 38 artificial controls which increased the total number from

12 to 50. The greatest length was 142 feet, and the average, about 50 feet. These controls were generally of the Trenton type which Hartwell originated in 1933. Six controls in the Wanaque River Basin were built for the dual purposes of stabilizing the stage-discharge relations of and chlorinating the water which passes over the structures.

In 1934, when cooperation with the North Jersey Water Supply Commission was arranged,374/ two existing stations were taken over by the Survey

374/ p. 23.

and seven additional stations were established on streams entering Wanaque Reservoir, including one on the main stream at the head of the reservoir. Cooperation with the Delaware River Joint Toll Bridge Commission, started in 1935, led to the establishment of wire-weight gages at 13 Delaware River bridges. These gages were read twice daily except during floods when the bridgetenders read the gages hourly and telegraphed the readings to the district office. The hydrograph for the Trenton station which was a regular discharge station, was kept current during the floods and by comparison with the readings from the upstream stations, the crest heights and times of their arrival at each station could be forecasted closely.

Following the drought year of 1931, Mr. Hartwell began the practice of computing each month the records for stations on three uncontrolled streams in order that the public which had been aroused "when the well went dry" might be kept informed regarding trends in stream flow. These records were furnished to the cooperating State official monthly, and were used in answering inquiries. During the drought year the records at several stations suffered in accuracy as a result of attempts by bathers to deepen pools by placing rocks and sods on the artificial controls.375/

375/ Water-Resources Bulletin, Nov. 10, 1930, p. 12.

The proposal of New York City to obtain an additional water supply from the Delaware River Basin was resisted by New Jersey, which objected to the large diversion contemplated, and a suit was filed in the United States Supreme Court. In accordance with usual procedure, hearings were held by a Special Master. The Trenton office was busily engaged for a considerable period in 1930, supplying records and other data for use at the hearings. In the report of the Special Master, presented to the Supreme Court at the October 1930 term,376/ referred to the use of

376/ State of New Jersey vs. State of New York and City of New York, No. 16 Original.

the Survey records as follows:

> There was a vast volume of evidence accompanied by numerous exhibits as to the effect of the proposed New York Diversion from the Delaware River. * * * The most reliable information obtainable consisted of the stream-flow records of the gaging stations of the United States Geological Survey and some State records.

A WPA project that was worthy of special note related to the gaging station at Great Egg Harbor, where channel-improvement work required the employment of 30 men for about 4 months. Two oxbows in the river were cut off and the improved channel widened and deepened. The cost of the work was about $22,000.

Although the famed Jersey mosquito does not appear in the annals during this period, other forms of wild life do. At one station a family of mice set up housekeeping inside the drum of a Gurley recorder and spent a good share of their time nibbling off the tabs of the chart which was placed on the recorder weekly. At another station, Hartwell writes:377/

377/ Water-Resources Bulletin, July 11, 1932, p. 42.

> Recently yellowjacket hornets invaded one of the instrument shelters and drank up the ink in the Simplex pen, after which they walked about on the recorder paper leaving very good records of their travel covering a period of one week on the automatic chart.

To avoid uncertainties due to erroneous dates on recorder charts, Hartwell installed a calendar in each shelter, and in that connection stated that the engineers needed the calendars as much as the observers.378/

378/ Water-Resources Bulletin, Jan. 11, 1932, p. 6.

Mr. Hartwell continued as district engineer during the period, and had the following Civil Service engineering personnel:

Otto Lauterhahn	July 1, 1928 to June 30, 1939
Harry Barnett	Aug. 6, 1928 to June 30, 1929
R. E. Marsh	July 1, 1928 to Mar. 24, 1930
W. L. Heckler	June 20, 1929 to July 1931
E. G. Barron	Nov. 8, 1930 to June 30, 1939
R. O. Martin	July 15, 1931 to Nov. 16, 1934
J. T. Tucker	Nov. 5, 1934 to Aug. 24, 1937
R. W. Thompson, Jr.	July 22, 1936 to June 30, 1939
E. G. Miller	Oct. 24, 1938 to June 30, 1939
R. H. Tice	Oct. 24, 1938 to June 30, 1939

Harrisburg, Pa.- The Harrisburg district was unique in that when a district office was established in Harrisburg on June 1, 1931,379/ with

379/ p. 24.

J. W. Mangan as district engineer, the district was already a "going concern." To the hundred stations maintained by Pennsylvania, three stations were added by transfer from the New Jersey district. These hundred-odd stations so covered the streams that there was need for but little expansion, and the number was only increased to 109 by the end of the period. The station equipment was improved by the increase in the number of recorders from 47 to 85. Until 1936 standard concrete installations were made, but subsequently concrete or cinder blocks were used because that type of construction was considerably cheaper.380/

380/ Statement of R. H. Hosmer to author.

Cables were installed at six stations, and 10 artificial controls of the Columbus type were constructed, the longest being 75 feet.

During 1938-39, 10 stations, chiefly in the Ohio River Basin, were established for the Army Engineers. For efficiency and economy of operation of those stations, as well as others in western Pennsylvania, a sub-office was established at Pittsburgh on July 1, 1938. The low-water year of 1931 caused industrial interests along the lower Delaware to become concerned over the encroachment of salt water in the tributary streams. As the State of Pennsylvania was conducting a salinity survey, the Harrisburg district established and maintained from 1931 to 1933 four stations in Delaware on streams entering Delaware River and Bay.381/

381/ Letter from G. C. Stevens to author.

Pennsylvania streams are subject to severe floods and the forecasting of floods in the Susquehanna River Basin was one of the chief reasons for the creation of the State Division of Hydrography in 1914.382/ When

382/ Op. cit.

the Survey entered the picture in 1931, 40 rain gages were being maintained in areas having few Weather Bureau gages. The forecasts were based primarily on gage-height reports from the upper reaches of the streams and were issued by both the State and the Weather Bureau as separate agencies, although working together.383/

383/ Letter from J. W. Mangan to author.

The widespread storms of March 1936 caused unprecedented floods in Pennsylvania. Immediately after the floods subsided, all important streams were visited in order to record and preserve the high-water marks, which were later referenced to sea level datum. The time of crest flow was also obtained wherever possible. It was generally possible to compute peak discharges by extension of rating curves but where this could not be done, computations of crest discharges were made by means of slope-area measurements, and of formulas for flow over dams or spillways. Search was made for records of outstanding floods since the settlement of Pennsylvania. A report on the floods was published by the State.384/

384/ The Floods of March 1936 in Penn: Dept. Forests & Waters.

The need for a more complete flood-warning service after the 1936 floods was realized and at the Pittsburgh meeting of the American Society of Civil Engineers in 1936, the members stressed the need for more complete hydrologic data on floods. Officials of the National Resources Committee, Weather Bureau, State Department of Forests and Waters, and the Geological Survey held a number of conferences which on April 5, 1937, resulted in a cooperative agreement between the Weather Bureau, Department of Forests and Waters, and the Geological Survey for the purpose of developing new and more adequate methods of river forecasting for the State's principal cities and towns, to establish new sources of

basic hydrologic data necessary for forecasting, and for the design and operation of flood control works; to make available to the State, basic data regarding the surface waters upon which Federal, State, and private interests may be coordinated; and to improve communication facilities (which had broken down during the 1936 flood) to prevent a repetition of those conditions during subsequent floods. An organization was formed whose leaders were experienced in unit-hydrograph and flood-routing methods of forecasting. Technical supervision rested with Merrill Bernard, Chief of the Weather Bureau's River and Flood Division. General administrative supervision rested with C. E. Ryder, chief engineer of the Department of Forests and Waters, and personnel and general operation were under J. W. Mangan's direction.

The stream-gaging program was expanded to include new stations needed in the flood studies and recorders were installed at some of the older stations. To prevent repetition of the 1936 experience when many river gages were inaccessible, a new type of staff gage having upper limits several feet higher than the 1936 flood crests was designed for use in overflow sections of streams at bridges and in the business district of cities and towns. About 100 recording rain gages were installed at control points throughout the State. The new flood-warning service, known as the Federal-State Flood Forecasting Service, was placed in actual operation early in the following period.

As aids to the flood studies, Mr. Mangan's office prepared two reports which were published by the State: Flood discharge records relating to Pennsylvania streams, 1938; and natural water losses from Pennsylvania drainage basins, 1940. The latter was a comparison between precipitation and stream flow for all gaging stations having at least 5 years' records, if precipitation records were also available, for the upper Ohio River Basin.385/

385/ Statement prepared by J. W. Mangan.

Mr. Mangan was district engineer during the period and had the following Civil Service engineering assistants:

P. R. Speer	Feb. 1, 1932 to Mar. 16, 1935
F. L. Le Mert	Apr. 18, 1932 to June 30, 1939
J. V. B. Wells	Apr. 26, 1932 to June 30, 1939
J. L. Saunders	June 21, 1935 to Mar. 3, 1938
S. E. Rantz	July 11, 1936 to June 30, 1939
George Weber, Jr.	June 1, 1937 to June 30, 1939
R. C. Culler	Aug. 2, 1937 to June 30, 1939
H. M. Erskine	June 26, 1938 to June 30, 1939
M. I. Rorabaugh	Nov. 1, 1938 to Jan. 14, 1939
P. B. Williams	Apr. 1, 1939 to June 30, 1939

Middle Atlantic States.- About the beginning of the period, the 13 stations in the Ohio River Basin in West Virginia were transferred from the Middle Atlantic States district to the Virginia district, which had been performing the field work at those stations for several years. Thereafter the Middle Atlantic States district comprised the State of Maryland, the District of Columbia, the Potomac River Basin in West Virginia, and two stations in Pennsylvania. Army-Engineer and other cooperation required the establishment of 10 stations during 1929.

Additional stations installed later brought the number to 40 in 1939, 32 being equipped with recorders.

Two of the stations established were near the sites of two historic stations, one on the Potomac 2½ miles above Chain Bridge where in 1891 the first station was established in the East,[386] and the other on the

386/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 67.

Shenandoah River near the Millville station established in 1895 and equipped with the first cable and suspended car erected in the East.[387]

387/ Op. cit., p. 76.

Both stations had been discontinued for many years. The Point of Rocks station on the Potomac which had been operated continuously since 1895 was equipped with a recorder. The chain-gage station on the Monacacy River near Frederick, which had been maintained since 1895, was discontinued in 1930, and, in its stead, a recorder installation was made several miles downstream as the Army Engineers, for their "308" studies, desired records as near the mouths of the streams as possible and provided funds for the recorder installation.

The flood of 1936, which was the greatest known in the Potomac River Basin, overturned the 60-foot concrete shelter at Hancock, which had been constructed near the edge of a 15-foot bank where bedrock was found a short distance below the surface. As a row of trees from 2 to 4 feet in diameter lined the bank for some distance upstream, the site, although subject to overflow, was considered to be safe from serious flood damage. The 1936 flood which at Hancock was about 8 feet higher than the greatest known previous flood (1889, commonly known as the Johnstown flood) carried so much debris that it washed out or "tipped over" the trees as A. H. Horton expresses it,[388] leaving the shelter

388/ Letter to author.

standing unprotected about 80 feet within the flood channel at that stage, and being unprotected the accumulated drift overturned it. During the 1936 flood, the Shepherdstown shelter located below a bridge abutment, was submerged except for a foot of the peak of the roof, and the shelter on the Cacapon River near Great Cacapon was overtopped by about 12 feet. After the flood the height of the latter shelter was increased about 15 feet.

Construction work constituted a large part of the district's activities during this period; 25 recorders were installed, 22 in concrete shelters, 2 in brick shelters, and 1 in a timber house on a concrete-block well. The well and shelter on the Potomac River opposite Paw Paw, W. Va., had an overall height of 73 feet. It was designed by the Army Engineers, and, profiting by the lessons learned from the Hancock shelter during the 1936 flood, it was given extra heavy reinforcing. The cost was about $7,000. The cable at the Great Cacapon station was of the articulated type which had been suggested by Lasley Lee. The main cable spanned a distance of 600 feet between A-frames, and a separate cable connected each A-frame with the anchorage. Six artificial controls, generally of the Middle Atlantic type, were

also constructed.

Of the various causes for the stoppage of a recorder, perhaps the oddest was experienced at the Burtonsville station on the Patuxent River. The recorder was housed in a circular brick shelter, located near a group of trees. Lightning struck one of the trees and jumped to the shelter, apparently striking first the metal hinges on the door. It tore out screws on the wooden door over the window, melted the cable and clock cables, and burned a shovel and bucket in the shelter.389/

389/ Statement of A. H. Horton to author.

Mr. Horton was district engineer during the period. Other engineering personnel were:

J. W. Mangan	July 1, 1928 to June 1, 1931
W. D. Mitchell	May 1, 1929 to June 30, 1930
K. F. Schumaker	Oct. 1, 1929 to Sept.30, 1930
R. H. Brigham	July 1, 1930 to Sept.28, 1930
R. O. Martin	Sept. 1, 1930 to July 13, 1931
M. T. Thomson	June 15, 1931 to July 13, 1938
L. L. Harrold	(July 6, 1931 to Mar. 7, 1934
	(July 16, 1935 to Sept.30, 1935
W. R. Eaton	Aug. 18, 1931 to Nov. 15, 1932
F. M. Veatch	July 1, 1932 to Mar. 3, 1934
J. L. Saunders	Apr. 24, 1934 to June 30, 1935
L. A. Westby	May 24, 1934 to Dec. 22, 1935
D. S. Jenkins	July 1, 1935 to Sept. 5, 1935
A. D. Ash	Feb. 3, 1936 to June 30, 1939
J. L. French	July 23, 1936 to July 11, 1937
L. B. Peirce	July 24, 1936 to July 30, 1939
G. E. Ferguson	May 4, 1938 to June 30, 1939
E. J. Kennedy	Jan. 19, 1939 to June 30, 1939
Harold Cladny	Jan. 19, 1939 to June 30, 1939

Charlottesville, Va.- In 1928 the Charlottesville district was operating 58 stations in Virginia and was maintaining 14 stations in the Ohio River Basin in West Virginia, which had been transferred from the Middle Atlantic district. When the Charleston district was created on July 1, 1929, the West Virginia stations, which had been increased to 29, were transferred to it, and thereafter the Charlottesville district activities were confined to the State of Virginia.

The period was characterized by marked activity not only in an increase in the number of stations to 91, but also in special investigations. The first of these investigations was a study of the progress of waves down the New-Kanawha River caused by the release of water from storage. A similar study had been made in 1927.390/ The present

390/ p. 123, 1919-1928.

study was brought about by the application of the Appalachian Electric Power Company to the Federal Power Commission for permit to construct a power plant and high dam on New River at Radford, Va. The Army Engineers contended that the operation of that plant would cause waves which would interfere with navigation on the Kanawha River, and the

Federal Power Commission withheld action on the application. To determine the effect of the operation of the power plant, the Charlottesville district joined with the Charleston district, the power company, and Army Engineers in making a study from Ivanhoe, Va., to Lock 2 near Charleston, W. Va. Nine stations were operated on the New-Kanawha River. Water was stored for half a day or more at various times and then released at a steady rate for a number of hours, so that abrupt waves 4 to 5 feet high and about a day and a half apart were registered on the gage at Ivanhoe. Farther downstream the waves were gradually flattened out to less than a foot in height at the lower end of the course. This study was made during March and April 1930.

A study of tidal currents made in cooperation with the Army Engineers was started in 1931 and carried on at intervals during the period.391/

391/ p. 126.

The development of the Skyline Drive in the recently-created Shenandoah National Park caused a demand for water supplies in the comparatively high altitudes of the Blue Ridge, and in 1933 the National Park Service called upon the Survey for help. Cooperation continued during the period.392/

392/ p. 87.

The special activities noted constituted only a small part of the district's program. During the period 91 concrete shelters were constructed, including 5 for the Middle Atlantic district. Eighteen cableways, 15 supported by square steel towers, were constructed. Of these cableways, the longest had a span of 1,194 feet over the New River at Radford. Artificial controls of a modified Trenton type were installed at four stations, the longest being 142 feet. Serious floods during February and March 1936, augmented by the breakup of ice, damaged station equipment to an estimated amount of $32,000. During this flood a solid mass of ice 15 feet thick, which had formed on the overflow section and around the shelter on the Rappahannock River at Kellys Ford, was moved slightly by the current and tipped the concrete shelter 10 degrees from the vertical. Later the shelter was righted by excavating around the well, attaching a 1-inch cable to the shelter, carrying it across the river and 300 feet upstream to a huge tree, and, by means of a chain block, "easing" the shelter back to the vertical.393/ During

393/ Letter from F. F. Schrader to author.

the same flood period J. J. Dirzulaitis had an unusual experience. The recorder on the South Fork of the Shenandoah River at Front Royal is located a third of the way across the highway bridge, and 5 feet downstream from the pier with which it was connected by a walkway. Dirzulaitis, who was in the shelter changing the chart when he heard the ice breaking up, hurriedly left the shelter and the bridge itself, and as he reached the abutment the center bridge span, as Schrader phrases it,394/ "went out with a bang."

394/ Op. cit.

An investigation of the 1936 flood was made. Cross sections of channel to the crest of the flood were surveyed at about 40 gaging stations, high-water marks were referenced, descriptions of the type of overflow section obtained, and local information relative to rainfall recorded. Six slope-area determinations were made. To preserve records of the height of the flood, 22 flood markers were placed at strategic points. Intensive office studies of the flood flows were made to eliminate inconsistencies. All available sources of information regarding previous floods were investigated. One of the most prolific sources was the information compiled by the Army Engineers for the "308" report. The results of the flood investigations were published in Water-Supply Paper 800.

The lesson that the highest flood is yet to come was brought home to the Virginia district the year following the 1936 floods. The old timber shelter on the Rappahannock River near Fredericksburg was replaced by a concrete structure in March 1937. A continuous record covering 30 years had shown a maximum stage of 16.5 feet, and to be safe the new structure was given sufficient height to allow the recorder to register a stage of 20 feet. One month after its completion a flood stage of 25 feet occurred during which only the top of the shelter was visible.395/

395/ Op. cit.

Both field and office work was performed by means of successive CWA-FERA-WPA projects, the largest being for the repair of station equipment damaged by the floods of February and March, 1936, for which $27,000 was allotted.

At the end of the period 91 stations, of which 86 were equipped with recorders, were being operated. Seven of these stations on the headwaters of the Tennessee River were maintained in cooperation with the TVA. This maintenance, however, consisted chiefly in computing the records, as the field work was performed by a suboffice under the Tennessee district.396/

396/ Letter from J. J. Dirzulaitis to author.

Mr. Dirzulaitis was district engineer throughout the period. Fewer changes in engineering personnel subsequent to 1929 occurred during the period than in almost any other district, as shown by the following list of Civil Service engineering personnel:

N. B. Usler	July 1, 1928 to Dec. 10, 1928
M. T. Thomson	July 1, 1928 to July 1, 1929
C. T. Gordon	Aug. 1, 1928 to Dec. 15, 1928
R. W. Sundstrom	Aug. 7, 1928 to Aug. 20, 1930
O. D. Mussey	Aug. 8, 1928 to June 30, 1939
W. S. Eisenlohr, Jr.	Dec. 3, 1928 to Mar. 8, 1929
F. F. Schrader	Apr. 15, 1929 to June 30, 1939
A. R. Green	June 1, 1929 to June 30, 1939
T. F. Hanly	June 17, 1929 to June 30, 1939
H. C. Eagle	Aug. 10, 1930 to Aug. 16, 1931
A. D. Ash	Dec. 1, 1930 to June 30, 1939
R. F. Conard	July 28, 1936 to Nov. 15, 1937

Asheville, N. C.- Prior to the establishment of the Columbia, S. C., office on Nov. 1, 1930, the Asheville district comprised the States of North Carolina and South Carolina, but, subsequently thereto, the State of North Carolina, only. At the beginning of the period, 57 stations were being maintained of which 6 were in South Carolina. In 1929, Army-Engineer cooperation increased the number of stations to 68 in North Carolina, and in 1930, the number was increased to 74 in North Carolina, and 16 in South Carolina. The number of North Carolina stations was gradually increased to 103 in 1939, with a temporary recession to 71 stations during the depression years, beginning in 1932.

All but one of the 103 stations were equipped with recorders. Ninety installations were made during the period, of which 56 were in concrete structures. Twenty-three of the concrete structures were circular, a type devised by E. D. Burchard,397/ and 29 were of the standard square

397/ p. 105.

type. The other structures were chiefly concrete and timber or masonry. Forty cableways were installed, the longest having a span of 850 feet. The 500-foot span cableway on Cape Fear River near Tarheel, was over a navigable stream and a hand-operated winch was provided for lowering it to clear the channel for navigation. Burchard continued his interest in artificial controls and installed 11 during the period. Three were of the Asheville type, and seven were Parshall flumes. To meet the needs of the TVA, a suboffice was maintained in Murphy, N. C., jointly with the Chattanooga district, from 1935 to 1938. Half of the 24 stations operated by that office were in Tennessee.

A special feature of the district operations related to the High Point project of the Soil Erosion Service. That cooperative work was started in the spring of 1934 and continued during the remainder of the period. Six gaging stations, all equipped with recorders, cableways, and concrete Parshall flumes were maintained. In addition to making flood measurements day or night, sediment samples were obtained, 24 observation wells and 58 rain gages were operated. A resident engineer was detailed to the project. Burchard states398/ that the

398/ Letter to author.

greatest problem of the engineer was to get sediment samples during night floods, especially after the observer had gone to bed.

Flood measurements figured quite prominently in the district operations and the one on the Santee River at Parker's Bridge, made during the peak of the August 1928 flood, was outstanding. The main channel had an average depth of 40 feet and was 800 feet wide; the overflow area was 2½ miles wide and heavily wooded, and measurements of flow over it were made from a trestle; the temperature was 110 degrees and the lone engineer spent 14 hours in making the measurement. In referring to the measurement399/ Mr. Burchard stated that it met

399/ Water-Resources Bulletin, Sept. 10, 1928, p. 7.

perfectly Sherman's definition of war. During that same flood, which was caused by two tropical hurricanes, peak measurements were obtained

at two other stations. The washout of bridges prevented the making of peak measurements at two additional stations.

Seizing an opportunity for publicizing the Survey's work, King, Burchard, and Dirzulaitis, in charge of the three districts cooperating with the Army Engineers in the Tennessee River Basin, put on a stream-gaging exhibit which attracted much favorable comment at the Southern Appalachian Power Conference held at Atlanta, in October 1928.

Mr. Burchard continued as district engineer and had the following engineering personnel:

Karl Jetter	July 1, 1928 to Sept. 15, 1930
F. M. Bell	July 1, 1928 to Dec. 8, 1931
A. E. Johnson	June 1, 1929 to Oct. 31, 1930
P. R. Speer	July 10, 1929 to Oct. 5, 1929
H. W. Palm	(June 16, 1929 to July 5, 1930
	(Nov. 30, 1936 to Apr. 20, 1938
H. A. Taylor	June 17, 1929 to Sept. 8, 1934
A. G. Hely	Aug. 11, 1930 to June 4, 1937
R. W. Sundstrom	Aug. 22, 1930 to Aug. 17, 1931
R. E. Cabell	Dec. 14, 1931 to Oct. 2, 1936
F. C. Ames	Nov. 24, 1934 to Dec. 9, 1936
E. H. Curtis	Aug. 13, 1934 to Dec. 11, 1938
J. L. Lamson	Apr. 19, 1935 to June 30, 1939
W. P. Tiencken	Sept. 30, 1935 to Aug. 31, 1936
Clark White	Sept. 21, 1936 to Sept. 20, 1937
J. W. Gambrell	Oct. 12, 1936 to June 30, 1939
R. W. Leonard	Nov. 2, 1936 to June 30, 1939
E. B. Hodges	June 24, 1937 to June 30, 1939
V. W. Rupp	May 2, 1938 to June 30, 1939
K. A. MacKichan	Nov. 1, 1938 to June 30, 1939

Columbia, S. C.- Prior to the beginning of State cooperation and the establishment of a district office in Columbia on November 1, 1930, with A. E. Johnson as district engineer, stream gaging in South Carolina was, as Mr. Burchard expresses it,[400] "kept alive with

[400] Letter to author.

a couple of Federal Power Commission licenses, and the '308' work of the Army Engineers." The Army Engineers' civilian engineer who co-operated in the installation of the 10 Army stations, was C. C. Babb who had been F. H. Newell's right-hand-man in the early days of the Branch.[401] These 10 stations, and 6 stations maintained through

[401] Follansbee, Robert, History of the Water Resources Branch of the the U. S. Geol. Survey to June 30, 1919, p. 66.

Federal Power Commission licensees and other interests, were transferred from the Asheville office and were the nucleous of the new district's stream-gaging program.

The value of stream-flow records having been demonstrated, the State Highway Department soon after the establishment of the Columbia office,[402] began sending to Johnson the tentative designs for new

402/ p. 27.

bridges showing proposed bridge openings, and requesting him to determine the adequacy of such openings for the passage of major floods. In some instances, Mr. Johnson was able to show that the proposed openings were excessive. The resulting revision of plans led to substantial savings in the cost of the bridges. An outstanding example was that of a bridge over the Wateree River which was designed for a length of 2,880 feet. Near the site of the bridge was a gaging station at which a large number of flood measurements had been made. The records showed that the main channel carried 65 per cent of the flood discharge, the right overflow area 2 per cent and the left overflow area the remainder. On the basis of these records, the proposed bridge was shortened by nearly 900 feet. So gratifying to the Highway Department were Mr. Johnson's reports on the adequacy of bridge openings that it became standard practice to submit all bridge plans for his examination. In addition, the Highway Department now places wells in new bridge piers with provision for intakes for gaging stations.

Soon after Mr. Johnson went to Columbia, he became interested in the civil engineering students in the State University. When the students reached the subject of stream-gaging in their course in hydraulics, he with one or more assistants would take them to a nearby gaging station, and dividing them into groups, would have each group make a measurement using heavy equipment and compute the discharge. The following day, the students would come to the office where Johnson or one of his assistants would explain the rating curves and methods of computing daily flow. This procedure was followed twice each year. A single incident will indicate the students' interest: One day a class in astronomy was trying to make solar observations, but as clouds interfered, they decided to spend the class period in the Survey office in order to learn more about stream-gaging. As a result of this close contact with the engineering students and of their interest in hydraulics that grew out of that contact, a number of them entered the Survey after graduation. 403/

403/ Statement of A. E. Johnson to author.

The initial stream-gaging program remained substantially unchanged until the Tyger River project started in March 1934 in cooperation with the Soil Erosion Service, 404/ required the installation of 4 additional

404/ p. 81.

stations.

Renewed cooperation with the Army Engineers in 1938 brought about the installation of 6 more stations. At the end of the period, 54 stations, of which 33 were equipped with recorders, were being maintained. At one station, two recorders were so equipped that the operator at the power house could determine the head-water and tail-water elevations from dials on the switchboard. A station on the Augusta power canal was operated as a slope station with two recorders installed about 3½ miles apart.

During the period 19 recorder installations were made, all but one in concrete structures. The greatest overall height of a concrete structure was 61 feet. Six cables were erected and five artificial controls, chiefly of the Trenton type, were constructed. An unusual method of surmounting construction difficulties was used on the Tyger River project. A concrete well was under construction during February 1934, with temperatures below freezing. The water was 4½ feet deep in the well, and although a centrifugal pump was used it was impossible to lower the water level. As it was necessary to work in the water the construction foreman placed two old oil drums in the water and built a large fire in each. These fires heated the water sufficiently to allow the men to work in it without clothing.[405]

[405] Letter from A. E. Johnson to author.

Another unusual construction job involved moving a concrete shelter weighing 31 tons through a distance of 80 feet. This structure had been overturned by a flood in October 1929. In July 1931, funds became available for its rehabilitation. By means of steel cables and two 10-ton chain falls the structure was rolled out of the hole in which it rested. 12" x 12" walers were lashed to the sides and the structure then turned 90 degrees with the footing facing the new location. It was then moved on the walers and 12" x 12" skids toward the new location, where an inclined trench leading to the excavated site had been dug. By means of cables and chain falls the structure was finally raised to its proper position. In describing this work, A. E. Johnson writes[406] that the cost involved was about a

[406] Letter to author.

third of that of the original installation.

Mr. Johnson was district engineer during the period and had the following Civil Service engineering assistants:

F. W. Wagener	Dec. 1, 1930 to June 30, 1939
J. M. Terry	Mar. 1, 1934 to June 30, 1939
L. B. Yarger	July 11, 1938 to June 30, 1939.

Atlanta, Ga.- Cooperation having been arranged with the State Division of Mines, Mining, and Geology of Georgia, a district office was opened in Atlanta on March 1, 1937, with F. M. Bell, transferred from the St. Louis office, as district engineer. Thus, after a lapse of 16 years a district office was again established in Atlanta. It may be noted that a Survey office was first established in Atlanta in July 1895.[407] Five stations that were being operated by the Montgomery

[407] Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 82.

office, five by the Ocala office, and one by the Columbia office were turned over to the new district. In describing plans for the new office, Bell stated:[408]

[408] Water-Resources Bulletin, May 10, 1937, p. 61.

> The stream-gaging program contemplates the immediate installation of 40 gaging stations at strategic sites throughout the State. The majority of the stations will be of the non-recording type; however, the records will be watched closely and recorders installed as soon as possible where they are most needed.

PWA funds made available in 1938, renewal of Army-Engineer cooperation for flood-control studies, and cooperation with the Flood Control Coordinating Committee,[409] made it possible to increase the number of sta-

[409] p. 89.

tions to 64 by the end of the period, and of these 40 were equipped with recorders. Thirty-two recorder installations were made of which 10 were made of concrete, 10 were pipes, 9 were timber, and 1 was a concrete well and timber shelter. The greatest overall height of a recorder structure was 50 feet. Three cableways were installed.

State cooperation included not only a stream-gaging program but also quality of water[410] and ground-water investigations.

[410] p. 29.

Mr. Bell continued as district engineer, and had the following Civil Service engineering assistants:

M. R. Williams	Mar. 1, 1937 to June 30, 1939
R. F. Conard	Nov. 16, 1937 to June 30, 1939
J. L. French	July 12, 1937 to June 30, 1939
J. M. Carns	Nov. 16, 1938 to June 30, 1939.

Ocala, Fla.- With the prospect of limited State cooperation and a small amount of cooperation with the Army Engineers and Federal Power Commission permittees, W. R. King, whose Chattanooga district included Florida, established a suboffice in Florida on May 1, 1930, with D. S. Wallace in charge. Ocala was selected for the suboffice because it was a central point from which to operate the stations, particularly four new stations on the Oklawaha River, and not least important, because rent-free office space could be obtained in no other city in the State. The importance of being close to the State agencies was not a controlling consideration, as there was no single cooperating State agency. With State cooperation effective in July 1930, Wallace hoped to create sufficient interest in stream-gaging in Florida to justify a separate district, and as he was willing to take the chance with very limited funds, a separate district was created on August 4, 1930. In that connection Mr. Wallace writes:[411]

[411] Letter to author.

> For several months I carried on by myself, being office and field engineer and clerk combined, in other words, from office boy on up or boss on down, depending on one's view.

Sixteen stations were in operation at that time.

Mr. Wallace's optimism was justified, not so much on the grounds of obtaining increased State cooperation as on increased Federal funds, and the personnel had been increased to four at the end of the period, and the number of stations to 56. The number of recorders was increased from none to 31. Three cableways were installed.

Stream gaging was very different from that in other districts and presented many interesting and difficult problems. Except in northern Florida, the streams generally have flat slopes, many are clogged with water hyacinth and other aquatic growths, resulting in velocities as low as a tenth of a foot per second or even less. To check meter determinations of such velocities, rod floats were made in jointed sections for use in water of different depths. In general, the velocities measured by floats agreed closely with meter observations.

Because of the flat slopes, tidal influence extended long distances above the mouths of many streams, and, where necessary, slope stations were operated. Three such stations were operated during the period. Because of the constantly changing stage and the variable backwater in the extremely flat slopes, it was necessary to use recorders and each station was equipped with two, having a ratio of 10:12 or nearly natural scale, that were set to thousandths of a foot by means of hook gages. This precision was necessary for measuring the slope which frequently was less than a tenth of a foot in 5 miles. To avoid the possibility of negative readings, zeros of the gages were placed a foot or more below mean sea level. Referring to the accuracy of the records obtained at these stations, Wallace writes:412/

412/ Letter to author.

> In spite of the almost impossible conditions, we obtained surprisingly good results. On the St. Johns River the Army Engineers measured at frequent intervals throughout day and night for two- or three-week periods, and our curves generally gave very close agreement with the mean of their measurements.

Boats were used commonly in making measurements as many streams are deep and navigable, and at several gaging stations no bridges were available. The cost of cableways was prohibitive because of the clearance needed for navigation. Also, the banks were so low and marshy that a slight rise would cause the streams to overflow low, wooded valleys on both banks. For use in making measurements, light booms with wooden reels were made locally and used on rowboats which were hired locally. The boat was held in position by a light cable stretched across the stream.

In describing the work of the district, Wallace writes:413/

413/ Letter to author.

> I found soon after arriving in Florida, that I need not look for section controls, and I found after several years of stream gaging that we could develop some really good records from channel controls which would remain fairly constant. * * * I have been up and down many of the

Florida streams by boat and the experience was a very enjoyable and different one because of the densely wooded low banks with sub-tropical vegetation and the abundance of fish, reptile, and bird life which was very different from most of the other States.

Florida abounds in large springs, a dozen or more having discharges exceeding 100 second-feet, and Wallace felt that such an important source of water supply should not be neglected. He accordingly established stations on six large ones and made monthly measurements. The largest, Silver Spring, has an average discharge of more than 800 second-feet. In addition to furnishing valuable data on actual flow, the records served as a rough index of ground-water levels. Ground-water and surface water are very closely related in Florida, and as funds for investigating the former were very limited, a few index wells were read for the Ground Water Division in connection with routine field work.

Mr. Wallace was district engineer during the period and had the following Civil Service engineering assistants:

Verne Alexander	Jan. 2, 1931 to Aug. 16, 1934
R. P. Mangold	Jan. 1, 1932 to Oct. 1, 1934
H. A. Taylor	Sept.10, 1934 to June 5, 1937
J. W. Kuhnel	Dec. 4, 1934 to Aug. 31, 1936
E. L. Hendricks	Apr. 22, 1935 to June 30, 1939
B. P. Slater	Oct. 11, 1937 to June 30, 1939
H. H. Cooper, Jr.	Sept.26, 1938 to June 30, 1939.

Montgomery, Ala.- Before Army-Engineer cooperation was started in 1928, the States of Georgia, Florida, Alabama, Mississippi, and Louisiana were a part of the Chattanooga district, by which 13 stations were being operated in Alabama and Florida. Army-Engineer cooperation increased the number of stations in the five States to 46, and it was felt that a district office should be established in order to maintain those stations, except a few in Florida retained by the Chattanooga district, even though no State cooperation was in effect. Accordingly, C. E. McCashin was transferred from the Texas district on September 16, 1928, and established a district office in Tuscaloosa, Ala., in space provided by the Army Engineers at their district headquarters.

Describing his early "troubles" Mr. McCashin writes:[44]

[44] Letter to author.

When I got there, there were 46 stations (of which 33 had just been installed and were unrated), mostly staff gages with about 10 water-stage recorders to be constructed. I had no force except two inexperienced junior engineers and one experienced engineer. Within a month the experienced engineer fell and was killed, and during the first eighteen months I saw one junior engineer three times because the balance of the time he was measuring floods. We had the maximum rainfall of record in that area during the first year I was there. At Tuscaloosa * * * we had 87 inches of rainfall in 12 months.

The Army-Engineer cooperation continued until 1931, and the number of gaging stations, including those maintained for permittees and licensees of the Federal Power Commission, increased to 71 during that period. Anticipating the discontinuance of Army-Engineer cooperation, Mr. McCashin almost from the beginning started a campaign of education as to the controlling importance of water in all five States.[415] But

[415] p. 30.

the depression was on and his educational program was successful only to a limited extent. As he describes the financial situation,[416]

[416] Letter to author.

> * * * each year for the first few years the district faced a blank wall as far as finances went (as the announcement of the annual Army-Engineer allotment was not made until August or September.) The financial status was like a hydrograph of a power-regulated stream and each year I put up every man in the district for transfer and each year lost the best of the flock.

But Federal funds with a small amount of local assistance kept the district alive, and with the gradual increase in State cooperation the financial status was improved. In August 1930, Florida became a separate district, as did Georgia in March 1937, leaving at the end of the period the States of Alabama, Mississippi, and Louisiana in the Montgomery district. After the separation of Florida and Georgia from the district, the number of stations was decreased to 55 in 1938. Thereafter, a resumption of Army cooperation and an increase of State cooperation resulted in the establishment of additional gaging stations which brought the total to 141 by June 30, 1939. Much of that increase came during the last year of the period.

After the discontinuance of Army-Engineer cooperation on September 30, 1931, and the suspension of Alabama cooperation in 1932, Mr. McCashin felt that the district office should be moved to Montgomery, the State capitol, in order to service better the needs of State officials. This was done on June 7, 1933. With substantial State cooperation, suboffices were established in Jackson, Miss. on August 5, 1938, and in Baton Rouge, La. on August 16, 1938. A resident engineer was detailed to the Vicksburg station on the Mississippi on its establishment in July 1931.[417] Similarly, an engineer was

[417] p. 164.

detailed to the cooperative project of the Flood Coordinating Committee in the Tallahatchee Basin,[418] which was started in January 1939.

[418] p. 90.

A special investigation which lasted from November 1933 to June 1935 was made at Warm Springs, Ga., in cooperation with the Ground Water Division.[419] The Surface Water participation consisted

[419] p. 351.

in the maintenance of gaging stations on Warm Springs and 10 other springs, both warm and cold, and the maintenance of two rainfall stations. The discharge of the springs was reported in gallons per minute.[420] In des-

[420] Water-Supply Paper 819.

cribing this project, D. H. Barber writes:[421]

[421] Letter to author.

> The Ground Water Division was short of men, and after the geologists finished their intensive work * * * it was easier for us to carry on certain of the studies from Montgomery * * * even though some of them were more closely related to ground water than to surface water.

Floods during the period reached stages at some stations much higher than those previously recorded. At the station on Strong River at Dlo, Miss., the flood of 1935 overtopped by 8 feet the previous record stage. At that time the highways were under water and as the railroad bridges were the only structures above the flood, it was necessary to make measurements from them. As an example of the difficulties to be overcome, in measuring the discharge at the Merrill station on the Pascagoula River, it was necessary for the Survey engineer to travel 8 miles from the point on the right bank of the flooded area where he had parked his car to reach the left bank of the measuring section. This was done by trail, railroad speeder, and on foot along the railroad. At that station almost as much of the peak discharge was carried by the overflow area, which had a width of about 7,000 feet, as by the main channel with a width of 400 feet.[422]

[422] Water-Resources Bulletin, Apr. 10, 1935, p. 35.

During the period 84 recorders were installed, of which 60 were in concrete structures, 6 in bridge piers, and the others in pipe or timber installations. The Vicksburg recorder was installed in a bridge pier having a height of 120 feet.[423] The highest recorder

[423] p. 164.

shelter constructed by the Survey was about 88 feet, on the Alabama River at Claiborne. Four concrete structures ranged from 71 to 80 feet. Two cables were installed.

Mr. McCashin was district engineer until September 18, 1934, when he was transferred to the Chattanooga office and was succeeded by D. H. Barber who had been in the district since October 16, 1933. Miss Annie L. Hardin was district clerk. Other Civil Service engineering personnel were:

P. E. Hanson	Sept. 1, 1928 to Oct. 22, 1928
C. H. Prior	Sept. 1, 1928 to May 1, 1933
K. C. Tippy	Sept. 1, 1928 to Sept. 15, 1929
P. P. Livingston	Nov. 19, 1928 to July 1, 1930
W. S. Eisenlohr, Jr.	Mar. 11, 1929 to Apr. 6, 1931
J. L. Saunders	Apr. 8, 1929 to Apr. 21, 1934

E. J. Tripp	July 1, 1929 to Apr. 15, 1932
D. M. Corbett	Sept. 5, 1929 to June 13, 1932
W. M. Littlefield	Oct. 17, 1932 to Apr. 8, 1933
I. E. Anderson	(Mar. 11, 1930 to Apr. 15, 1932
	(July 26, 1932 to Nov. 5, 1937
D. D. Lewis	Nov. 3, 1933 to Jan. 28, 1936
E. B. Rice	Nov. 15, 1934 to June 30, 1939
S. C. Moore	Mar. 19, 1935 to June 30, 1939
J. K. Searcy	Apr. 18, 1935 to June 30, 1939
R. E. Curtis	Apr. 27, 1935 to Sept.11, 1937
J. S. Hale	Feb. 20, 1937 to Dec. 16, 1938
W. S. Daniels	July 1, 1937 to June 30, 1939
D. F. Dougherty	July 7, 1937 to June 30, 1939
H. C. Bolon	June 13, 1938 to June 30, 1939
C. H. Hardison	July 25, 1928 to June 30, 1939
E. J. Hanemann	Aug. 11, 1938 to Apr. 10, 1939
R. E. Marsh	Aug. 16, 1938 to June 30, 1939
E. H. Orleman	Oct. 25, 1938 to June 30, 1939
E. I. Clancy	Nov. 3, 1938 to June 30, 1939
N. O. Thomas	Nov. 4, 1938 to June 30, 1939
W. C. Griffin	Nov. 16, 1938 to June 30, 1939
F. B. Sessums	Mar. 22, 1939 to June 30, 1939.

Charleston, W. Va.- The Charleston district was established on July 1, 1929, to handle increased State cooperation in West Virginia.[424]

[424] p. 33..

When Wm. Kessler, the district engineer, sought office quarters at Charleston, he found none available in either Federal or State buildings. In South Charleston, 4 miles distant, the Naval Ordnance plant which had been built during World War I, was closed, but the large administration building was open and in it ample space was available. He therefore established the district office in that building.

Although the district comprised the whole of the State of West Virginia, the stations in the Potomac River Basin in West Virginia continued to be operated by the Middle Atlantic States district, as formerly, and the Charleston district allotted annually the funds needed for that purpose. The stations in West Virginia formerly maintained by the Charlottesville district were transferred to the new district and during the first year, Army-Engineer and State cooperation, and Federal Power Commission permittees, increased the number of stations to 48. A few additional stations were established later chiefly in connection with Army-Engineer studies, and on June 30, 1939, 54 stations were being maintained, of which 41 were in cooperation with the Army Engineers. Thirty-five stations were equipped with recorders chiefly in concrete shelters, with a few in pipe wells. Referring to one installation, Kessler stated:[425]

[425] Water-Resources Bulletin, Sept. 10, 1929, p. 7.

> We are installing a recorder on the Greenbrier at Alderson, which has been operated as a chain or staff gage since 1895, and it is about time to reward it with a recorder.

Severe floods occurred during the period and as the highways were frequently impassable, attempts to obtain flood measurements were not always successful. Describing one such experience, Kessler stated:[426]

426/ Water-Resources Bulletin, Sept. 10, 1932, p. 27.

> Anticipating a flood on the Gauley, we made a trip to measure the Williams River in the upper Gauley Basin, July 4. This measurement was never made as 5 feet of water covered the road leading to the station. Then attempted to visit the station on the Elk River at Webster Springs, but the attempt was abandoned when a lake 3 feet deep was encountered on the main road.

Returning to the hotel, which was 7 feet above the roadway, Kessler found the water 18 inches deep on the floor. Not to be baffled completely, he spent the night setting high-water marks by flashlight. Two weeks later he ran the high-water slopes and computed the peak discharges. As a result of this and later experiences, it became the district practice for each engineer to reach one station on receipt of flood warnings, await the flood's arrival, and make as many measurements as possible instead of attempting to reach several stations and perhaps miss the flood entirely.

The flood of March 1936 was the highest recorded on the upper Ohio River. Immediately following it, a considerable number of high-water marks were painted on bridges and houses along the Ohio River from Huntington to Wellsburg. PWA funds allotted for the study of that flood were devoted to compilation of hourly discharges, intensive study of high-water curves and extensions, compilation of rainfall and other climatological data, and preparation of a report which was included in Water-Supply Paper 800.[427]

427/ Letter from Wm. Kessler to author.

The West Virginia district found, as did several other districts, that the single circuit meter hookup served as an excellent radio receiver. While measuring the Monongahela at Fairmount, which was near a broadcasting station, the engineer making the measurement was regaled by concert music, stock reports, and other programs for a period of three hours. The reporter of this phenomenon was discretely silent regarding the accuracy of the measurement.

Mr. Kessler continued as district engineer during the period. Other Civil Service engineering personnel were:

M. T. Thomson	July 1, 1929 to June 15, 1931
A. O. Patterson, Jr.	Aug. 24, 1932 to July 20, 1935
E. J. Tripp	(Dec. 6, 1934 to Feb. 28, 1937
	(Oct. 4, 1937 to Nov. 30, 1937
R. F. Conard	Mar. 8, 1937 to June 30, 1937
H. A. Taylor	June 9, 1937 to June 30, 1939
H. A. Weggel	Nov. 22, 1937 to June 30, 1939
L. B. Holland	Feb. 1, 1939 to June 30, 1939.

Louisville, Ky.- Although the district was not actually organized until April 18, 1938, with F. M. Veatch as district engineer, two members of the district reported April 1, and started the installation of stations. Seven stations were transferred to the new district from the Indianapolis district, four from the Chattanooga district, and one on the Ohio at Metropolis, from the St. Louis office. By means of the State cooperative funds and cooperation with the Army Engineers, which latter agency furnished most of the field data for a considerable number of stations, the number of stations was increased to 32 by the end of the fiscal year 1938, and to 50 June 30, 1939. The increase during the last year was due chiefly to the WPA project for the construction of new stations.[428] Thirteen stations were equipped with recorders. As

[428] p. 96-97.

many of the stations were on navigable streams having locks and dams, 13 were operated as slope stations either during the entire year or through periods of high water. Under the cooperative agreement with the Army Engineers, the Survey made check measurements at the Army stations and computed the records. The only Ohio River station operated entirely by the Survey was that at Metropolis.

The short life of the district during the remainder of the period was devoted largely to establishing new stations. The outstanding construction of the Louisville station,[429] started soon after the

[429] p. 170.

district was organized.

Mr. Veatch was the district engineer and had the following Civil Service engineering assistants:

F. N. Hansen	Apr. 1, 1938 to June 30, 1939
A. L. Reed	Apr. 1, 1938 to June 30, 1939
R. E. Fish	Dec. 1, 1938 to June 30, 1939
M. I. Rorabaugh	Jan. 16, 1939 to June 30, 1939.

Chattanooga, Tenn.- At the beginning of the period the Chattanooga district was operating 59 stations in Tennessee, and operating or supervising the operation of 7 stations in Georgia, 15 in Alabama, and 9 in Florida. With the creation of an office in Alabama in September 1928, the Georgia stations and most of those in Florida and Alabama were transferred to it. Thereafter the sphere of operation was limited chiefly to Tennessee and the Tennessee Basin in Alabama. During the first 3 years the number of stations was gradually increased to 77. In 1932, W. R. King, district engineer, began cooperation with several small cities and established 38 gaging stations on small streams nearby. The stations were equipped with staff gages and in an effort to promote the interest of cities' people in their water-supply and pollution problems, King arranged to have the gage readings furnished gratis by citizens. This did not prove to be such a good idea as, like observers the country over, many lost interest, and it was necessary to pay them after the novelty had worn off; also, some of the records were so uncertain that 15 stations were soon dropped and later all were discontinued. Thus ended another "noble experiment."

Another experiment, this one a success, was that tried at gaging stations on small streams that had extremely high stages at rare intervals only. The cost of building structures sufficiently high to be above stages as great as 60 feet was prohibitive, and in 1929 King installed three recorders at elevations which he knew to be as much as 20 feet under maximum flood stages. The instruments were equipped with water-tight metal covers to protect the vital parts of the recorders.[430] These installations proved very satisfactory as

430/ Water-Resources Bulletin, Nov. 10, 1929, p. 7.

the recorders operated accurately to the stages at which the float came in contact with the recorder shelf, and again when the water fell below those stages. From high-water marks, the stages of the peaks were determined and the missing parts of the hydrographs were sketched in.

From 1934 to the end of the period the chief activities were those required by the cooperation with the TVA and described in some detail on pp. 657 to 665. Those activities were concerned with equipping existing stations with recorders and cables where needed, rather than with increasing greatly the number of stations. Thirteen stations were equipped with auxiliary staff gages, and operated as slope stations.

An investigation worthy of note was made on the Tennessee River near Chattanooga, in the spring of 1939. Its purposes were to compare the accuracy of boat and bridge measurements, and to determine the effect of variable slope on the discharge at various sections in a 4-mile stretch of river. The measurements of discharge were made at a bridge several miles downstream. Various slope determinations and combinations of slope reaches were used through a considerable range of stage and over a period of several months.[431]

431/ Statement of H. C. Bolon to author.

The number of gaging stations was gradually increased to 118, of which 102 were equipped with recorders. A total of 105 recorder installations were made of which 72 were concrete structures and the others pipe wells chiefly. The greatest overall height was 110 feet on the Cumberland River at Burnside, Ky. The range of stage is about 70 feet and the pipe well was built sufficiently high to reach the bridge floor. The highest concrete structure was 69.5 feet. Among the concrete structures was the one on the Mississippi River at Memphis.[432] Thirty-seven cableways were erected, the longest having

432/ p. 165.

a span of 1,646 feet across the Tennessee River at Florence, Ala. A cableway across the Tennessee River at Breedenton was 1,600 feet long between end supports. It was supported by a tower 65 feet high, 900 feet from one end, thus dividing the total span into two separate spans. Four artificial controls were installed.

Mr. King was district engineer until his death July 26, 1934. He was succeeded by C. E. McCashin who was transferred from the

Montgomery district. Miss Gladys Boulton was district clerk. Other Civil Service engineering personnel were:

Warren Withee	July	1, 1928	to Feb.	3, 1938
P. R. Speer	July	1, 1928	to July	1, 1929
P. E. Hanson	July	1, 1928	to Aug.	31, 1928
C. E. Knox	July	1, 1928	to May	23, 1936
C. H. Prior	July	1, 1928	to Aug.	31, 1928
	June	1, 1933	to Sept.	1, 1937
P. P. Livingston	July	1, 1928	to Nov.	18, 1928
K. C. Tippy	July	1, 1928	to Aug.	31, 1928
Duncan Charlton	July	1, 1928	to Aug.	16, 1933
Murray McGovern	Feb.	7, 1929	to Oct.	31, 1929
M. R. Williams	Apr.	18, 1929	to Feb.	27, 1937
W. R. Eaton	June	3, 1929	to Aug.	15, 1931
	May	1933	to June	30, 1939
D. S. Wallace	July	8, 1929	to July	31, 1930
S. C. Moore	June	14, 1930	to Nov.	30, 1931
W. J. Perry	July	1, 1930	to June	30, 1939
F. W. Wagener	Sept.	11, 1930	to Nov.	30, 1930
H. M. Erskine	Jan.	16, 1931	to Apr.	1, 1938
R. P. Mangold	Jan.	20, 1931	to Dec.	31, 1931
K. M. Kelley	Feb.	22, 1934	to Apr.	9, 1935
J. I. Perrey	Sept.	20, 1934	to May	25, 1939
G. H. Wood	July	12, 1935	to June	30, 1939
A. O. Patterson, Jr.	July	22, 1935	to June	30, 1939
Chas. Wells	Nov.	22, 1935	to June	30, 1939
D. S. Jenkins	Sept.	5, 1935	to Dec.	2, 1935
D. D. Lewis	Jan.	30, 1936	to June	30, 1939
R. H. Otness	May	19, 1936	to June	30, 1939
W. S. Hamilton	Dec.	9, 1936	to May	28, 1937
Max Noecker	Mar.	1, 1937	to June	30, 1939
M. F. Cook	June	4, 1937	to June	30, 1939
H. C. Bolon	June	12, 1937	to June	12, 1938
L. T. Keefe	Dec.	30, 1937	to Oct.	18, 1938
F. C. Ames	Jan.	26, 1938	to June	30, 1939
D. M. Corbett	Apr.	30, 1938	to June	30, 1939
W. M. Branch	Sept.	19, 1938	to June	30, 1939
E. N. McClure	Mar.	1, 1939	to June	30, 1939

Columbus, Ohio.- The enlarged program in Ohio with its goal of 120 stations, which had been started in 1923, [433] was continued during the

433/ p. 29, 1919-1928.

first 3 years of the present period and the number of stations was increased from 98 to 106. The curtailment of State funds in the years 1932 to 1935, and the failure of the legislature to appropriate funds for the years 1936 to 1938, made it necessary not only to discontinue the expansion program, but also to reduce drastically the number of stations. The low point in this reduction came in 1937, when only 44 stations were operated. The greatest reduction was in the Great Lakes Basin where the 30 stations were reduced to 4.

The Army-Engineers' flood studies of the Ohio River which were enlarged during 1937 and 1938, resulted in the establishment or

reestablishment of 35 stations, and other cooperation made possible the establishment of other stations, with the result that at the end of the period 91 stations were being operated, of which only 4 were in the Great Lakes Basin. Seventy-five of the stations were equipped with recorders.

This was a period of intensive work as funds from various cooperative agencies, chiefly Army Engineers and PWA, made possible the equipment of many stations with water-stage recorders. A total of 56 recorder installations were made of which 36 were standard concrete structures and 20, chiefly for Army-Engineer stations, were galvanized iron pipe wells, as the Army Engineers did not approve the more expensive concrete structures for those stations. Of the concrete installations, the most notable were two on the Ohio River near Huntington, W. Va.[434] Fifteen cableways were erected, and 6 artificial

434/ p. 169.

controls, the longest being 200 feet, were constructed.

When Army-Engineer cooperation was started in 1928, the Columbus district was called upon to install 21 stations in Indiana and western Kentucky. After installing these stations, Lasley Lee found that he could not operate some of the stations economically and the Indiana stations and a part of the Kentucky stations were transferred to the Urbana district in January 1929. The remaining Kentucky stations were transferred to the newly-established Indianapolis district in 1931.

An unusual condition experienced in the Columbus district, although fortunately only at a few stations, was an aquatic growth which was so luxuriant at certain times that it was necessary to cut a wide swath through it before a discharge measurement could be made. The luxuriance of the growth was apparently due to pollution by sewage.[435]

435/ Water-Resources Bulletin, Nov. 10, 1932, p. 21.

Flood investigations played a very considerable part in district activities. Outstanding floods occurred in the Muskingum River Basin in August 1935, in the upper Ohio River Basin in March 1936, and in the entire Ohio River Basin in January 1937. Field investigations were made to obtain all pertinent data on rainfall and run-off, as a basis for this preparation of reports on those floods.[436]

436/ p. 134.

During the period most of the work of developing new equipment and procuring it by contract for use by other districts, was made the responsibility of the Columbus district.[437] This work constituted a

437/ p. 111

not inconsiderable part of the district activities.

Lasley Lee continued as district engineer until his death on November 15, 1937. He was succeeded by C. V. Youngquist, who had been in the Ohio district since March 2, 1928. Mrs. Anita J. Lawler was

district clerk. Other classified Civil Service engineering personnel were:

J. I. Perrey	July 1, 1928 to Sept. 26, 1934
E. P. Coady	July 1, 1928 to Feb. 18, 1930
E. G. Barron	July 2, 1928 to Nov. 2, 1929
F. L. LeMert	July 9, 1928 to Dec. 25, 1928
LeRoy Engstrom	July 13, 1928 to Sept. 16, 1931
G. E. Ferguson	Aug. 8, 1928 to Aug. 31, 1928
C. L. Muntz	June 24, 1929 to Mar. 15, 1931
H. E. Cox	Nov. 8, 1929 to June 30, 1939
J. P. Bonner	Feb. 17, 1930 to Aug. 26, 1931
H. P. Brooks	June 16, 1930 to Aug. 28, 1938
H. E. Eagle	July 1, 1930 to Aug. 9, 1930
A. G. Hely	July 1, 1930 to Aug. 9, 1930
G. R. Smith	June 27, 1936 to July 26, 1937
C. Reber	Jan. 11, 1937 to Mar. 14, 1938
E. J. Tripp	July 7, 1937 to June 30, 1939
C. V. Mills	Apr. 27, 1938 to Oct. 5, 1938
C. J. Rossow	Oct. 17, 1938 to June 30, 1939
L. L. Sphar	Nov. 28, 1938 to June 30, 1939
E. H. Curtis	Jan. 10, 1939 to June 30, 1939.

Indianapolis, Ind.- Upon the completion of cooperative agreements with the State Department of Conservation of Indiana,[438] the

438/ p. 36.

Indianapolis district was established on August 18, 1930, with H. E. Grosbach as district engineer. The Army-Engineer stations in the Licking, Green, and Kentucky River basins in Kentucky, and those in Indiana which had been operated by the Urbana district, were transferred to the new district. The short-lived Lansing district was discontinued in June 1931 and the records were turned over to the Indianapolis district together with the supervision of 13 stations that were continued by the Michigan Stream Control Commission, and private assistance. Cooperation in Michigan was resumed in November 1932 and continued during the remainder of the period, this adding the lower peninsula of Michigan to the Indianapolis district. When the Louisville district was created in April 1938, the Kentucky stations were transferred to it.

In Indiana, the 26 stations operated by the State and 4 Army Engineer stations operated by the Urbana district became a part of the cooperative program. The number of stations was gradually increased to 38 by the end of the period. Of these, 25 were equipped with recorders, 19 in concrete structures, 4 in pipe wells, and 2 in timber structures. Two stations were equipped with cables. The recorder installation involving the greatest difficulties was that made for the Weather Bureau on the Ohio River at Evansville.[439] The

439/ p. 170.

work was most intensive in the vicinity of Indianapolis. Stations at a number of dams on the West Fork of the White River maintained for power and municipal water supply, involved the installation of six

recording gages in a stretch of 18 miles, and a seventh on a tributary stream. Because of small fall some of the stations were affected by variable slopes and backwater, and two were operated as slope stations. At the station near Nora, a recorder installed some 4 miles above the dam was believed to be above backwater from the dam, as there was a riffle some distance below the station. Measurements made after the installation of the recorder showed definitely, however, the effects of the operation of the gates in the dam, which caused at low stages differences in flow at the same stage of as much as 40 per cent. A second recorder was then installed at the dam, and a special three-dimension computation method was devised for the station,[440] using the

[440] Water-Resources Bulletin, May 16, 1932, p. 19.

slope as determined by the recorders. The Vincennes station on the Wabash River also was operated as a slope station, the high-water slope being determined by means of an auxiliary gage 33 miles downstream. The station on the Wabash River at Lafayette was used as a stream-gaging laboratory by engineering students of Purdue University.

In Michigan a district office was opened at Lansing on August 24, 1930, with Berkeley Johnson as district engineer. At that time, stream-flow records at six stations were being obtained by private interests, chiefly for power. Twenty-three stations, mostly equipped with staff or chain gages, were established within a few months. One station was situated near the Michigan State College, the engineering department of which cooperated in the installation and maintenance of a recorder and used it as a laboratory for the engineering students. Three stations were established within the limits of Detroit, for which the City of Dearborn (a city within a city) furnished gage heights and some discharge measurements. These stations were all situated in southern Michigan where the population was concentrated and where stream pollution was serious. With the ending of cooperation in June 1931, the State continued the operation of 13 stations with city and private assistance. Cooperation was resumed in November 1932, under the Indianapolis office and the 13 stations constituted the nucleus of the program; 7 additional stations were established or reopened, making a total of 20 stations during that fiscal year. The number of stations was gradually increased to 30 in 1939, of which 17 were equipped with recorders. Five stations were equipped with cables, and one with an artificial control.

In Kentucky, the Ohio district established 20 stations in the Licking, Green, Kentucky, and Tradewater Basins, as a result of Army-Engineer cooperation which started in 1928. A part of these were operated by the Urbana district from January 1929 to August 1930, others by the Columbus district until August 1930. Thereafter all stations in these basins were operated by the Indianapolis district. The discontinuance of both Army-Engineer and State cooperation in June 1932, reduced the number of stations from a high of 27 in 1931 to 6 in 1932. The establishment of a station on the Ohio River at Louisville, Ky., in 1935, increased the number to 7. One was operated as a slope station with staff gages 8 miles apart. The flood of January 1937 was so severe that the recorders on Kentucky rivers were submerged even though they had been installed at elevations well above previous high-water marks. The flooded areas prevented the use of ordinary

means of transportation, and as the air was the only medium unaffected by the flood, W. D. Mitchell used a plane in an attempt to reach the Kentucky River stations. No airports were available for landing but a race track near Versailles afforded a landing field. As no other landing fields were available, only the one station near Versailles could be reached. Refusal to accept hospitality in the form of liquid refreshments appears to have been regarded in the same light in Kentucky as in the old West. Two Survey engineers while working at a gaging station were accosted by a native and offered a drink. Upon their refusal the aforesaid native started toward the house to get his gun, saying that unless they accepted his invitation he would shoot. It is almost needless to add that by the time he returned the engineers had disappeared.

Mr. Grosbach continued as district engineer of the Indiana district during the period, and had the following Civil Service engineering assistants:

F. L. MeMert	Aug. 18, 1930 to June 30, 1931
W. P. Cross	Sept. 8, 1930 to Jan. 31, 1932
W. D. Mitchell	Sept.26, 1930 to Apr. 4, 1939
W. P. Tiencken	Jan. 9, 1935 to Sept.29, 1935
C. P. Parkinson	Jan. 29, 1936 to Apr. 11, 1938
L. T. Keefe	July 21, 1937 to Dec. 28, 1937
I. A. Heckmiller	Aug. 23, 1937 to June 30, 1939
J. I. Perrey	May 26, 1939 to June 30, 1939
L. E. Widman	June 16, 1939 to June 30, 1939

Urbana, Ill.- The Urbana district was limited to the State of Illinois until January 1929, when 21 stations which had been installed for the Army Engineers in Indiana and Kentucky by the Columbus district were turned over to it. An engineer was transferred with those stations and by that action to Urbana district lost its one-man status which it had held during the previous period. In 1929 a lone station in Iowa was reestablished in connection with a Federal Power Commission permit. The Indiana and Kentucky stations remained within the Urbana district until August 1930 when the newly established Indianapolis district took them over.

The small slope of many Illinois streams led to marked variations in slopes on rising and falling stages, and it was necessary to take these changes into account in computing the records. A start in this work had been made during the previous period when the records for the Illinois River at Beardstown had been computed on that basis.[41] With

[41] p. 138, 1919-1928.

more funds available during the present period, and with a mathematically-minded district engineer, additional stations were converted into slope stations by the addition of second gages at each station. The first of the stations so converted was on the Wabash River at Mt. Carmel, which was operated as a slope station beginning in 1930, when a second gage was installed 3 miles downstream. In 1933, however, it was discovered that the second gage had a well-defined and effective control, and the station was moved to that gage and therafter operated as an ordinary stage-discharge station. From 1931 to 1938, when the construction of the

Lagrange dam put the Peoria station on the Illinois River out of commission, the slope at that station was measured by means of two Army-Engineer staff gages situated 9 miles apart. The station on the Big Muddy River at Murphysboro was not only affected by the variable slope due to rising and falling stage, but also by backwater from the Mississippi River to such an extent that at times the flow was actually negative. Beginning in 1931 the slope was measured by means of a recorder at the station and an auxiliary gage located 7,000 feet upstream. The fall so measured varies between a minus quantity of a few hundredths of a foot to +1.19 feet. J. H. Morgan states[442] that this

442/ Statement to author.

station was used as a laboratory in which studies of the effect of variable slopes were made, and as a result of these studies, it was the first station at which the four elements of stage, slope, discharge, and backwater were considered in computing the records. The station on the La Moine River at Ripley, Ill., was also operated as a slope station until 1935. With reference to slope stations, Morgan writes:[443]

443/ Letter to author.

> About that time we learned to differentiate between flat water-surface slopes produced by backwater and flat water-surface slopes produced by flat bed gradients. We learned that in the first case we could dispense with slope ratings and apply percentage-submergence ratings directly to normal discharge ratings and get better results than with the slope ratings.

During floods the slight fall of the streams causes widespread overflow which required special equipment at some stations. At flood stage, the Wabash River at Mt. Carmel overflowed the valley to a width of 7 miles. Measurements were made from the nine railraod bridge openings having a total width of 7,100 feet in the overflow section. The overflow openings carried nearly as much discharge as the main channel, and as the overflow openings were pile-bent trestles, a special measuring car was devised by L. C. Crawford and J. H. Foster.[444]

444/ Water-Resources Bulletin, Oct. 10, 1935, p. 34.

It was a movable boom whereby the meter could be placed sufficiently upstream from the piling to be uninfluenced by it. The boom was mounted on four wheels which operated on the railroad track; the railroad company furnished a gasoline speeder to move the boom. A flood measurement required 24 pages of notes for the 179 measuring sections. A station worthy of mention was that on the Big Muddy River at Plumfield, which had been maintained since 1914. L. K. Sherman, a consulting engineer of Chicago, used those records, one of the longest in the State, in devising the unit-hydrograph method for computing flood flows.[445]

445/ Letter from J. H. Morgan to author.

The district operations during the period were intensive rather than extensive, as the number of Illinois stations was only increased

from 4 to 23, of which more than half were installed in concrete structures. One of these had a height of 45 feet, the lower 11 feet of which was in solid rock. Other types of installation were timber shelters on concrete wells and corrugated iron pipes. Three cables were installed, the longest span being 700 feet. Seven artificial controls of various types were constructed. Two were of special design for submerged controls giving a head of 0.2 to 0.3 foot, and had the bottoms of the V-notch at the stream bed which was a concrete slab. Another special control was designed for the Plumfield station on the Big Muddy River. The City of Zeigler had so raised the height of its dam that it drowned out the Plumfield station, and the river had so little fall that it was impossible to obtain low-water measurements within a distance of 16 miles upstream from the dam. The control which was a modification of a design developed in the Urbana district, was built with a middle gap of 10 feet the bed of which was composed of rock-fill placed lower than the crest of the control in order to concentrate the low-water flow for meter measurements.

Mr. Grosbach was district engineer until August 17, 1930, when he was transferred to the newly-created Indiana district and was succeeded by Mr. Morgan. Other Civil Service engineering personnel were:

F. L. LeMert	Dec. 26, 1928 to Aug. 17, 1930
P. J. Houser	Apr. 9, 1929 to July 13, 1929
E. F. Rutkowski	July 15, 1929 to May 31, 1930
L. C. Crawford	July 1, 1930 to Oct. 4, 1935
C. L. Muntz	Mar. 16, 1931 to Sept. 1, 1934
A. G. Hely	Apr. 1, 1933 to July 1, 1933
J. H. Foster	Sept. 8, 1934 to Dec. 10, 1938
H. G. Strom	Oct. 8, 1935 to Feb. 15, 1939
Meyer Kramsky	Sept. 7, 1937 to June 30, 1939
J. H. Montgomery	Feb. 1, 1939 to June 30, 1939
W. D. Mitchell	Apr. 5, 1939 to June 30, 1939.

Madison, Wis.- At the beginning of the period, the newly-established district in northern Minnesota[446] took over the operation of the stations

446/ p. 218.

in that part of the State, leaving those in the Mississippi drainage in Minnesota to the Madison district. On July 16, 1930, the Minnesota office was transferred to St. Paul, and the 12 stations in the Mississippi River basin in Minnesota were transferred to it. Thereafter, the area of the Madison district was limited to Wisconsin until March 1938, when the northern peninsula of Michigan was added to handle the cooperation with the Biological Survey[447], which led to the establishment and maintenance

447/ p. 88.

of 16 stations in that peninsula.

The transfer of the Minnesota stations to the St. Paul district left 41 stations in the Madison district and these were gradually increased to 60 in 1936. Wisconsin lakes are an important factor in attracting tourists, and the low years had so reduced the lake levels that in 1936 gages were placed on 23 lakes as a step in an investigation to determine the cause of the recession and the measures needed to restore the lakes to normal levels.[448] Including the lake stations the number of gaging

448/ Water-Resources Bulletin, Oct. 10, 1936, p. 29.

stations in Wisconsin was increased to 89 at the end of the period. With the 16 stations in northern Michigan, the district was operating a total of 105 stations. The number of recorder installations was increased from 9 to 43, of which, 19 were concrete structures, 11 were concrete wells with timber shelters, and 2 were corrugated iron wells. Sixteen stations were equipped with cables.

In January 1934, the Coon Creek, Wisconsin, cooperative project with the Soil Erosion Service was started. Three gaging stations were equipped with recorders, and cables, and one Parshall flume were installed. A high degree of accuracy was required and as the streams were subject to short floods, a resident engineer was detailed to the project who made weekly measurements and additional measurements during floods. To measure all floods, many of which occurred at night, the stations were equipped with floodlights.[449] An assistant who analyzed sediment samples and help-

449/ Statement of S. B. Soule to author.

ed the resident engineer was furnished by the Soil Erosion Service. Sixteen rain gages of which 10 were recording gages, were also operated. Weekly observations at 14 ground-water wells were also made. The project was continued during the period.

The Seney Refuge project of the U. S. Biological Survey, in the Manistique River basin in northern Michigan[450] which began in March 1938,

450/ p. 88.

was cooperative in the sense that half of the field work was performed by each party. It was not necessary to detail a resident engineer to the project.

A comparison between computed records of discharge through a power plant and current-meter measurements showed surprisingly close agreement. Two meter measurements gave discharges of 1,640 and 2,490, and the computed discharge through the Rapide Croche Dam, 1,650 and 2,480 second-feet. In commenting on this comparison, S. B. Soulé stated:[451]

451/ Water-Resources Bulletin, Jan. 10, 1931, p. 15

> Of course, we do not believe that we can make discharge measurements correct within about half of one per cent, or that the power house computations were that accurate. It was, however, a very agreeable coincidence that two consecutive measurements checked so closely.

The deficiency tables which had been started during the previous period[452] proved of so much value that they were kept current during this

452/ p. 135, 1919-1928.

period. Also, the practice of publishing in the Water Resources Bulletin timely warning regarding necessary precautions was continued. In 1933, Mr. Soulé failed to contribute his annual warning, and Mr. Grover called attention to the omission and the need for the warning.[453]

453/ Water-Resources Bulletin, Dec. 11, 1933, p. 26

Mr. Soulé continued as district engineer until his retirement August 31, 1938. He was succeeded by F. C. Christopherson. Other Survey Civil Service Engineering personnel were:

A. H. Frazier	July 1, 1928 to July 1, 1930
S. H. Crowell	Apr. 11, 1929 to Dec. 13, 1929
C. C. Yonker	Jan. 1, 1930 to June 30, 1939
R. H. Brigham	May 5, 1932 to June 30, 1939
M. S. Sachs	June 19, 1934 to June 30, 1939
D. C. Hurtgen	Mar. 8, 1938 to June 30, 1939
J. H. O'Keefe	Feb. 13, 1939 to June 30, 1939

St. Paul, Minn.- The St. Paul district was reestablished on July 16, 1930. At the beginning of the period, Minnesota was a part of the Madison district which was operating 10 Minnesota stations. The special Roseau River investigation for the State Department,[454] which was started

454/ p. 159.

in July 1928, resulted in the establishment of six stations in northern Minnesota. To operate those stations and make the other investigations required, C. L. Batchelder was reinstated in the Survey, as district engineer with headquarters at Thief River Falls.[455] In 1929, the five

455/ p. 160.

stations in the Hudson Bay drainage of North Dakota, previously maintained under the supervision of the Wisconsin district, were transferred to Minnesota and by 1930, the number of stations in northern Minnesota and North Dakota had been increased to 26. In July 1930, an increase in State cooperation made it advisable to consolidate the Minnesota work

under one head, and on July 16 a district office was reopened in St. Paul, in the same quarters occupied prior to the discontinuance of the St. Paul office in July 1917. Mr. Batchelder was put in charge of the district and moved his headquarters to St. Paul. The new consolidated Minnesota district started with 38 gaging stations. When the district office was moved, the Thief River Falls office was retained as a sub-office.

Unlike the situation in most of the districts, Army-Engineer cooperation continued during the entire period, being confined chiefly to stations on the Mississippi River in the interest of navigation. Several stations were situated at points where bridges were not available for measurements and A. H. Frazier devised special boat-measuring equipment.[456] One result of the improvement of navigation was the construction

456/ p. 125.

of a dam which rendered the St. Paul station, records for which extended back to 1887, useless as a simple stage-discharge station, and it was thereafter operated as a slope station at low stages with water-stage recorders installed 7 miles apart.

The thousands of lakes in Minnesota are an important factor in attracting tourists and the dry years which persisted during most of the present period depleted the lakes to such an alarming extent that a State-wide program of control dams at the lake outlets was started. In connection with that program, stages of lake levels were needed and an increasing number of lake staff gages were installed, the number being 239 at the end of the period.

In North Dakota, Batchelder, operating from the Thief River Falls office, was maintaining seven stations of which two on the Red River had been maintained since 1901, and one on the Pembina River since 1903 with one break in the records. The other four were established in connection with international boundary problems. Cooperation with the Biological Survey in 1937 increased the number of stations by five, and other needs led to the installation of a few additional stations, bringing the total in North Dakota to 19 stations. The stream slopes are so flat, that of the Souris River being only a few hundredths of a foot per mile, that reversals and loops in the curves due to rising and falling stages occur at stages when the artificial controls are drowned and the natural channels are the controls.[457] Backwater from beaver dams was also a major

457/ Statement of C. H. Prior to author.

problem.

At the end of the period, 324 gaging stations, of which 239 were lake stations, were being maintained. Fifty-five stations, chiefly on streams, were equipped with recorders, 16 cables were installed, and 18 stations equipped with artificial controls, including 6 dams built for other purposes.

The cable installed on the Poplar River, at Lutsen, was reminiscent of the days of the Irrigation Survey; a traveller similar to that designed by Trowbridge about 1890,[458] was attached to the cable spanning a

458/ Follansbee, Robert, History of the Water Resources Branch of the

U. S. Geol. Survey to June 30, 1919, p. 61.

deep rocky canyon, by means of which the meter could be operated from the bank.459/

459/ Water Res. Bull, Feb. 1940, p. 37.

Mr. Batchelder continued as district engineer until his death on January 18, 1939. He was succeeded by P. R. Speer. Other Civil Service Engineering personnel were:

E. F. Chandler	July 1, 1928 to Dec. 31, 1930
K. B. Nelson	Dec. 31, 1929 to June 30, 1939
A. H. Frazier	July 1, 1930 to Jan. 5, 1935
Frank Stermitz	July 7, 1930 to Dec. 6, 1930
G. L. Oakland	July 8, 1930 to Nov. 11, 1938
O. B. Johnson	July 21, 1932 to Dec. 21, 1934
B. R. Colby	July 30, 1934 to June 30, 1939
O. H. Jeffers	Nov. 1, 1934 to June 30, 1939
J. W. Odell	Apr. 23, 1935 to Aug. 31, 1935
H. G. Strom	July 1, 1935 to Oct. 6, 1935
W. B. Hanlon	Oct. 4, 1935 to Aug. 10, 1937
C. H. Prior	Sept. 3, 1937 to June 30, 1939
A. V. Leppanen	Nov. 7, 1938 to June 30, 1939
J. C. Merrell, Jr.	Nov. 1, 1938 to June 30, 1939
R. E. Oltman	June 25, 1938 to June 30, 1939

Iowa City, Ia.- When cooperation was resumed in Iowa, a district office was opened in Iowa City on October 17, 1932, with R. G. Kasel as district engineer. In announcing the establishment of the new district, Mr. Kasel stated:460/

460/ Water-Resources Bulletin, Nov. 10, 1932, p. 30

> There have been 20 to 30 gaging stations operated in the State in past years. Which of these to put into repair and operation first is our most pressing problem.

During the period of non-cooperation, the Mississippi River Power Co. had maintained four of the old Survey stations. These stations were taken over by the Survey, nine others reopened, and two new stations established. An Army-Engineer station on the Mississippi River at Clayton which had been maintained since 1930 by the St. Paul district, was transferred to the Iowa City district. Thus by the end of the first year 16 stations were in operation.

With the gradual increase in cooperation, the number of stations was increased to 28 in 1936. Beginning in 1937, studies of the Army Engineers in connection with flood control required additional stations, and increased the total number to 59 at the end of the period. For convenience of operation, six stations in western Illinois, and two each in southwestern Wisconsin and northeastern Missouri were operated by the Iowa City district, making a total of 69 stations operated.

Twenty-eight stations were equipped with recorders, most of them in all-concrete structures or in concrete wells with timber shelters. Twelve

cables were installed, the longest span being 450 feet, and 8 artificial controls were built, the longest being 110 feet.

Iowa rivers are subject to floods which at times overflow the banks and isolate the recorder shelters. To reach the recorders and measure the overflow sections, Mr. Kasel obtained boat equipment of the type developed in the St. Paul district. This equipment was also used in checking measurements made from some bridges where measuring conditions were very poor.

During the drought years of 1934 and 1936, many miscellaneous measurements were made.

Mr. Kasel was in charge of the district from its reestablishment to the end of the period and had the following Civil Service engineering personnel:

S. K. Jackson	Nov. 6, 1933 to July 2, 1937
G. L. Whitaker	Oct. 5, 1934 to June 30, 1939
W. I. Travis	July 4, 1937 to June 30, 1939
V. A. Koelzer	Nov. 1, 1938 to June 30, 1939

Rolla, Mo.- At the beginning of the period the Rolla district comprised the States of Missouri and Arkansas, but in April 1929 the Arkansas stations were transferred to the newly-established Fort Smith district. In 1933, new Army-Engineer stations on the Mississippi River from Alton, Ill., to Memphis, Tenn., and on the Ohio River at Paducah, Ky., were installed and maintained by the newly-established St. Louis office which was under the supervision of the Rolla office. The Paducah station proved to be unsatisfactory and was soon abandoned. In its place a station was established farther downstream at Metropolis, Ill.[461]

461/ p. 168.

In May 1934, Army-Engineer stations on the Missouri River from Bismarck, N. D., to Omaha, Nebr., and on principal tributaries in North Dakota below Bismarck, and in South Dakota were transferred to the Rolla district, the Bismarck station from the Helena district, and the remainder from the Denver district. In 1935, the Memphis station was transferred to the Fort Smith district. Additional Army-Engineer stations in 1938, and a Biological Survey project the same year,[462] added the entire State

462/ p. 88.

of South Dakota to the Rolla district. Thus at the end of the period the Rolla district was operating stations in North Dakota, South Dakota, Nebraska, Missouri, and Illinois.

Army-Engineer cooperation continued during the entire period on a larger scale than in any other district. After the close of the "308" work, the construction of Fort Peck reservoir and its relation to navigation required the continuation of the stations on the Missouri River and principal tributaries, which was done by means of Army-Engineer and Federal-type-station funds. Additional cooperation with the Army Engineers beginning in 1933 resulted in the establishment of five stations on the Mississippi, Missouri, and Ohio Rivers. Flood-control work beginning in 1938 increased the number of Army-Engineer stations to 29.

The cooperation which resulted in the installation and maintenance of stations on the Mississippi and Ohio Rivers was closely related to the cooperation with the Army-Engineers' Kansas City district office on the lower Missouri River. In 1931, the Rolla district was maintaining stations at Bonnots Mill and Hermann, Mo. for the Army-Engineers' district office at Kansas City, and had been making frequent measurements at both of those stations during the open-water period, using an Army-Engineer boat with a crew of four men. At the same time the Army-Engineer district office at St. Louis was making almost daily measurements at St. Charles, 100 miles downstream from Bonnots Mills by means of a boat and crew of five men at very considerable expense. A comparison of the records obtained at St. Charles with those obtained at Bonnots Mills and Herman showed close agreement, indicating that the rating curves for the Survey stations based on measurements made at 10-day intervals gave practically as good records as the daily measurements. In March 1932 funds for the "308" investigation were running low, and the St. Louis office discontinued its measurements at St. Charles in favor of the Survey-operated stations. This comparative study constituted the first direct Survey contact with the Army-Engineers' St. Louis office, which had charge of operations on the Mississippi River below the Missouri to the mouth of the Ohio. The following year, in March 1933, H. C. Beckman arranged cooperation with the Army-Engineers' St. Louis office for the installation and operation of stations on the Mississippi and Missouri Rivers in the vicinity of St. Louis. During the first year the Army Engineers paid nearly the entire cost of the work, but during the next year about half of the cost was paid from PWA and Federal-station funds. This was the first time that the Survey had been able to share with the Army Engineers the cost of operating stations and was made possible by the allotment of PWA funds and the availability of Federal-station funds. Gaging stations were established on the Mississippi River at Alton, Ill., St. Louis and Cape Girardeau, Mo., and on the Missouri River at Ruegg, Mo., 8 miles above the mouth. These were operated by the Survey's St. Louis office. The Alton, Ill. and Ruegg, Mo. stations were equipped with wire-weight gages. The former was discontinued in January 1938, and the latter in October 1935.

When cooperation was started with the Army's St. Louis office in March 1933, the Army-Engineer staff gage was used at the St. Louis station. Within a few months PWA funds became available and a concrete well and shelter 6 feet by 6 feet in cross section, having an overall height of 65 feet, was constructed at the levee in St. Louis and a recorder installed. The lowest of three intakes was placed 8 feet below the ordinary low water and 5 feet below the lowest known stage. For flushing, the intakes were connected with the city water system. This installation was built by contract and cost $6,500. Discharge measurements are made from a highway bridge using a hand-operated reel and boom. Since the establishment of the St. Louis station, the discharge has varied from 649,000 second-feet to 27,900 second-feet.

Cooperation at the Cape Girardeau station was started in March 1933 using the Army-Engineer staff gage. In 1934, available PWA funds made it possible to install a recorder. The shelter which had an overall height of 59 feet was equipped with three intakes 4 feet apart, each attached to a flushing device. The lowest intake was 75 feet long and the upper, 30 feet long. A diver was employed to place the intake pipes and connect them with the well. This was the first Survey station constructed by use of the pneumatic-caisson method. Owing largely to excavation through loose rock, the cost of the station was about $8,000.

Discharge measurements were made from a highway bridge using a hand-operated reel and boom. The station is 52 miles above the mouth of the Ohio River and at times backwater is caused by that river. The variable slope due to backwater was determined by means of auxiliary gages 14 miles upstream and 6 miles downstream. This station was discontinued in February 1938 when Army-Engineer cooperation ceased.

Cooperation with the State Highway Commission[463] resulted in the establishment in 1930 of 18 stations on small streams; 6 of these stations were later discontinued when the road maintenance men did not visit the stations sufficiently often to obtain the necessary gage readings.

463/ p. 43.

The drought of 1934 resulted in a new use for the stream-flow records. The streams at that time were so low that weekly reports were made to the Missouri Relief and Reconstruction Commission, by means of which the Commission was able to assist towns in obtaining emergency water supplies.[464]

464/ Water-Resources Bulletin, Aug. 10, 1934, p. 29.

At the beginning of the period 58 stations were being maintained and at the end, 132 stations, of which 69 were equipped with recorders. All but two of these were installed during the present period, two-fifths in metal pipes attached to piers, an equal number in concrete structures, and the remainder in large metal pipe 42 to 48 inches in diameter set in the bank. All wells except those attached to piers were equipped with flushing devices. Three cables were erected, the longest having a span of 600 feet. Six artificial controls were constructed, four were of the concrete Trenton type and two, for the Soil Conservation Service's Tarkio project, were of creosoted timber; none extended more than a foot above the stream bed; lengths ranged from 40 to 100 feet.

The Tarkio project was started in March 1934. It consisted in the installation and operation of two gaging stations, the collection and analysis of sediment samples, and the collection of records from 45 rainfall stations and 80 ground-water wells. One of the sediment sample observers kept his apparatus in a small shack near the gage for convenience. This proved to be a satisfactory arrangement until a high flood occurred during which the shack was marooned by the flood waters, and samples could not be obtained until the flood had receded several feet. Thereafter the equipment was kept at the observer's residence. One Survey engineer was detailed to the project, and he was furnished an assistant in July 1938. The project was in operation at the end of the period.

The temporary project on the St. Francis River, conducted in cooperation with the Flood Control Coordinating Committee, required the establishment of 12 temporary stations, and the detail of two engineers to it.[465]

465/ p. 91.

A sub-office was maintained in Pierre, S. Dak., for the operation of the stations in South Dakota. Mr. Beckman was district engineer during the period. Other Civil Service engineering personnel were:

A. L. Hill	July 1, 1928 to Sept. 17, 1929
V. L. Austin	July 1, 1928 to Feb. 28, 1930
H. C. Bolon	Sept. 19, 1929 to June 11, 1937
R. D. Schmickle	Oct. 16, 1929 to Feb. 1, 1935
C. J. Eyberg	(Feb. 27, 1930 to July 2, 1934
	(July 16, 1937 to June 30, 1939
C. H. Jennings	May 17, 1930 to June 30, 1939
W. M. Littlefield	Apr. 10, 1933 to June 30, 1939
F. M. Bell	Nov. 23, 1933 to Feb. 28, 1934
S. C. Moore	June 1, 1934 to Mar. 16, 1935
G. A. LaRocque, Jr.	June 13, 1934 to Aug. 15, 1937
F. N. Hansen	July 2, 1934 to Apr. 20, 1937
V. R. Bennion	Mar. 10, 1935 to Mar. 7, 1938
J. W. Odell	Sept. 3, 1935 to June 30, 1939
G. N. Mesnier	July 13, 1936 to June 30, 1939
W. L. Doll	June 23, 1937 to June 30, 1939
A. G. Hely	June 27, 1937 to June 30, 1939
E. R. Leeson	Mar. 3, 1938 to June 30, 1939
J. A. Short	Nov. 1, 1938 to June 30, 1939
J. H. Meyer	Nov. 7, 1938 to June 30, 1939
K. J. Craig	Nov. 28, 1938 to June 30, 1939
J. C. Berkenbosch	Apr. 3, 1939 to June 30, 1939

Fort Smith, Ark.- The Fort Smith district had its inception in September 1927 as a subdivision of the Rolla district with one engineer detailed to establish and operate 10 gaging stations in cooperation with the State of Arkansas. In March 1928 it was established as a separate district comprising the States of Arkansas and Oklahoma, with headquarters at Fort Smith, Ark., on the Arkansas-Oklahoma State line, with W. S. Frame as acting district engineer, in anticipation of Army-Engineer "308" cooperation which eventually required the establishment and operation of 25 stations of which 22 were in Oklahoma.

Prior to September 1927, only a few stream-flow records in Arkansas were available. A station on the Ouachita River at Malvern, had been established by the General Bauxite Co. in 1903 and maintained for 2 years during which period the Survey had made a few measurements. The Texas district had maintained a station on the Ouachita River at Arkadelphia during 1905 and 1906, and the State geologist of Arkansas had maintained six stations in the White River Basin during 1909-10. At none of these stations had sufficient measurements been made to warrant the computation of records of daily discharge. Beginning in 1922, three stations on the Ouachita River were established and operated by the Rolla district for Federal Power Commission permittees. The Army Engineers were maintaining seven stations of which those on the Arkansas River dated from 1883 at Little Rock, from 1886 at Dardanelle, from 1889 to 1904 at Pine Bluff, and from 1897 with some breaks at Yancopin. The records on the White River at Clarendon dated from 1879, and on the Petit Jean River at Danville from 1916. At none of these stations had systematic discharge measurements been made, and continuous records of daily discharge had not been computed. The available records in Oklahoma were somewhat more extensive, as western Oklahoma was within the semi-arid belt, and during the early days of the Reclamation Service, irrigation investigations required the maintenance of about 20 stations during the period 1903-7 by the Oklahoma-Eastern New Mexico district.[466] Irrigation investigations

[466] Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 163.

required the maintenance of two stations by the Denver district during the period 1912-19, and Federal Power Commission permits required the maintenance by the Topeka district of five stations during the period 1924-25.

As a result of State cooperation which began in September 1927, H. C. Beckman, in charge of the Rolla office, detailed W. S. Frame to establish and operate 10 stations in Arkansas. When Army-Engineer cooperation was being considered in the spring of 1928, A. W. Harrington visited the Army-Engineer offices at Memphis and Vicksburg to ascertain what cooperative stations were needed in the lower Mississippi Valley. The needs of the Vicksburg office developed into a program in the Red River Basin and Ouachita River Basin during the period 1928-31. Arkansas was the only State cooperating in the lower valley and the only stream-gaging program being carried on was in that State. Therefore, as a district office was to be opened it seemed that it should be located in Arkansas, and with the indicated need for Army-Engineer stations in Oklahoma and Arkansas, and hoped-for State cooperation in Oklahoma, Fort Smith, near the Arkansas-Oklahoma State line, was selected. Previously there had been no definite field headquarters for the Arkansas work. The district office was opened in September 1928 with W. S. Frame as acting district engineer and O. B. Johnson as his assistant. In the first year, 24 stations were operated in Arkansas, of which 4 were Weather Bureau stations, 4 were Army-Engineer stations, and 3 were Federal Power Commission stations; 3 stations were operated in Oklahoma, and 1 in Louisiana. Of these, one was equipped with a water-stage recorder and the remainder with staff or chain gages.

The gradual decline in State and Army-Engineer cooperation reduced the number of Arkansas stations to 11 in 1932, the low point for the period. Thereafter, new cooperation with the State Highway Commission (1937) and Army-Engineers (1937), the latter in connection with flood-control stations, caused an increase in the number of stations to 28 by June 1939, of which 24 were equipped with recorders. In 1935, the station on the Mississippi River at Memphis was transferred to the Fort Smith district from the St. Louis office. A suboffice was opened in Memphis with a resident engineer operating not only the Memphis station, but also a number of stations in eastern Arkansas.

When the work was started it was a local novelty, and measurements from bridges frequently attracted a "gallery" who exercised their inalienable right to ask questions, as indicated by the following statement in the Water-Resources Bulletin:[467]

[467] May 10, 1929, p. 10.

> We are hoping that the next mechanical development will include an indicator for registering current-meter revolutions. We have had more than 50 spectators to a discharge measurement at one time. It is difficult to make explanations while counting the clicks of a current meter.

The stations in Oklahoma were increased from three to nine in 1930 through Army-Engineer cooperation. With the discontinuance of that cooperation the number of stations was reduced to three in 1932. Cooperation with the Soil Conservation Service in its Stillwater project which began in 1934 and continued until December 1937, increased the number of stations by three. These stations were equipped with recorders, cables,

and artificial controls. As most of the floods came at night, storehouses were equipped with cots and stoves. The floats were connected with alarm systems, which enabled the engineer to rest at intervals between flood measurements. As J. H. Gardiner writes,[468] practically

468/ Letter to author.

all essential measurements were made at night and headlights were used. Sediment analyses were made locally and well-gage and rain-gage observations were made. The intensive nature of this project required the detail of an engineer to it. State cooperation which began in September 1935, and Army-Engineer cooperation resumed in 1938, caused an increase in stations to 30. Of these stations, 26 were equipped with recorders, chiefly in galvanized corrugated iron pipes attached to bridge piers. With the increase in State cooperation in 1938, it appeared advisable to have a Survey office in Oklahoma which would have direct charge of the operation of the Oklahoma stations. A suboffice was established in Oklahoma City on March 12, 1938, with Verne Alexander in charge.

W. S. Frame resigned September 11, 1929. He was succeeded by J. H. Gardiner who continued in charge of the district until March 27, 1938, when he was transferred to Arizona as district engineer and was succeeded by J. L. Saunders. Other Civil Service engineering personnel were:

O. B. Johnson	July 17, 1928 to Sept. 27, 1931
C. A. Young	Oct. 19, 1933 to Sept. 12, 1936
J. A. Allis	Dec. 17, 1934 to Apr. 8, 1937
H. G. Thomasson, Jr.	Aug. 1, 1936 to June 30, 1939
Verne Alexander	Mar. 31, 1937 to June 30, 1939
L. L. Laine	June 1, 1937 to June 30, 1939
S. K. Jackson	July 6, 1937 to June 30, 1939
F. J. Shaefer	July 6, 1937 to June 30, 1939
C. J. Chappell	July 12, 1938 to June 30, 1939
J. L. Patterson	Nov. 1, 1938 to June 30, 1939
A. O. Gierow	Nov. 28, 1938 to June 30, 1939

Austin, Tex.- The enlargement of the cooperative program with the International Boundary Commission, which took place in 1928, increased materially the operations of the Austin district at the beginning of the period,[469] and five suboffices were established to handle not only the

469/ p. 162.

Commission's stations, but also other stations in the vicinity. With the discontinuance of that cooperation on August 1, 1931,[470] most of the sub-

470/ p. 163.

offices were closed and the personnel reduced.

Cooperation with the Soil Erosion Service on the Elm Creek project was started in January 1934 and continued until October 1936. An engineer was detailed to this project with headquarters at Temple. Four gaging stations were maintained, each equipped with a recorder and an artificial control. Sediment samples which were analyzed in a special laboratory at Temple, were collected at each station daily, and much

oftener during flood periods. Eight recording rain gages and 43 standard rain gages were installed and operated, and water-level records were obtained at 36 wells, 6 of which were equipped with recorders. The Soil Erosion Service furnished the services of a field and laboratory assistant.

The practice of making seepage runs on natural streams, which had been started by G. A. Gray in 1918, [471] was continued. About 50 seepage

471/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 404.

runs were made covering a total of more than 1,600 miles, principally in the Nueces, Guadalupe, and Pecos River basins. During this period the seepage work was done in connection with the studies of the Ground Water Division. Other work for that division consisted in making miscellaneous measurements of numerous springs and operating temporary stations on springs and streams. From June 1932 to June 1933 a suboffice was maintained at Balmorhea, and half of the time of the engineer detailed to that office was devoted to ground-water work.

An outstanding feature of the district operations was the study of the record-shattering floods of 1932, 1935, 1936, 1938, and 1939. All available personnel were engaged in the field work incidental to the flood studies, which included searches for all possible rainfall records obtained by local residents. The results for the 1935 floods were published as Water-Supply Paper 796-G, those for the 1936 floods as Water-Supply Paper 816, and for the 1938 and 1939 floods as Water-Supply Paper 914. As a result of these floods the Army Engineers provided funds for the operation of 55 stations during 1939.

The number of stations was increased from 105 in 1928 to 112 in 1929, and then was gradually decreased to a low point of 86 in 1937. The Army-Engineer cooperation increased the number to 140 at the end of the period. This enlarged program required the establishment of several additional subоffices, increasing the total number to nine. Of the 140 stations, 97 were equipped with recorders, the installation of which was divided chiefly between concrete and pipe structures. Thirty-two of the concrete structures were of the circular type devised by E. D. Burchard. [472]

472/ p. 105.

In 18 of the installations, the recorders equipped with submergence covers [473] were placed well below possible flood levels. During the flood

473/ p. 208.

of July 1932 one of these recorders was overtopped by 17 feet and continued to function. Referring to these installations, C. E. Ellsworth writes: [474]

474/ Letter to author.

> * * * they have functioned perfectly in every case. They were used wherever the recorders are below anticipated flood height. In some cases recorders are deliberately set below expected flood levels because of excessive cost of building the wells to those levels; in other cases the recorders were originally

set at levels thought to be above maximum flood height but subsequent experience proved we were wrong. In such cases when not practicable to raise the instrument, submergence covers were installed.

The flash floods of many Texas streams carry such great quantities of sediment that a special sediment trap located between the stream and the well was devised and made a part of standard equipment on such streams. Twenty-three cableways and 16 artificial controls were installed. Eleven controls were made of concrete or masonry, and five were of creosoted-timber.

Mr. Ellsworth continued as district engineer and had the following Civil Service engineering personnel:

C. E. McCashin	July 1, 1928 to Aug. 16, 1928
Trigg Twichell	July 1, 1928 to June 30, 1939
S. D. Breeding	July 1, 1928 to June 30, 1939
D. M. Corbett	July 1, 1928 to Sept. 3, 1929
H. C. Pritchett	(July 1, 1928 to Feb. 1, 1929
	(Dec. 1, 1930 to Aug. 27, 1931
V. W. Rupp	July 1, 1928 to Feb. 26, 1934
Tate Dalrymple	July 1, 1928 to Mar. 28, 1937
R. G. Fisher	July 1, 1928 to Sept. 22, 1928
L. W. Miller	Sept.16, 1928 to Jan. 2, 1929
G. E. Ferguson	Sept.18, 1928 to Aug. 20, 1931
A. B. Goodwin	Jan. 31, 1929 to July 31, 1931
C. A. Young	(Mar. 1, 1929 to Aug. 26, 1931
	(Feb. 7, 1939 to June 30, 1939
B. S. Odom	June 1, 1929 to Sept. 30, 1929
W. M. Littlefield	June 17, 1929 to Aug. 21, 1929
E. B. Rice	June 17, 1929 to July 31, 1929
A. A. Fischback, Jr.	July 1, 1929 to July 31, 1929
F. C. Ames	(Dec. 2, 1929 to Sept. 10, 1934
	(Dec. 12, 1936 to Jan. 24, 1938
S. H. Crowell	Dec. 12, 1929 to Sept. 14, 1931
V. L. Austin	Mar. 1, 1930 to June 30, 1939
J. M. Terry	July 1, 1930 to Feb. 26, 1934
F. T. Lander, Jr.	Nov. 14, 1938 to June 30, 1939
E. L. Willis, Jr.	Nov. 15, 1938 to June 30, 1939
C. E. Earhart	Dec. 1, 1938 to June 30, 1939
E. R. Watson	Mar. 16, 1939 to June 30, 1939

Topeka, Kans.- Although the Topeka district was theoretically reopened on July 1, 1928, it was not until September that J. B. Spiegel gave his entire time to the duties of district engineer. During the first year the stations which Spiegel had previously maintained for the State were taken over. These were situated in the western part of the State, and were operated chiefly in the interest of irrigation. In addition, 21 stations desired by the Army Engineers were installed, making a total of 46 stations. After the discontinuance of the Army-Engineer cooperation in 1932, State cooperation was increased sufficiently to continue most of those stations until the Army Engineers resumed cooperation in 1936, when they cooperated in the operation of 11 stations. In 1938, additional Army-Engineer cooperation increased the number of such cooperative stations by three. The total number of stations remained nearly constant during the period, 49 being operated in 1939 of which 40 were equipped with recorders. Thirty-eight recorders were installed

during the period, chiefly in galvanized iron shelters. Two cables were installed. These spanned main channels only, as during floods the area overflowed is too wide to be spanned by cables; discharge measurements are then made from bridges.

Cooperation with the Soil Erosion Service at its Limestone Creek project[475] required the establishment of five gaging stations and the

475/ p. 82.

detail of a resident engineer to the headquarters for that project at Mankato. Four of the gaging stations were equipped with recorders and three with V-notch weirs. Twenty-seven rain gages were operated and frequent sediment samples analyzed by an assistant under the direction of the Quality of Water Division. To insure obtaining measurements and sediment samples during floods, the recorder floats were connected with an alarm system which rang a bell at the sediment sampler's residence and he notified the engineer. This project was continued until July 1, 1938.

A special study of the Republican River flood of May-June 1935, in Kansas, was made and a report by Spiegel was published in Water-Supply Paper 796-B.

Following the review and revision of records of Kansas stream flow, as a WPA project, Spiegel compiled them for the period from 1928 to 1935 and they were published by the State as the third in a series of such compilations, the first and second having been published during the previous period.[476]

476/ p. 142, 1919-1928.

J. B. Spiegel was district engineer during the period. Other Civil Service engineering personnel were:

R. V. Smrha	Mar. 28, 1929 to Dec. 31, 1929
W. M. Littlefield	Aug. 22, 1929 to Oct. 14, 1931
	Mar. 7, 1932 to Oct. 15, 1932
Chas. Wells	Jan. 1, 1930 to Nov. 18, 1935
L. C. Crawford	Oct. 8, 1935 to July 16, 1938
C. H. Hardison	Mar. 11, 1937 to July 25, 1938
C. J. Eyberg	Nov. 18, 1935 to Dec. 31, 1936
H. P. Brooks	July 9, 1938 to June 30, 1939
A. J. Ferrin	Nov. 1, 1938 to June 30, 1939

Helena, Mont.- In 1928, a number of Army-Engineer stations were established on the Missouri River and its principal tributaries in North Dakota, and that portion of North Dakota was again added to the Helena district. In May 1934, the station on the Missouri River at Bismarck, and stations on tributary streams entering the Missouri below Bismarck, were taken over by the Rolla District for unity of operation. The period was one of steady expansion during which the number of gaging stations was nearly doubled.

The program related to the division of the waters of the St. Mary and Milk Rivers continued practically unchanged. So accurate had been the forecasts of run-off in the St. Mary River basin, on the basis of

snow surveys,[477] that in 1934, the Army-Engineers requested a similar

477/ p. 139, 1919-1928.

snow survey of the headwaters of the Missouri River in connection with the Fort Peck Reservoir project. Such snow surveys were started that year and snow samples were collected on March 1 and May 1 of each year thereafter, at eight points along the Continental Divide.

The Rocky Mountain Power Company made application to the Federal Power Commission to construct a dam 2 miles below the outlet of Flathead Lake and this application was protested on the ground that it would flood lands bordering the lake. The Commission required data on natural conditions prior to the construction of the dam and arranged with the power company to pay the Survey for the cost of obtaining such data. As this project was under permit and awaiting license by the Federal Power Commission, a special investigation of Flathead Valley was undertaken. It was started at the beginning of the period. Six stations were established on Flathead River at which stage only was observed, to determine the natural slopes of the river above Flathead Lake for comparison with the slopes after the dam had been completed. Several gaging stations were installed also on tributaries above Flathead Lake. A ground-water investigation in Flathead Valley was also started and the field work was performed by the Helena district.[478] This included the sinking of 47

478/ p. 359.

observation wells and the making of readings of ground-water levels at intervals of a month or less. The investigation continued during the period.

Much of the northwestern part of the State is heavily timbered and during a forest fire in 1929, the cable car at one gaging station was burned. A chain gage had been read by the only inhabitant (a squatter) within 20 miles, and the forest fire having destroyed his buildings he moved away, as one experience of that nature was enough. Thereafter it was necessary to install a recorder. At another time the same station was mentioned in a popular magazine by Mary Roberts Rhinehart, of thriller mystery fame. While vacationing in Glazier National Park and vicinity, she came upon the North Fork station and was so intrigued by the cable car, which she described as a "basket", that she wished to ride in it and was greatly disappointed to find it securely locked.

During the period the number of stations was increased from 80 to 151, of which 90 were equipped with recorders. Of these, 62 were installed during the present period, 11 in concrete structures and the others in timber structures. An unusual installation was that at the gate-tower of Sherburne Lake Reservoir where a 12-inch steel pipe was used as a floatwall, on a batter of 1 horizontal +.8 vertical. Thirty-three cables were installed, the longest having a span of about 1,300 feet on the Missouri River below Fort Peck Reservoir. Sixteen artificial controls were also built, six being concrete and the remainder timber-stone construction.

W. A. Lamb continued as district engineer until his death February 9, 1938. A. H. Tuttle who had been in the district since January 3, 1916, succeeded him. Other engineering personnel were:

C. S. Heidel	July 1, 1928 to June 30, 1939
G. C. Sanders	July 11, 1928 to Dec. 31, 1929
W. J. Parsons	Oct. 15, 1928 to Mar. 6, 1930
E. H. Bekkedahl	Feb. 3, 1930 to June 30, 1939
Edward Post	Feb. 20, 1930 to Feb. 26, 1936
R. G. Kasel	May 13, 1930 to July 16, 1930
H. C. Smith	Mar. 22, 1930 to June 30, 1933
G. L. Oakland	May 9, 1933 to June 30, 1933
V. W. Rupp	Feb. 28, 1934 to Nov. 30, 1935
Frank Stermitz	June 8, 1936 to June 30, 1939
W. A. Blenkarn	Sept.16, 1936 to June 30, 1939
H. C. Eagle	Oct. 16, 1937 to June 30, 1939
G. E. Harbeck, Jr.	Oct. 25, 1937 to June 30, 1939
A. H. Williams	Sept.10, 1938 to June 30, 1939

Denver, Colo.- The Denver district had the greatest expansion of any district during the years 1928 to 1939; the number of stations was increased from 76 to 357, and the personnel from 2 to 11 engineers. In 1928 the district comprised the States of Colorado and Wyoming, in which 76 stations were being maintained. The "308" work of the Army Engineers which was started in July 1928 led to the establishment of stations not only in Colorado and Wyoming, but also in Nebraska, South Dakota, and western Iowa that were assigned to the Denver district, as those states were at that time in a no-man's land. These additions increased the number of stations to 119. In August 1931, cooperation with Nebraska, increased the number of stations to 143. In November 1933, expanded cooperation with Colorado brought further increase in the number of stations to 232. In May 1934, the stations in South Dakota and western Iowa, and the Missouri River station at Omaha, were transferred to the Rolla district to provide unity of operation, as that district was operating other stations in the Missouri River basin. This transfer reduced the area of the district to the states of Colorado, Wyoming, and Nebraska during the remainder of the period.

In the three states, particularly Colorado and Nebraska, the State engineers had had their own stream-gaging organization long before cooperation was effected, and these organizations continued to operate some of the gaging stations under general Survey supervision.

The search by the Bureau of Reclamation for new projects, limited at first to the Colorado River basin but later expanded to cover the entire arid west, gave an impetus to State interest in additional irrigation possibilities that was augmented by the drought years. This situation brought increased cooperative State funds with which to establish and operate additional stations, and the number was steadily increased to 357 in June 1939. A part of this increase was due to the policy of the Bureau of Reclamation to establish stations equipped with recorders and turn them over to the Survey to operate by means of cooperative State funds, a procedure that was advocated by the cooperating State officials. In May 1937 the transfer of stations established by the Santa Fe district in the San Juan Basin added eight stations, and in 1938 the flood-control work of the Army Engineers added 13 stations.

Some of the stations were established under adverse conditions that resulted from the proneness of engineers to determine their needs for additional stations by office studies made during the winter, and the attempt to translate their needs into action before the spring run-off

started. These stations were usually on streams high up in the mountains where the snow was deep and roads were blocked. One group of six stations in this class was installed in March and April 1937 in the San Juan River basin, a region of very heavy snowfall. "The ubiquitous bystander" said the work couldn't be done, but by adopting specially designed gage shelters, using snowshoes and sleds, and camping in nearby cabins and school houses, the work was accomplished in time for the spring run-off which started in April.

Before entering into cooperation with the Survey, both Colorado and Nebraska had been conducting their own stream-gaging programs, and many of their gaging stations required rehabilitation which was undertaken as rapidly as funds became available. The magnitude of this work made necessary the use of relatively inexpensive but substantial shelters. A total of 321 recorder installations were made, divided chiefly between timber and galvanized-iron pipe structures. Ninety cableways were installed, the longest of which had a total length between end towers of 881 feet but broken into two spans by a tower about midway.

A special feature of the work in Nebraska and Wyoming was a study of the increase in flow of the North Platte and Platte Rivers from Whalen, Wyo., to Overton, Nebr., a distance of 305 miles. The water in this section of river is seriously over-appropriated, and one of the conditions under which the State of Nebraska began cooperation was that the Geological Survey would make that study. The Survey engineer who had charge of the study worked from headquarters in the State office in Bridgeport, Nebr. Recorders were installed at 10 gaging stations on the main river and at the mouths of the principal tributaries and drains. This special study continued during the remainder of the period. It may be mentioned in passing that on the North Platte and Platte Rivers from the headwaters in North Park, Colo., to the mouth at Plattsmouth, Nebr., a distance of about 700 miles, 23 gaging stations, each equipped with a recorder, were operated. This is believed to be the greatest number of stations operated on any stream of similar length in the United States.

A special feature of the work in Colorado was the participation from April to December 1936 [479] in the Rio Grande Joint Investigation,

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479/ p. 78.

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sponsored by the National Resources Committee.

Studies were made of floods which were chiefly of the cloudburst type. The most notable study was that of the Republican River flood of May-June 1935, which started as a cloudburst flood but became a major flood by reason of the sustained heavy rain over the entire upper basin in Colorado and Nebraska. The results were published as Water-Supply Paper 796-B. In 1938, a compilation of all known floods in Colorado was started. This compilation required search of newspaper files, writings of early-day settlers, and of technical reports, published and unpublished. It was started as a PWA project. The resulting report was published as Water-Supply Paper 997.

The author continued as district engineer and Miss Nellie L. Esterly as district clerk during the period and had the following Civil Service Engineering assistants:

P. V. Hodges	July 1, 1928 to July 24, 1931
F. F. LeFever	(July 26, 1928 to Oct. 1, 1930
	(Aug. 3, 1931 to Jan. 14, 1936
R. E. Cabell	Aug. 10, 1928 to Dec. 5, 1931
H. P. Eisenhuth	Feb. 8, 1929 to June 30, 1939
F. B. Campbell	Mar. 18, 1929 to May 15, 1930
D. S. Jenkins	May 1, 1929 to Dec. 31, 1931
L. F. Hanks	Mar. 13, 1930 to June 30, 1939
J. H. Baily	Dec. 1, 1930 to June 30, 1939
S. C. Moore	Dec. 1, 1931 to May 31, 1934
M. C. Boyer	Jan. 1, 1932 to Nov. 30, 1936
H. H. Odell	June 1, 1935 to June 30, 1939
C. B. Ham	July 2, 1936 to June 30, 1939
L. R. Sawyer	Jan. 22, 1936 to June 30, 1939
F. D. Reed	Sept. 5, 1936 to June 30, 1939
C. J. Osborne	May 2, 1938 to June 30, 1939
R. A. Wahl	June 28, 1938 to June 30, 1939
R. F. Kaser	Nov. 1, 1938 to June 30, 1939

In each state, a number of state employees were also engaged in the cooperative program.

Santa Fe, N. Mex.- As an incident of State cooperation, a district office was opened in Santa Fe on July 1, 1931, with Berkeley Johnson as district engineer. E. L. Barrows, who had been chief hydrographer for New Mexico and was eligible for a civil service appointment by reinstatement, was given a Survey appointment, and became office engineer. Other State employees were continued on the cooperative work and additional engineers were furnished by the Survey, as needed. The State engineer's office had conducted its own stream-gaging since cooperation was terminated on January 1, 1915. When cooperation was resumed 16 years later, about 60 stations were being maintained of which all but 2 were equipped with recorders.

The history of the Santa Fe district is one of rapid expansion because of new or intensified needs for additional records, each requiring a large group of stations. In 1935, the Bureau of Reclamation was making a study of the San Juan River Basin and of the possibility of diverting water to it from the headwaters of the Rio Grande. As these transmountain diversions would be made in Colorado, the gaging stations required would be situated in Colorado, but as New Mexico would be the beneficiary, the Santa Fe district, at the request of the Bureau of Reclamation, established eight stations in the Colorado portion of the San Juan River Basin and operated them until May 1937, when they were transferred to the Denver district. The period of greatest expansion came in 1936. The Indian Service cooperation which was started at that time[480] resulted in the establishment in the Rio Grande Valley of 63

480/ p. 84.

gaging stations, later increased to 79 stations, on Indian ditches and the streams from which those ditches diverted water. The Rio Grande Joint Investigation sponsored by the National Resources Committee,[481] which was

481/ p. 78.

started in the spring of 1936, required the installation of 144 gaging stations on streams, ditches, drains, and wasteways in the Rio Grande Valley in New Mexico. This investigation was continued until June 1938,

at which time many of the stations were discontinued.

An intensive hydrographic survey was made of the San Juan River Basin in New Mexico prior to an adjudication of the water rights by the State engineer's office, and 85 gaging stations were established and operated by the Survey to obtain the necessary data regarding water supply. As a result of the various investigations, records were collected at a maximum of 329 gaging stations, the number being 159 at the end of the period. Of these, 82 comprised the regular stream-gaging program. For efficient operation, field headquarters were maintained at Bernalillo, Albuquerque, and Belen from 1936 to 1938; at Farmington and Socorro from 1936 to 1939; at Roswell from 1937 to 1939; and at Lordsburg, Carlsbad, and Santa Rosa during 1939.

Most of the stations were equipped with recorders. In the intensive study for the Indian Service artificial controls were required. These controls were mostly concrete Parshall flumes in ditches, and concrete structures of the ogee type in natural stream channels. On other streams in the district, 30 concrete controls of various types were installed. The length of these controls ranged from 12 to 70 feet.

Berkeley Johnson was district engineer and had the following Civil Service engineering assistants:

E. L. Barrows	July 1, 1931 to June 30, 1939
W. G. Bratschi	July 1, 1931 to Feb. 15, 1939
C. A. McClelland	Dec. 13, 1935 to June 30, 1939
R. E. Cook	Mar. 3, 1936 to June 30, 1939
A. B. Goodwin	Mar. 9, 1936 to June 30, 1939
F. F. LeFever	Jan. 17, 1936 to June 30, 1939
R. E. Curtis	Sept. 14, 1937 to June 30, 1939
V. R. Bennion	Mar. 10, 1938 to June 30, 1939

Boise, Ida.- The area covered by the Boise district remained the same as in the previous period and comprised the State of Idaho, except the stations in the Snake River Basin, and included seven stations in Yellowstone National Park. The district activities were enlarged at the close of the previous period by the special Kootenai River investigation[482]

[482] p. 156.

which continued during the present period. Headquarters for that investigation were established at Bonners Ferry in March 1928 with a force of three engineers, gradually reduced to a single engineer as the scope of the work was reduced during later years. The Corra Linn Dam north of the International Boundary served to store several feet of water on Kootenay Lake in the fall of 1931, which caused dissatisfaction among the owners of diked lands in Idaho. At the beginning of the high-water period in 1932 the International Joint Commission requested the Survey to assign an engineer to inspect operations of the dam, measure the outlet discharge, and observe river and lake stages.[483] Accordingly, an

[483] Ann. Rept. Boise District 1932.

engineer was stationed at Nelson for several weeks. In 1934, a 150-pound Columbus weight was obtained, with specially rated meter equipment, for measuring the discharge of the Kootenai River as accurately as possible.

During 1935, much time was devoted to work of the Governor's Emergency Drought Committee in determining the feasibility of emergency projects for obtaining supplemental irrigation and domestic water supplies. Investigations for that Committee finally developed into cooperation with the Water Conservation Board, beginning in 1938. Just before the close of the period, cooperation with the Flood Control Coordinating Committee resulted in a special investigation in the Boise River Basin to which three engineers were detailed for full or part time.[484] This work was

484/ p. 90.

started in November 1938. An unusual assignment occurred in September 1929 when the Secretary's office appointed a committee consisting of C. G. Paulsen, district engineer at Boise, A. W. Harrington, district engineer at Albany, and J. H. Rothrock of the Solicitor's Office, to conduct hearings and recommend the ratio of participation in the ownership of profits from power plants of the irrigation districts under the Minidoka project.[485] The Secretary adopted the recommendations made by

485/ Ann. Rept., Boise District 1930.

this Committee.

The first use of an airplane as a means of transporting a Survey Engineer in field work was made in April and May 1931, when J. A. Allis took a mail plane from Cascade to Yellow Pine, a distance of 65 miles over two mountain ranges in order to reach stations in the Yellow Pine region. As the roads were blocked by snow it was the only means of transportation, and by using the airplane, measurements were obtained a month earlier than would have been possible by regular means of transportation. On that same trip in the same general region, a truck, pack train, and dog team were used in travelling a distance of 50 miles.[486]

486/ Letter from J. A. Allis to author.

The work of the district during the present period was intensive rather than extensive, when compared with that during the previous period with its large increase in the number of stations. During the first year, the number of stations was increased from 131 to 154, largely as a result of the Kootenai River investigation, but thereafter the number fluctuated between 146 and 162 until 1938, when it was increased to 181 as a result of the need for run-off data on small streams in southern Idaho. The drought years had shown small communities the need for improving irrigation supplies by constructing small reservoirs or enlarging existing reservoirs deriving their water supplies from small streams.

At the end of the period 188 stations were being maintained, of which 125 were equipped with recorders. Ninety-four recorder installations were made, 36 with concrete structures, 24 with concrete wells and timber shelters, 26 with timber structures, and 8 with pipe wells. The greatest over-all height was 56 feet. One of the first installations of valves, riser pipes, and flush tanks was made on the Kootenai River in 1929. An unusual installation was made on the Yellowstone River at the outlet of Yellowstone Lake where the concrete structure was faced with rough masonry to meet the requirements of the Park Service, for obtaining more harmonious blending with the scenery than would be possible by use of bare concrete walls. Several recorder installations were pushed out

of the vertical by the pressure of saturated earth behind them, and one of them was straightened by excavating behind the structure, looping two cables with turnbuckles about the top of the shelter, anchoring the cables to trees, and tightening the turnbuckles, thus bringing the structure back into place without cracking the concrete.[487] Forty-five cable-

[487] Water-Resources Bulletin, Jan. 10, 1933, p. 19.

ways were installed, the longest having a span of 710 feet. This was a tramway cable having open-bridge sockets, located on the Kootenai River at the International Boundary. Another cableway was installed on the Middle Fork of Salmon River at a site so isolated that the cable and car had to be transported 20 miles by pack train. A special design was used to reduce weight. Fifteen artificial controls were constructed, 6 being sharp-crested and 9 broad-crested.

C. G. Paulsen was district engineer until March 1, 1931, when he was transferred to Washington to become chief of the Surface Water Division, and was succeeded by T. R. Newell. Other Civil Service Engineering personnel were:

Berkeley Johnson	July 1, 1928 to Aug. 22, 1930
R. G. Kasel	(July 1, 1928 to Mar. 29, 1929
	(July 11, 1929 to Oct. 12, 1932
F. M. Veatch	July 1, 1928 to Jan. 5, 1932
E. Hazel Haugse	July 1, 1928 to June 30, 1939
K. K. Hoyt	July 1, 1928 to Oct. 3, 1928
W. J. Parsons, Jr.	July 1, 1928 to Oct. 26, 1928
E. L. Harrington	July 1, 1928 to Nov. 23, 1928
M. C. Boyer	July 5, 1928 to Sept. 22, 1929
W. V. Iorns	June 17, 1929 to May 1, 1931
F. C. Craig	July 1, 1929 to June 30, 1939
P. C. Benedict	July 16, 1930 to June 30, 1939
W. I. Travis	Aug. 1, 1930 to Apr. 7, 1934
J. R. Throckmorton	(Sept. 15, 1930 to Mar. 15, 1937
	(Dec. 30, 1938 to Mar. 22, 1939
J. A. Allis	Mar. 19, 1931 to Dec. 13, 1934
L. R. Sawyer	Aug. 1, 1931 to Jan. 20, 1936
F. C. Christopherson	May 1, 1932 to July 11, 1938
T. O. Miller	Oct. 25, 1934 to June 30, 1939
C. J. Espy, Jr.	Mar. 15, 1937 to Aug. 13, 1938
E. G. Bailey	Apr. 10, 1937 to June 30, 1939
L. J. Snell	Oct. 17, 1938 to June 30, 1939
C. A. Thomas	Nov. 14, 1938 to June 30, 1939
E. J. Rusho	Jan. 10, 1939 to June 30, 1939
P. H. Andros	Feb. 11, 1939 to June 30, 1939
H. W. Johns	Feb. 17, 1939 to June 30, 1939

Idaho Falls, Ida.- The program outlined for the Idaho Falls district when it was created in 1919, described in detail in the history of the previous period,[488] proved so successful that it remained practically un-

[488] p. 184, 1919-1928.

changed. It was directly concerned with the distribution of more than 6,000,000 acre-feet of water annually, including the delivery of water stored in Jackson Lake, Henrys Lake, American Falls Reservoir, and Lake

Walcott with combined storage capacities of 2,700,000 acre-feet.[489] Early

[489] Letter from Lynn Crandall to author.

in the period, G. C. Baldwin resigned and Lynn Crandall succeeded him on March 31, 1930, as State water-master for Snake River, and Survey district engineer in charge of the Idaho Falls district. For 10 years previously, Crandall had been Commissioner of the Federal Court in charge of water distribution and ground-water studies in Big Lost River Basin, Idaho, and that experience had convinced him of the need for the highest degree of accuracy in stream-gaging records for use in water distribution. His further experience gained in the Idaho Falls district strengthened this conviction as shown by his contribution to the Water Resources Bulletin of September 10, 1932:

> The many, varied, and conflicting water rights on the Snake River make it necessary to determine discharges as accurately as is humanly possible. A variation of even 2 per cent in the rating at this station (North Side Canal at Milner) is equivalent to 60 second-feet which at a conservative value of $1 per acre-foot is equivalent to $120 per day.

This requirement of accuracy may be considered as the keynote of stream-gaging in the Idaho Falls district during the remainder of the period.

The operation of the large reservoirs on Snake River and the segregation between natural and stored water in the river below made it necessary to investigate the amount of bank storage in the reservoirs during times of filling and the amount released during times of drawdown. This was done by measuring all reservoir inflow and outflow, recording evaporation, precipitation, and reservoir stages, the latter making it possible to compute from the capacity tables the amounts in storage.[490]

[490] Water-Resources Bulletin, Aug. 10, 1933, p. 31.

The comparison between the amounts in storage on different dates, and the other quantities measured, indicated the loss to bank storage on rising stages in the reservoir, and the gain from bank storage on falling stages. This investigation was discontinued about 1933 as the data already obtained gave results in subsequent operations. In describing the effect of bank storage, Crandall stated:[491]

[491] Op. cit.

> Long sections of river channel, where ground-water inflow occurs, act in a manner similar to reservoirs, and *** will show losses on rising stages and gains on falling stages. This matter should be considered in comparing stream-flow records at different stations along the same stream during periods of changing stage.

Another bank-storage investigation was made in cooperation with the Bureau of Reclamation on the Island Park Reservoir, located on Henrys Fork. It was started in 1936, three years before the completion of the reservoir, and continued until 1940, thus obtaining records before and after the construction of the reservoir. From this investigation, a

plan of reservoir operation was devised by which a loss is charged to the reservoir during the spring and early summer, when at high elevation. This loss is recovered from bank storage during the draw-down period.492/

492/ Letter from Lynn Crandall to author.

To meet more fully the needs of the water users, Mr. Crandall began in 1930 to prepare a single page summary of the stream flow and reservoir storage which was sent to the water users daily during the irrigation season, and weekly during the remainder of the year.

An average of 125 stations was maintained, of which 18 were river stations, 6 reservoir-content stations, and the remainder on canals.

Lynn Crandall continued as district engineer and had the following engineering assistants:

C. A. McClelland	July 1, 1928 to Sept. 30, 1929
H. S. Kollenborn	July 1, 1928 to June 25, 1931
W. V. Iorns	May 1, 1931 to June 30, 1939

In addition, two hydrographers who devoted their entire time to measuring, and four hydrographers (deputy watermasters) who divided their time between measuring and distributing water, were employed during the irrigation season.

Salt Lake City, Utah.- The area operated by the Salt Lake City district continued to be the States of Utah and Nevada. A few stations in the Walker River Basin in California and a few in the Bear River Basin in Idaho, were also operated by the Salt Lake City district. The number of stations in the district was increased during the period from 71 to 90, and 42 recorder installations were made, divided between pipe and timber structures. Six concrete wells, twenty-three cables and three artificial controls were installed.

A new use for stream-flow records in both Utah and Nevada was created by the snow surveys in those States. Early in the present period snow surveys came into prominence, largely as a result of investigations made by Prof. J. E. Church of the University of Nevada. Such surveys were made in Utah by Prof. G. D. Clyde of the Utah State College, who used them as the basis for forecasts of stream flow for the irrigation season. To establish normals and to verify the predictions, the snow-survey organization required preliminary records of winter run-off at the end of the winter for six stations in Nevada and some 30 stations in Utah, and complete records for those stations at the end of the water year.

Annual appropriations for base stations on the Colorado River and principal tributaries were started in 1929, and the following stations were included in that category: Green River at Green River, Colorado River at Cisco, San Juan River near Bluff, all in Utah, and Virgin River at Littlefield, Ariz. The station on the San Juan River had previously been operated by the resident engineer at Lees Ferry who made monthly trips to it, but beginning in April 1929, on account of its inaccessibility, a resident engineer was stationed at the Bluff station and made almost daily measurements during the remainder of the period. He also took daily sediment samples and analyzed them. The problem of sediment

in the Colorado River was assuming increasing importance, and in May 1930 the Quality of Water Division decided that daily samples would be required at the Green River and Cisco stations. Therefore, a resident engineer was detailed to each station to obtain those samples and make daily measurements of discharge. By October 1931, daily discharge measurements were no longer considered necessary and the two stations were placed in charge of one resident engineer.

Until 1932, the number of gaging stations in Utah was increased only from 56 to 58. During the remaining years, however, growing interest in the State's water resources brought about an increase in cooperative funds and by 1939, 74 stations were being maintained, of which nearly 20 were financed in part by private contributions. Nearly all of the stations were equipped with recorders. Three artificial controls, of which two were Parshall flumes, were installed.

The small amount of cooperation available in Nevada did not permit any expansion of the stream gaging in that State and the number of stations remained nearly constant, varying from 13 to 16 during the period.

A. B. Purton was district engineer and Miss Lysle Christensen, district clerk, during the period. The Civil Service engineering assistants were:

M. T. Wilson	July 1, 1928 to Dec. 1, 1931 Dec. 3, 1933 to June 30, 1939
J. A. Allis	Apr. 1, 1929 to Mar. 19, 1931
J. B. Ringwood	May 21, 1929 to Apr. 4, 1931
F. N. Hansen	May 14, 1930 to Sept. 9, 1933
B. M. Tanner	May 14, 1930 to Mar. 19, 1934
V. R. Bennion	July 8, 1931 to Mar. 10, 1935
F. M. Bell	Dec. 15, 1931 to Nov. 18, 1934
H. W. Palm	Apr. 23, 1934 to Nov. 27, 1936
G. M. Sherwood	Mar. 11, 1935 to Aug. 15, 1937
La Phene Harris	Jan. 29, 1937 to June 30, 1939
E. J. Rusho	Aug. 2, 1937 to Jan. 8, 1939
J. M. Herndon	Dec. 1, 1937 to June 30, 1939
J. R. Conrath	July 18, 1938 to June 30, 1939
A. B. Harris	May 11 to June 30, 1939

Tucson, Ariz.- The special non-cooperative item for the Colorado River stations which became a part of the Survey appropriation during the period,[493] made possible an increase in the number of base stations in

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[493] p. 9.

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the Colorado River basin, most of which required resident engineers. Thus the installation and maintenance of the lower Colorado River stations became an important feature of the Tucson district activities, about 1/3 of the total operations.

When special non-cooperative Survey funds were appropriated for the Colorado River stations, cooperative State and Federal funds became available for work in other parts of Arizona, and W. E. Dickinson, district engineer, prepared for the cooperating State officials a 10-year program, designed to meet the stream-gaging needs of the State. Under this program, the total number of stations, including those on the Colorado River,

was increased from 43 at the beginning of the period to 61 in 1931. By that time the Colorado River work had been placed on a satisfactory operating basis and an extra effort was made to place the work in other parts of the State on an equally satisfactory basis.[494] In this under-

494/ Letter from W. E. Dickinson to author.

taking 16 canal stations and 3 stations on minor streams were discontinued and 3 new river stations were established. Thus the improvement program reduced the number of stations to 45 in 1933. The failure of the State to appropriate funds for cooperation during the fiscal years 1934 and 1935 reduced the number of stations to 36. With the resumption of State cooperation in July 1935, the improvement program was again put into operation and within a year all of the older stations had been rehabilitated and equipped with recorders. The total number of stations was increased to 52 in the first year, and the beginning of Army-Engineer cooperation in 1939 further increased the number to 58 at the end of the period. Of these, 54 were equipped with recorders, 50 having pipe-well, and 4 having concrete structures. The highest pipe well was on San Carlos Reservoir where a 12-inch welded-steel pipe 159 feet high, made in 10-foot lengths, was placed on the gate tower. To avoid the effect of draw-down when water was released through the tower, the pipe was made water-tight and the only connection with the reservoir was made by means of a 4-inch intake pipe 70 feet long extending along the upstream face of the dam.[495] Thirty-five cables were erected, the longest being

495/ Water-Resources Bulletin, Feb. 10, 1937, p. 32.

on the Colorado River near Picacho, which had a clear span of 883 feet and a total length of 1,117 feet, due to the necessity for placing one anchorage beyond a gully behind the A-frame. Two artificial controls were constructed.

At the beginning of the period, Colorado River stations were being operated at Lees Ferry, Grand Canyon, and Topock. On July 21, 1928, the station at Yuma, which had been operated by the Bureau of Reclamation since 1907, was transferred to the Survey. The construction of Boulder and Parker Dams made necessary the recording of the flow of the Colorado below those dams and gaging stations were established at Willow Beach in April 1934, and below Parker Dam in February 1934; a station near Picacho, 135 miles below Parker Dam and 14-1/2 miles upstream from the diversion for the All-American Canal at Imperial Dam, was established in July 1934; and on June 3, 1935, the Needles station, which had been established in April 1931 by the Metropolitan Water District of Southern California, for the purpose of determining the possible backwater effect from the Parker Dam, was transferred to the Survey. A station on Lake Havasu, formed by Parker Dam, from which water was pumped to the Colorado River aqueduct, was installed in 1937 before the completion of the dam. With the construction of the All-American Canal to the Imperial Valley, four canal stations were established, as follows:

All-American Canal above Pilot Knob wasteway, October 1938
All-American Canal below Pilot Knob wasteway, April 1939
Yuma Main Canal at siphon-drop power plant, October 1938
Yuma Main Canal below Colorado River siphon, October 1938

Thus by the end of the period, eight stations on the Colorado River and four on canals in the vicinity of Yuma, were being operated.

The Lees Ferry, Grand Canyon, Willow Beach, Topock, Parker Dam, Picacho and Yuma stations each had a resident engineer, reinforced by an assistant during high water, who made almost daily discharge measurements not only on the Colorado River, but also at nearby stations, if any. At some stations daily samples of Colorado River water were obtained and generally analyzed locally for sediment content. Two engineers residing at Yuma, measured not only the main river but also the nearby canals. Toward the end of the period the residencies at Topock and Picacho were discontinued.

Prior to the completion of Boulder Dam in 1935, daily reports, usually telephoned to the nearest telegraph office, were sent out to those interested in the lower river. So widespread was this interest that two Los Angeles newspapers published daily telegraphic reports from two stations, and the Denver office of the Weather Bureau made use of the reports in predicting floods at Yuma.[496] Subsequently the daily

496/ Water-Resources Bulletin, Aug. 10, 1933, p. 51.

reports were discontinued and preliminary records of discharge computed weekly were sent to the district office for distribution as a weekly mimeographed report in place of the earlier daily reports.

Of the varied problems to be solved in installing the Colorado River stations, that at the Willow Beach station was the most unusual. The site of the station was 8 miles downstream from Boulder Dam, and the engineers of the Bureau of Reclamation estimated that after the closing of the dam the clear water released would scour the river bed to a depth of 20 feet. To meet this situation a pipe well was hung on a vertical cliff at a point where borings had indicated that the cliff was vertical for a depth of at least 15 feet below the (then) stream bed. As scour occurred the lower end of the pipe could be lengthened.[497] By 1939, the lower

497/ Water-Resources Bulletin, Apr. 10, 1934, p. 41.

limit had nearly been reached.[498]

498/ Letter from W. E. Dickinson to author.

As a part of the program to improve the operating basis of the non-Colorado River stations, which comprised three-quarters of the entire number in Arizona, suboffices were established at Bartlett Dam, Roosevelt, Camp Verde, Safford, McDowell, and East Verde. The two latter, however, were discontinued toward the end of the period. Referring to the need for the suboffices, Dickinson writes:[499]

499/ Letter to author.

> In general, because of great distances and sudden needs, as well as continuous need, the responsibility for the field work was decentralized as much as possible. In times of general storm and extra need all over the place, I was something like a railroad train dispatcher, keeping activities coordinated by telephone. The local men did theirs and gave us information helpful at other places.

W. E. Dickinson continued as district engineer until April 4, 1938, when he was detailed to the Water Utilization Division for a general

study of the Colorado River water supply, with headquarters in Los Angeles. He was succeeded by J. H. Gardiner, who had been in the Arizona district from October 1, 1921, to August 24, 1929, and was then transferred to Fort Smith, Arkansas, where he was district engineer until his return to Arizona. C. T. Pynchon was district clerk. The other Civil Service engineering personnel were:

D. H. Barber	July 1, 1928 to Oct. 15, 1933
J. A. Baumgartner	July 1, 1928 to June 30, 1939
J. S. Gatewood	July 1, 1928 to June 30, 1939
H. S. Leak	July 1, 1928 to Apr. 3, 1938
A. H. Williams	July 1, 1928 to Feb. 14, 1929
R. E. Cook	July 16, 1928 to Mar. 21, 1936
Charles Wells	Aug. 1, 1928 to Dec. 31, 1929
H. C. Pritchett	Jan. 2, 1929 to Oct. 31, 1930
D. D. Lewis	Mar. 20, 1929 to Oct. 31, 1933
R. G. Kasel	Mar. 28, 1929 to July 10, 1929
W. S. Eisenlohr, Jr.	Apr. 4, 1929 to Nov. 9, 1933
M. B. Scott	Oct. 29, 1929 to Dec. 31, 1934
J. M. Meier	Feb. 12, 1930 to July 16, 1934
C. C. McDonald	Mar. 1, 1930 to Sept. 21, 1936
R. E. Marsh	Apr. 1, 1930 to Aug. 13, 1938
R. H. Monroe	May 19, 1930 to June 30, 1939
W. L. Heckler	July 21, 1931 to June 30, 1939
I. E. Anderson	Apr. 26, 1932 to June 30, 1932
E. J. Tripp	Apr. 26, 1932 to Nov. 17, 1933
K. F. Shumaker	May 8, 1933 to Oct. 9, 1934
B. C. Colby	May 8, 1933 to Oct. 2, 1934
L. L. Laine	Jan. 1, 1934 to May 28, 1937
D. A. Dudley	Jan. 3, 1934 to Sept. 27, 1934
A. A. Fischback, Jr.	July 24, 1934 to June 30, 1939
C. A. McClelland	Sept. 17, 1934 to July 6, 1935
J. W. Montgomery	Nov. 1, 1934 to Mar. 18, 1939
R. H. Otness	Nov. 10, 1934 to June 17, 1936
S. O. Decker	Feb. 1, 1935 to June 30, 1939
H. S. Hunter	Mar. 15, 1935 to June 30, 1939
E. W. Fehsenfeld	Mar. 30, 1935 to Dec. 31, 1935
C. V. Mills	May 3, 1935 to Apr. 11, 1938
G. P. Green	May 6, 1935 to July 13, 1936
A. B. Harris	May 8, 1935 to May 24, 1939
F. S. Anderson	Nov. 18, 1935 to June 30, 1939
E. S. Borgquist	June 1, 1936 to Sept. 24, 1936
M. A. Patch	July 29, 1936 to Apr. 13, 1938
R. E. Cabell	Oct. 10, 1936 to June 30, 1939
W. T. Stuart	Nov. 5, 1936 to June 30, 1939
H. E. Dahman	Dec. 1, 1936 to June 30, 1939
A. J. Hanson	Jan. 6, 1937 to June 30, 1939
R. D. Goodrich, Jr.	Sept. 23, 1937 to Jan. 10, 1939
E. C. Metz	Nov. 12, 1937 to June 30, 1939
C. T. Jenkins	Nov. 1, 1938 to June 30, 1939

Tacoma, Wash.- Prior to 1928, 80 per cent of the gaging stations in Washington had been maintained chiefly in the interest of water power. During the present period, however, new cooperation decreased somewhat the predominance of the water power interest, and increased the relative interests in flood control and irrigation, and also in international problems, chiefly irrigation and water power, in the boundary streams. By

the end of the period the gaging stations were about equally divided between those west of the Cascade Mountains where the chief value was for water power, and those east of the Cascade Mountains where the value was divided between water power and other interests. Water-power interests, both municipal and private, continued to furnish gage-height records and discharge measurements. In addition, Federal Power Commission permittees and licensees expended about $4,000 annually through the Survey in obtaining records required by the Commission.

The greatest amount of new cooperation was that of the Army Engineers. The first phase lasted until September 30, 1931, and resulted in the operation of 60 stations. Of these, some were discontinued, others incorporated in the regular stream-gaging program, and 10 became Federal-type stations. The second phase of the Army Engineer work, started in 1938, resulted in the operation of 10 stations. The creation of international gaging stations in 1931 [500] resulted in 11 stations being so

500 p. 154.

designated, of which 5 were in Washington and 6 in British Columbia. Although the burden of maintaining the British Columbia stations rested with the Canadian engineers, the Survey made occasional measurements and conferred with the Canadian engineers in the computation of the records.

The exchange of field work between Washington, Oregon, and Idaho continued although in lessened degree as improvement in transportation facilities rendered such exchange less important. In 1929, 6 of the 10 stations in northern Idaho that were being operated for the Boise office were transferred to the Idaho district.[501]

501/ Ann. Rept. Tacoma Office, 1929.

A special investigation that required perhaps as high a degree of accuracy as any ever made by the Survey was started in September 1928 and continued for 18 months. Power plants of the Washington Water Power Company were located at each end of a 15-mile stretch of the Spokane River near Spokane and the flow through each plant had been measured by the very accurate Gibson method. Although there was no surface inflow, the records indicated an increase in flow between the plants of 500 second-feet. This apparent discrepancy resulted in a dispute between the owners of the power plants and irrigation users. D. W. Mead, consulting engineer, who was called in as consultant, requested the Survey to investigate the indicated increase in discharge. One gaging station was already in operation and two more were installed for that purpose, the three being equipped with recorders and cableways. In outlining the investigation, Mead specified that in making the discharge measurements velocity determinations should be so made that at no point in the cross section would the distance between velocity observations in any direction be more than 18 inches. This required vertical velocity curves at each point of measurement. As the river was 300 feet wide and as much as 20 feet deep, a single measurement of discharge required nearly an entire day. During the 18 months six sets of measurements were made at the three stations using new meters that had been rated with 30- and 50-pound weights. A water power company's engineer made simultaneous measurements from the same cable car. The Survey records checked those of the power plants within 1-1/2 per cent.

Activity on the Columbia River brought about the installation of three notable gaging stations. A Federal Power Commission license required the installation of a station below Rock Island Rapids and a year was spent in finding a suitable site. Finally one was found at Trinidad, where a recorder well and shelter having an overall height of 60 feet and a cable of 1,654-foot span supported by a steel tower 89 feet high on one side and 42 feet high on the other, were required. Three intake pipes placed 2 feet apart vertically were provided. Plans were developed in collaboration with the Federal Power Commission, and the construction work was done by contract at the expense of the licensee under Survey supervision. The installation was completed in October 1930 at a total cost of about $14,000.[502]

[502] Statement of G. L. Parker to author.

The Army-Engineer investigations included the Columbia River Basin project, a combined irrigation and power project of vast size, which had been advocated by local interests and investigated in a preliminary way by the Bureau of Reclamation about 1923. In June 1928, a station was established at Grand Coulee consisting of a recorder installation 80 feet high, and a cable of 1,100-foot span. The total cost of $12,000 was paid from Army-Engineer funds. Two years later the Bureau of Reclamation began an intensive investigation of the Columbia River Basin which led to the construction of what is known as the Grand Coulee Project. During the course of construction of the Grand Coulee Dam an earth slide tipped this gaging station and broke off the intake pipes, and plans were made to move the station to the new highway bridge that was constructed 4,000 feet below the dam. A well about 4 feet square was made in one pier for the installation of the recorder. The Bureau of Reclamation assisted in the installation of the new station and replaced the cable in 1934 with a larger size strand. The new well and shelter, which had a height of 77 feet, was equipped with five intakes, three of which were connected to pressure water pipes. The ventilation of the well was accomplished by lowering a 1,000-watt electric heater to a point near the water surface and leaving it there until the heat induced circulation, which brought the foul air to the top of the well.

The Grand Coulee Dam when completed would cause backwater at the International Boundary, and to determine the amount of such backwater the State Department authorized the construction of a station at that point in 1938. This was a reinforced concrete structure 5-1/2 by 6 feet in plan, having an overall height of 71 feet of which 16 feet was above the ground. Of the two intakes, the lower was 3 inches in diameter and had a length of 170 feet, and the upper, 40 feet above the lower intake, was 2 inches in diameter, and 39 feet long to a concrete pier. To flush the intakes and light the shelter, 1,000 feet of 2,300-volt transmission line was constructed from a nearby power line to the shelter. Quicksand and water which yielded a flow of 10,000 gallons per hour, made it necessary to use sheet piling and pump continuously during construction, and the services of a diver were required to install the static tubes at the ends of the intakes. The cost of the structure, with accessories, was $15,900. A cableway of 1,148-foot span, having a steel A-frame 32 feet high at one end and direct anchorage connection at the other end was erected at a cost of $2,547. This installation was made by the Bureau of Reclamation.[503]

[503] Letter from F. M. Veatch to author.

Another special feature during the period was the cooperation with the Soil Erosion Service in the Pullman project.[504] This cooperation

[504] p. 81-82.

required the construction of five stations equipped with recorders, and artificial controls. The latter were Parshall flumes with removable weir crests of various sizes in the throat. V-notch weirs measured discharges as low as .01 second-foot. This project, which required a resident engineer, was started in the spring of 1934 and continued during the period.

To bring up to date the summary of stream-gaging records which had been published through 1919 in Water-Supply Paper 492, Parker in 1936 prepared a supplemental summary from October 1, 1919 to September 30, 1935, which gave the monthly records of 1,470 years at 203 gaging stations, and a bibliography of all stream-gaging records in the State. The report was published as Water-Supply Paper 870, and was largely assembled by Agnes P. Martinson, clerk, who later was reclassified as engineering aid, SP 5.

The number of gaging stations was increased from 66 in 1928 to a high point of 133 in 1930, and then decreased to 106 in 1939. At the beginning of the period 73 per cent were equipped with recorders, and at the end, 90 per cent. In addition, an average of 10 complete records obtained by the Bureau of Reclamation in connection with its Yakima project were furnished for publication.

G. L. Parker was district engineer and Miss Lucille F. Peterson, district clerk, during the period and had the following Civil Service engineering assistants:

D. J. F. Calkins	July 1, 1928 to June 30, 1939
D. A. Dudley	July 1, 1928 to Sept. 30, 1930
R. B. Kilgore	July 1, 1938 to June 30, 1939
W. E. Armstrong	July 1, 1928 to Nov. 30, 1928
Arthur Johnson	July 9, 1928 to May 15, 1931
G. M. Thayer	July 1, 1928 to June 30, 1939
H. C. Woster	June 20, 1929 to Feb. 10, 1937
M. C. Boyer	Sept. 22, 1929 to Dec. 31, 1930
Frank Stermitz	Dec. 7, 1930 to July 11, 1936
O. B. Johnson	Sept. 28, 1931 to July 13, 1932
J. P. Bonner	Aug. 27, 1931 to Feb. 1, 1938
B. M. Tanner	Apr. 3, 1934 to Dec. 21, 1935
A. H. Hanson	July 6, 1936 to Apr. 11, 1937
I. E. Anderson	Nov. 17, 1937 to June 30, 1939
G. M. Sherwood	Sept. 9, 1937 to June 30, 1939
G. I. Teufel	Apr. 22, 1937 to June 30, 1939
G. W. Caughran	Aug. 25, 1938 to June 30, 1939
E. Z. Gray	Oct. 24, 1938 to June 30, 1939

Portland, Oreg.- The division of work between the Survey and the State engineer of Oregon continued with increased cooperation, beginning in the fiscal year 1932 and, thereafter, practically all continuous stream-gaging stations in the State again came into the cooperative program. As a result, the number of cooperative stations was increased from 93 to 191. With some fluctuations during the ensuing years, the number was gradually increased to 215, of which 161 were equipped with

recorders at the end of the period. One hundred thirteen installations were made during the period, 19 in concrete structures, 10 in concrete wells and timber shelters, 10 in pipe wells, and 74 in timber structures. Of the 93 cables installed, the most notable were the two over the Columbia River, one at The Dalles, and the other near Maryhill.[505] Ten

505/ p. 173.

artificial controls of various types were installed. A type of recorder shelter worthy of note was that on Trout Creek near Denio, in one of the most desolate and isolated parts of Oregon, as Canfield described it,[506]

506/ Water-Resources Bulletin, July 10, 1932, p. 36.

130 miles from the nearest railroad point from which materials would have to be hauled, most of the way over desert roads. Such transportation was prohibitive in cost. As ranch buildings in the vicinity were constructed of native stone, a rancher was employed to use that material in building the recorder shelter. The well and shelter were built as a continuous structure 13-1/2 feet high with walls 14 inches thick, and inside dimensions 3 feet by 3-1/2 feet. The top was covered by a shingled roof.

An investigation of general interest to the Survey was made in 1931 and furnished further information upon the accuracy of operation of the Price meter when it is moved vertically in the water. Meters of the screw type were believed to be less affected by vertical motion. Comparative measurements by a Price meter and a 4-bladed Hoff meter were made on the Columbia River at The Dalles, where a heavy wind swayed the cable car, imparting a vertical motion to the meter. The Price meter indicated a discharge of 105,000 second-feet and the Hoff meter 107,000 second-feet, indicating less over-registering by the Price meter than by the Hoff meter. Hoff and Price meters were lent to the Army Engineers for a further comparison in measuring from a boat the tidal velocity at the mouth of the Columbia, where the wave motion caused considerable vertical motion of the boat and meters. The results obtained were practically the same with the two meters.[507]

507/ Water-Resources Bulletin, Sept. 10, 1931, p. 20.

The first recorded use of an airplane in Survey work was made during the winter of 1931. During the previous fall the Portland office had taken over several gaging stations in the upper Lewis River Basin which had previously been operated by a power company. As the stations were in a mountainous region of deep snow, they could only be reached in winter on snowshoes, and a cabin stocked with bedding and provisions had been constructed near a central point. On the first trip to the stations in January, M. C. Boyer and an assistant found that the provisions were not sufficient for the remaining winter trips. As the trip required two long days by snowshoe, some other means of transporting the provisions was necessary. The most feasible means was by airplane, and the officer in charge of an Army air field near Portland offered to assist as a part of routine training. Having returned to the cabin on snowshoes, Boyer and his assistant marked on the snow by means of a cross of streamers of red and yellow cloth, the exact spot where the food was to be dropped in 65-pound coffee cans. The cross was seen by the pilot and the provisions were dropped without mishap during the course of 4 days' training trips. When the last package was received, the letters OK

were tramped in the snow and filled with lamp black. This sign was seen by the plane on the return trip and the pilot dipped his wings in acknowledgment.508/

508/ Letter from M. C. Boyer to author.

G. H. Canfield continued as district engineer and Miss Belle Irwin, district clerk, and had the following Civil Service engineering assistants:

K. N. Phillips	July 1, 1928 to June 30, 1939
B. S. Barnes	July 1, 1928 to Aug. 17, 1936
A. H. Williams	July 1, 1928 to Sept.27, 1937
H. M. Orem	Jan. 1, 1929 to Oct. 31, 1930
W. T. Miller	Dec. 16, 1929 to June 30, 1939
A. R. Peracca	Dec. 1, 1930 to June 30, 1939
M. C. Boyer	Jan. 5, 1931 to Jan. 1, 1932
A. B. Goodwin	Aug. 14, 1931 to Mar. 10, 1936
C. A. Young	Sept. 4, 1931 to Oct. 23, 1933
I. A. Cooper	Sept.16, 1936 to June 30, 1939
G. A. Kirkpatrick	Mar. 4, 1937 to June 30, 1939
M. D. Brands	Mar. 10, 1937 to June 30, 1939
John Kovtynovich	Mar. 23, 1938 to June 30, 1939
K. J. Smouse	Nov. 1, 1938 to June 30, 1939

San Francisco, Calif.- The effect of the increase in Survey cooperative funds due to the recognition of the 50-50 principle, was greater in the San Francisco district than in any other. The cooperative State funds had previously been so far in excess of Survey funds that when 50-50 cooperation became operative, the Survey funds were increased from $5,000 to $50,000 or more, and the State funds were materially increased also.509/ As a result, the number of gaging stations was increased from

509/ p. 54.

225 at the beginning of the period, to 292 in 1932. During the depression years, the decrease in funds reduced the number of regular Survey stations to 253 in 1936, and thereafter the number was increased to 279 by June 30, 1939. In addition, some 50 stations, not listed as regular Survey stations, of the 100 odd stations were operated for and at the expense of Federal Power Commission licenses, and complete records for other stations, collected by other agencies and checked by the Survey, were published.510/

510/ Letter from H. D. McGlashan to author.

This was a period of intensive construction in which 193 recorder shelters, 114 cableways, and 26 artificial controls were installed, 17 being of a new type.511/ Of the recorder structures, 47 had concrete

511/ Letter from H. D. McGlashan to author.

wells and shelters, 127 had pipe wells chiefly of the McGlashan type, and the remainder had timber, or concrete and timber wells and shelters. A considerable part of the construction represented replacements after the disastrous flood of March 1938. As a result of changes in location, two concrete shelters weighing about 18 tons each were successfully

moved and the method employed merits mention. Both were cut off at the ground surface. One was hoisted by a locomotive crane to a flatcar and transported 4 miles to a new site and placed on a new foundation; the other was lifted to a trailer by a crane mounted on a caterpillar and hauled 800 feet to the new site and placed on its new base.[512]

[512] Water-Resources Bulletin, Sept. 10, 1929, p. 17.

Operation of stations for the Federal Power Commission represented a more important part of the district activities than in the previous period when the actual field work had been performed in large part by the licensees. More and more of that work was performed by the Survey during the present period, including the computation of all records for the 110 licensee gaging stations.

Operations of stations for the Hetch Hetchy project of City of San Francisco were continued and a sub-office was maintained at Groveland, from which C. J. Emerson operated not only the Hetch Hetchy stations but all other stations in the Tuolumne River Basin. The cooperative work with the East Bay Municipal Utilities District and the Ground Water Division became more intensive, not only in the number of measurements made weekly, but also in the number of stations operated, and as a result the number of engineers detailed to that project, with headquarters at Lodi, was increased from one to two beginning in 1932. The need for the more intensive work was based on the fact that, in the Ground Water Division's work of determining the ground-water recharge from the Mokelumne River, it was necessary to know as accurately as possible the discharge of the river through its shifting channel, as the seepage losses were less than 3 per cent of that discharge.[513]

[513] Water-Resources Bulletin, Sept. 10, 1931, p. 22.

The station on Mokelumne River near Mokelumne Hill is above the Pardee reservoir and to obtain advance information of stream flow entering the reservoir, a radio transmitter was installed in 1937. The Survey installed in the Lodi suboffice a radio receiving set by means of which signals in the Morse Code transmitted automatically from the gaging station were received every two hours. By means of this information the Survey engineers had warning of the approach of high water. A use not contemplated was made of the radio records when the gap in the regular chart record caused by clock stoppage was filled in by means of bihourly gage heights transmitted by radio.[514] On account of power regulation on

[514] Water-Resources Bulletin, Aug. 10, 1938, p. 187.

Mokelumne River it was necessary to make an occasional wading measurement at night, and in the true California spirit, the statement of that fact as given in the Water Resources Bulletin[515] added, "At times the salmon

[515] Jan. 10, 1931, p. 23.

are so numerous and so large that they have interfered with the operation of the meter and the movements of the hydrographer."

A cable car "borrowed" by State Highway employees prevented B. C. Colby from making a record measurement during a large flood on the North Fork of the Yuba River in 1937. By exercise of good judgment, hard

work, and long hours of driving, he reached the station at a higher stage than any measured but was unable to make a regular measurement, as the cable had been moved some miles downstream for the purpose of ferrying people across a small stream where the bridge had been washed out. He did make a float measurement by timing the drift over a measured course.

Cooperation with Los Angeles County in the maintenance of the 13 gaging stations in that project was continued, as was the detail to the Survey of H. J. Tompkins, a Forest Service engineer, for that purpose. This detail terminated in February 1936. Cooperation with San Bernardino, Riverside, and Orange Counties also continued, and to the 15 original stations, reduced to 14, at the base of the mountains,[516] were gradually

[516] p. 161, 1919-1928.

added 8 stations on the lower reaches.[517] To maintain these stations,

[517] Letter from F. C. Ebert to author.

as well as 15 other stations in that area, a suboffice with three engineers was maintained at San Bernardino, under the general supervision of the Los Angeles office. The tri-county investigation had among other objectives, a study of the fluctuations in flow of the valley portion of the Santa Ana River. In connection with that study, a continuous record of evaporation from a free water surface was desired and a recording evaporimeter designed by Ebert and Olson, was operated at Baldwin Park.[518]

[518] Water-Resources Bulletin, Aug. 10, 1933, p. 45.

A special investigation of particular interest to Orange County was concerned with the loss of water from the Santa Ana River between Riverside Narrows and the Orange County line. This involved the establishment of additional stations on the river, and of a series of four wells at right angles to the river in an endeavor to answer the question of Orange County water users, "What part of the Santa Ana River water is consumed by unremunerative plant life along the river?" This investigation was made by H. C. Troxell in 1932 and the results published in State of California Bulletin 44.[519]

[519] Letter from F. C. Ebert to author.

An unusual type of publicity and one that was very effective in telling the public about the work of the Branch, was a window exhibit in an office of the Pacific States Savings and Loan Co., on Market Street, the principal business thorofare in San Francisco. The exhibit consisted of a model of a gaging station, including recorder shelter and cable, various articles of equipment, photographs, hydrographs, and other items showing the importance and value of studies for power, irrigation, flood control, city water supply, drainage, and waterway openings. After being shown for 3 weeks at the company's main office, the exhibit was moved successively to branch offices in San Francisco[520] and neighboring

[520] Water-Resources Bulletin, Feb. 11, 1934, p. 27.

cities for a total period of 24 weeks. The exhibit was made at the request of the company which was featuring in its show windows various

types of business in San Francisco. A description of the flood investigations during the period was given on pages 133, 137-138.

Reminiscent of the early days of the Survey, was a statement in the Water-Resources Bulletin[521] that R. H. Bolster, who had been in

[521] Mar. 10, 1932, p. 21

charge of the computing section from 1907 to 1912, was a frequent user of Survey records, some of which he had reviewed while in the Washington office.

H. D. McGlashan continued as district engineer, and F. C. Ebert continued in charge of the Los Angeles office and Miss Helen C. Smith was district clerk. Other Civil Service engineering personnel were:

R. C. Briggs	July 1, 1928 to June 30, 1939
Wm. Kessler	July 1, 1928 to May 12, 1929
Charles Leidl	July 1, 1928 to June 30, 1939
Jesse Arnold	July 1, 1928 to June 30, 1939
C. J. Emerson	July 1, 1928 to June 30, 1939
A. C. Swanson	July 1, 1928 to June 30, 1939
Jarrett Oliver	July 1, 1928 to June 30, 1939
C. D. Bue	July 20, 1928 to June 30, 1939
C. R. Reed	Sept.24, 1928 to Nov. 22, 1929
H. C. McCrery	Oct. 28, 1929 to Sept.22, 1937
F. A. Johnson	Nov. 18, 1929 to June 30, 1939
H. C. Troxell	Dec. 1, 1928 to June 30, 1939
F. W. Bush	Dec. 1, 1928 to Mar. 31, 1929
K. R. Melin	Dec. 14, 1929 to June 30, 1939
L. E. Bossen	(June 1, 1930 to Aug. 5, 1933
	(May 2, 1938 to Dec. 31, 1938
R. S. Lord	June 16, 1930 to June 30, 1939
B. C. Colby	July 1, 1930 to June 30, 1939
D. A. Dudley	Sept.18, 1930 to June 30, 1939
K. F. Schumacher	Sept.30, 1930 to June 30, 1939
H. M. Orem	Nov. 1, 1930 to June 30, 1939
H. C. Pritchett	Sept. 7, 1931 to June 30, 1939
M. T. Wilson	Dec. 16, 1931 to Dec. 4, 1933
K. M. Kelley	July 5, 1932 to Feb. 21, 1934
H. F. Matthai	Dec. 21, 1936 to June 30, 1939
H. S. Leak	Apr. 4, 1938 to Dec. 10, 1938
G. I. Lang	Apr. 21, 1938 to June 30, 1939
H. J. Sexton	Aug. 15, 1938 to June 30, 1939
P. M. Alexander	Aug. 19, 1938 to June 30, 1939

Honolulu, T.H.- With increased funds resulting from the 50-50 cooperation authorized early in the period, practically all the gaging stations were, in the language of the 1931 report to the Governor of Hawaii,[522] "overhauled and put in first-class shape." The number of

[522] p. 57, Territorial Annual Report, 1931.

gaging stations in Hawaii was gradually increased from 83 at the beginning of the period to 90 in 1932. This increase was caused chiefly by the establishment in 1931 of six stations on large springs at Pearl Harbor, at the request of the Honolulu Board of Water Supply.

During the next fiscal year the reduction in funds made necessary the discontinuance of the operation of some of the more inaccessible stations including those on the windward side of Molokai which was virtually uninhabited; during World War I, the men living there had been drafted and the women and old people refused to stay alone. After the war they refused to return as they had found the new life in the cities much more attractive.[523] As an offset, however, the need for a more

523/ Statement of G. E. Ferguson to author.

accurate determination of the water supply available for irrigation on Maui made necessary the establishment, largely through local cooperation, of 17 additional stations on that island. Thereafter the number of stations in Hawaii remained fairly constant until 1937 when six stations were established on Molokai in connection with the investigations of an irrigation project by the Bureau of Reclamation. That project contemplated a tunnel through the backbone of the island to the arid leeward side, for the irrigation of sugar cane. At about the same time, five stations were established along the Napoli coast of Kauai, for a similar reason. One of those stations was located in Kalalau Valley, the scene of Jack London's story, "Koolai the Leper". At the end of the period 115 stations were in operation in Hawaii, all equipped with recorders.

With reference to the selection of gaging stations, the Commissioner of Public Lands stated in his 1929 report to the Governor:[524]

524/ Ann. Rept. Gov. of Hawaii to Sec. of Int., 1929, p. 57.

> Funds do not permit the measurement of all streams, so representative streams are selected, and preferably those draining Territorial lands or in the waters of which the government has some direct interest. The value of any particular stream flow is hard to establish. It is entirely dependent upon the possible future utilization, but the longer the accurate record of stream flow has been maintained, the more valuable it becomes to the Territory.

The unusual features of stream gaging in the Hawaiian Islands have been described in the previous periods covered by this history, and little remains to be added except a brief account of the more or less routine happenings. However, "local color" is given by the following incidents which have been noted:

In July 1928, the gaging stations on Wailuku River at Pukamaui near Hilo, was put out of commission by the opening up of an underground channel through a lava tube that completely drained the gage pool.[525]

525/ Water-Resources Bulletin, Sept. 10, 1928, p. 14.

By contrast, two years later high water at that station during August caused the pencil on the Au recorder to reverse so frequently that the sliding of the pin in the spiral groove practically wore it through.[526]

526/ Op. cit., Nov. 30, 1930, p. 26.

The following year earthquakes were of frequent occurrence during the fall, and several were sufficiently severe to make distinct marks on

recorder graphs. This was not an unmixed evil, as the marks served to check the time corrections.[527]

[527] Op. cit., Nov. 10, 1929, p. 18.

The installation of six stations on springs at Pearl Harbor was made under conditions that were more than unusual; they were unique. It was necessary to make the installations at tide levels. Carson has described the situation as follows:[528]

[528] Op. cit., July 10, 1931, p. 25.

> Handling the backwater effect from tides was a serious problem. It was impracticable to construct weirs with crests at a sufficient elevation to get above high tide, because of the chances of flooding the lowlands back of them. What we are doing is to construct weirs with crests about a foot below high tide. Each recorder well is divided into two compartments by a partition in the center. These compartments are connected respectively with the stream above the weir and below the weir. A duplex recorder gives, on the same sheet, a continuous record of both water surfaces. During periods of free flow the discharge can be taken directly from weir tables checked by occasional current meter measurements, and during periods of back water it is possible, when necessary, to compute the flow from submerged weir formulas. Our experience has shown, however, that with the help of the double graph we can determine by inspection when the flow is retarded by back water and increased by storage so that the mean flow line can be drawn in and the submerged-weir computation eliminated.

One of the stations was located on land formed by dredged material and the concrete structure was floated on the mud with a reinforced concrete matting. This proved satisfactory until unusually high water in February 1935 washed away the mud fill and tilted the structure so that its top was a foot or more out of line. By an ingenuous method involving piling and jacks the structure was righted and again placed in operation.[529]

[529] Op. cit., Apr. 10, 1936, p. 23.

G. E. Ferguson who was assigned to Hawaii for several years has made the following observations to the author:

> Hydrographers constantly find field work more exciting by the loss of saddle mules on mountain trails, by the dropping of harmless and too friendly lizards down one's neck while cleaning out wells, and by being trapped in upper valleys for several days by the frequent floods which make the trail fords impassable.
>
> So far as mountain roads are concerned, nothing takes the place of the old "Model T".

During the years of PWA projects, one of the resulting activities was the building of models of several gaging station sites, for the purpose of rating them in the University of Hawaii hydraulic laboratory. By this means, it was possible to extend rating curves for streams when it

was almost impossible to obtain measurements of the giant floods. As this was a new activity for the Branch, a description of the procedure is warranted.

A contour map of the site was prepared, the contours sawed out from sheets of plywood; the frame work built up step by step, the steps smoothed out with casting plaster, making in sections a plaster cast of the completed model. The model was taken to the site, trimmed to an exact replica, and then taken to the hydraulic laboratory for rating. Several month's time was required to construct each model. The results from the models were checked with actual current meter results at the gaging station, and were found to agree satisfactorily. Six models, all in Oahu, were rated during the period.530/

530/ Letter from M. H. Carson to author.

Mr. Carson continued as district engineer during the period. Other Civil Service engineering personnel were:

J. F. Kunesh	July 1, 1928 to June 30, 1931
W. E. Armstrong	Dec. 2, 1928 to June 30, 1939
J. L. Lamson	July 1, 1928 to Feb. 19, 1939
K. N. Vaksvik	July 1, 1928 to July 1, 1938
J. H. Hofmann	July 1, 1928 to Dec. 19, 1928
K. M. Kelley	July 1, 1928 to June 15, 1932
G. T. Hirashima	July 1, 1929 to June 30, 1939
Kenichi Kawamura	July 1, 1930 to Aug. 6, 1934
H. W. Palm	(Aug. 5, 1930 to Feb. 10, 1934 (May 12, 1938 to June 30, 1939
G. E. Ferguson	Sept.11, 1931 to Sept.17, 1937
C. A. Young	Sept.21, 1936 to June 30, 1939
E. J. Rusho	Oct. 14, 1936 to July 9, 1937
H. C. McCreery	Sept.11, 1937 to June 30, 1939
H. S. Leak	Dec. 16, 1938 to June 30, 1939
M. N. Nahm	July 1, 1938 to June 30, 1939
J. W. Montgomery	Mar. 22, 1939 to June 30, 1939

Stream gaging in foreign countries

Having described in considerable detail the development of methods and equipment used in stream gaging by the Survey, it only remains to review briefly the work of stream gaging in foreign countries to determine to what extent Survey methods are being used. Much of the information has been obtained by the author through personal contact or correspondence with engineers from various countries who have come to the Denver Office of the Bureau of Reclamation, to study that agency's methods and techniques.

With respect to their stream gaging programs, foreign countries fall into two groups. In the first group are (a) Continental Europe (except the Soviet Union), where stream gaging has been carried on as long, if not longer, than in the United States, and where equipment and methods has become "crystalized" before American methods and equipment had reached a high state of development, (b) most of those South American countries in which stream-flow studies are being made. Although stream gaging has been carried on only within recent years, except in Argentina and Peru where it was started in 1901 and 1904, the general

European orientation of those countries has caused them to look to Europe for guidance in stream gaging, and to use European instruments which are much less expensive than those made in the United States. In this group, neither equipment nor methods in general resemble closely those of the Survey. Two notable exceptions are Peru and Venezuela, where American engineers employed by the respective governments introduced Survey methods and equipment. As a judicious distribution of "stream gaging procedure" was made, particularly to South American engineers, it may be that in the future, Survey methods will be employed more extensively.

The second group consists of Mexico, the Soviet Union, the English dominions and mandated areas, and the countries of the far east, where English and American influence is great. In this group, American practice has been taken as a guide, as the Survey's development of equipment and methods was well advanced, when they started stream gaging. The Price meter was almost universally adopted in this group, but a number of the countries use the cumbersome vertical-velocity-curve method of obtaining mean velocities. In many of the countries, however, several men are required to make a measurement instead of the usual one-man party, which is the Survey's practice.

Continental Europe.- Most of the European countries have central governmental agencies to measure the rivers. The numbers of gaging stations operated is shown by National Resources Committee:[531]

531/ Deficiencies in basic hydrologic data, p. 50: Natl. Res. Com. Sept. 1936.

Country	Number of gaging stations
Austria	66
Czecho-Slovakia	718
France	1,000
Germany	408
Italy	1,199
Poland	513
Spain	148
Sweden	570[532]
Switzerland	128

532/ Including 270 lake stations.

For other European countries not listed above, available information is contained in the following pages.

Detailed information for each country is not available, but in general, the same methods are used in all. The screw-type meter (Ott, Amsler) is used almost exclusively. The velocity is measured at several points in the vertical, and the mean velocity obtained from the resulting vertical velocity curves, which are also used to determine points of equal velocity in the cross section. Lines of equal velocity are drawn through those points and from them the discharge is measured by planimeter. Another method is the Harlacher graphical method in which the discharge in each vertical is plotted as an ordinate to a curve of discharge, the area of which is then measured. The making of a discharge measurement is quite an operation requiring a party of three or more, one or more to handle the meter, another to handle the stop watch and supervise

operations, and a third to keep notes. It is apparent that not the least time-consuming factor is the subsequent computation of the discharge. When measurements are made from a bridge, it appears to be the practice to use a small, movable platform placed on a track outside the bridge truss. When a suitable bridge is not available, measurements are made from a boat or a cableway. For determining stages, water-stage recorders or vertical staff gages are used, the former quite generally. Daily discharges are computed by means of rating curves.

An excellent description of the best European practice is contained in "Hydraulic Structures," by A. Schokolitsch, an English translation of which was published, at the suggestion of John R. Freeman, by the American Society of Mechanical Engineers in 1937.

Austria.- In 1895, the Hydrographical Central Office was created in Austria for the purpose of studying water economy; 412 gages for recording floods were established. Systematic river surveys for the development of water power were started in 1907.533/

533/ Development and utilization of water power in Austria; Trans. First World Power Conference, vol. I, p. 684, London, June 30-July 12, 1924.

Estonia.- In 1921, the Department of Inland Waters of Estonia was created to make a power survey, which included the establishment of 30 gages and 10 gaging stations.534/

534/ Water Power resources of Esthonia: Trans. First World Power Conference, vol. I, p. 822, London, June 30-July 12, 1924.

An Estonian student at the Colorado School of Mines informed the author that the Hydrologic Division of the Department of Agriculture has maintained for some 20 years, about 100 gaging stations in the interest of draining the swamps caused by the overflow of a large lake. All stations are equipped with staff gages except two, which have recorders. The staff gages are read twice daily. German-type meters are used.

Finland.- The State Bureau of Hydraulic Resources of Finland is charged with the investigation of the different river basins, including the collection of records of stage and discharge.535/

535/ The power resources of Finland: Trans. First World Power Conference, vol. I, p. 827; London, June 30-July 12, 1924.

Hungary.- The chief interest in river flow in Hungary appears to be related to flood control and prevention, particularly on the Danube. Systematic observations of stage were started in 1823, and discharge measurements with a Woltmann meter made as early as 1835. As a matter of historical interest it may be noted that in 1845, Vasarhelyi studied the forms of the vertical velocity curve as developed by current-meter measurements. Because of lack of knowledge of the Hungarian language, these studies were not generally known by Engineers in other countries. The survey of rivers is conducted by the Hydrographic Institute under the Royal Hungarian Ministry of Agriculture. The Hungarian streams are large, having cross sections 1,000 feet or more in width and from 30 to 70 feet in depth. As they carry much fine silt, it was necessary to develop a special meter which could be kept free from silt. As the usual vertical velocity curve method was out of the question on such

large streams an improved vertical-integration method of obtaining the mean velocity is used.536/

536/ Statement of Dr. Ing. W. Lászloffy, Budapest, 1936, to Chief Hydraulic Engineer.

Sweden.- The only information available to the author regarding stream-gaging in Sweden was obtained in an interview by Grosbach with a Swedish engineer, a Mr. Svenson, engaged in governmental hydrographic work.537/ At the time of that interview, 120 gaging stations were being

537/ News letter, Aug. 11, 1924, p. 11.

maintained. Both Price and German screw-type meters are used, and the European method of computing the discharge is apparently followed. Measurements are made from boats or bridges, and where boats are used, one or two additional boats are stationed upstream during floods to divert drift. Recorders in simple shelters are installed at many if not all stations. A Royal Board of Waterfalls was organized in 1909 for the administration of the State-owned power resources. The following year the Board proposed a general water-power survey which was started by the Hydrographic Bureau, and since 1919 it has formed a part of the Government Meteorological-Hydrological Institute.538/

538/ Swedish Power Resources: Trans. First World Power Conference, vol. 1, p. 1334, London, June 30-July 12, 1924.

Norway.- Observation of water levels began as early as 1820, when a few years records on a few streams were collected for special purposes. In the early nineties, the need for power turned attention to the streams, and gaging stations were established both on the rivers and on the many mountain lakes which became reservoirs for power plants located below the lakes. The number of stations gradually increased until at the present time (1946) there are about 500 gaging stations, a large part of which are on lakes. About 40 stations, either on regulated streams or at remote locations are equipped with water-stage recorders and the remainder with staff gages. On many of the smaller streams, the stations are equipped with artificial controls. Measurements are usually made by means of screw-type current meters, and at stations having permanent beds, the depths are obtained from standard cross sections. The discharge is computed by the graphical method. Where satisfactory current-meter measurements can not be obtained, the relative-dilution method has been used. The records are computed for the water year ending August 31, and are published annually. The stream-gaging program is maintained by the Watercourse and Electricity Service, although the actual maintenance of about one-third the stations is required by power companies and local administrations, under the terms of the power concessions.539/

539/ Information furnished the author by the Watercourse and Electricity Service.

Yugoslavia.- Before World War II, a few gaging stations were being maintained, at which the stage was observed. A few discharge measurements by means of Ott meters were made, but these were insufficient for the construction of rating curves and computation of daily discharges.

During the war, the stream gaging was continued in those areas

remote from the fighting, and the number of stations was very considerably expanded. German or Swiss equipment, including Ott meters, was used and the general European practice followed. Measurements are made from boats in the case of small streams, from foot bridges.[50] Several

[50] Statement of Ivo Petyo engineer, Hydrologic Institute to author.

hundred gaging stations are in operation, only a few being equipped with water stage recorders. The work is under the direction of the Hydrologic Institute, although the field work is generally performed by the individual states. The chief value of the stream flow records is (1) flood control in the valley of the Sava River, one of the principal rivers which flows through a wide valley subject to inundation, and (2) for water power on the many small streams rising in the mountains which comprise a large part of Yugoslavia's area.

Greece.- Although need for flood control, irrigation, water power, and drainage had existed, Greece's troubled existence after World War I had not resulted in governmental action until 1930. In that year, a Division of Engineering Works for Greece was created in the Department of Agriculture, and Prof. Cristopoulos, chief engineer of the Region of Peloponnesus began the establishment of gaging stations in the Peloponnesus. As about 80 percent of the rainfall occurs during the three winter months, most of the streams, except a few fed by springs, are dry the greater part of the year. Staff gages were established at some 50 stations and those are read during the period of flow. A few water-stage recorders of German make were installed. As there are no bridges and boats and cableways are not used, flood measurements on the larger streams are made by floats.

On the smaller streams, German screw-type meters are used by parties of 2 or 3 men. The European practice of making measurements is followed. About 1938, the Division of Engineering was named Division of Hydraulic Works, now is called Division of Agricultural Hydraulics. In 1945, the Hydrographic Division was created in the ministry of Public Works.

Syria.- For some years after World War I, when Syria became a French Mandate, the Service Hydraulique carried on quite an extensive stream-gaging program. The Service is no longer operating and no details are available.[51] A guess may be hazarded that being under French

[51] Letter from M. G. Ionides to author.

auspices the general European methods were followed.

Palestine and Transjordan.- After World War I the movement to return Jews to the ancient homeland was started and as one result, an investigation of the scanty water resources of Palestine and Transjordan was begun with view to utilizing such resources to the fullest extent. One of the first projects was that of the Palestine Electric Corporation, Lt. to develop power on the River Jordan at the upper end of the Jordan Valley. A gaging station was established by the electric company at Deganiah in 1921. It appears that the discharge was computed by means of current-meter measurements and gage heights until 1932 after which time the discharge was computed from the flow through the turbines. The Government of Palestine organized the Department of

Development which installed and maintained five additional stations, chiefly on the Jordan, with some assistance from the electric company. The only information available regarding the methods used is that current-meter measurements were made, daily gage heights obtained, and the daily discharges computed by means of rating curves.

To determine the amount of uncultivated land that could be irrigated in Transjordan, the Palestine Royal Commission in 1937 recommended the Hydrographic Survey of Transjordan for which funds were made available late in 1937. The available surface-water supply consists of small streams and many springs. This was a reconnaissance survey and the measurements were made by portable weirs or volumetric tanks. No permanent gaging stations were established. The work covered a year or so, and a report was published.542/

542/ Ionides, M. G., Rept. on water resources of Transjordan and their development; Govt. of Transjordan, London, 1939.

In the absence of information to the contrary, the author assumes that the program of stream gaging in the Jordan Valley is carried out at the lowest elevations of any on the earth, as the surface of the Sea of Galilee is 680 feet below sea level and that of the Dead Sea into which the River Jordan flows is 1,300 feet below sea level.

Dutch East Indies.- The Service of Water Power and Electricity of the Dutch East Indies was organized in 1917 as a branch of the Department of Government Industries. Among its duties are the systematic investigation and registration of the water power resources.543/

543/ The water power resources of the Dutch East Indies: Trans. First World Power Conference, vol. I, p. 777, London, June 30-July 12, 1924.

Belgian Congo.- Soon after the Congo Free State was annexed to Belgium in 1908, and became the Belgian Congo, the Colonial Government began to establish staff gages on the Congo and the principal tributaries, in the interest of navigation. Those gages have increased to about 100, the greatest increase occurring since 1932. About that time, the Colonial Hydrographic Service began to make occasional discharge measurements at many points where the daily staff gage readings were available. A number of the stations have been rated, that near the mouth of the Congo having a mean discharge of about 1,380,000 second-feet for a drainage area of 1,475,000 square miles.544/ The author

544/ Observations Hydrographines du bassin Congolais (1932-1947): Institut Royal Colonial Belge, Section Des Sciences Technigues, Bruxelles, 1948, p. 107.

believes it is only exceeded in volume by that of the Amazon which is probably twice as great. As a comparison, the Mississippi River at Vicksburg has a mean discharge of 510,000 second-feet from a drainage area of 1,144,500 square miles.

European methods are used, and the Ott meter is used, sub-surface velocities being obtained which are reduced to mean velocities by use of a coefficient of .85. Apparently, the only water stage recorder in use is at Banana at the mouth of the river, where a Gurley recorder is installed to show the tidal effect.

On the headwaters, a number of mining companies have hydro-plants where records of daily discharge are obtained.

Argentina.- The first stream-gaging was apparently performed in 1871 when J. J. Revy was employed by the government in connection with large engineering works then contemplated. In his book[54] Revy describes

[54] Revy, J. J., Hydraulics of great rivers, 1874, E. & F.N. Spoon, 48 Charing Cross, London.

the method used in measuring the Parana near Rosario. He was strongly opposed to the use of floats then generally favored, and used a screw-type current water meter recently devised, making the measurement from a small steamer. It was not until the present century, however, that systematic stream gaging was started.

Three governmental agencies are engaged in stream-gaging: the Bureau of Navigation and Ports, the Bureau of Meteorology, Geophysics, and Hydrology, and the Bureau of Irrigation. The Bureau of Navigation and Ports, which confines its stream gaging to the large navigable rivers, began its work about 1901. The Bureau of Meteorology, Geophysics, and Hydrology, which is the principal stream-gaging agency, started that work in 1903 and gradually increased the stream gaging until at present 63 stations are being maintained. The Bureau of Irrigation was created in 1909 and to meet the needs of its irrigation studies started its own stream-gaging program in 1910. At present 72 stations are being maintained, but as the two last named bureaus cooperate closely, some of the seventy-two stations may be included in the sixty-three maintained by the Bureau of Meteorology, Geophysics, and Hydrology.

The Bureau of Navigation and Ports operating on larger rivers, the largest being the Parana, which has a mean annual discharge at Corrientes of 544,000 second-feet, makes its measurements from boats or launches, and has its comparatively few stations equipped with staff gages.

Ott meters are used, and the mean velocity is obtained both by means of vertical-velocity curves and by the .2- and .8- depth method and occasionally by the .6-depth method. In making vertical-velocity curves the meter is held at 15, 20, 50, 60, 80 and 85 percent of the depth, on the bottom, and other points, if considered necessary. The velocity is measured for a period of 90 seconds, with 70 seconds as the minimum, due to velocity pulsations. The discharge is determined by means of the Harlacher, graphic method. Measurements on smaller streams are generally made by means of folding canvas boats attached to cables stretched across the streams and where needed, reels and booms are used. On the large rivers, measurements are made from launches. At present, there are two permanent cableways with cars of the American type, and more are to be constructed in the future. One of these is supported by steel towers similar to that one the Columbia River above The Dalles. Rating curves are constructed in a manner similar to that used by the Survey. Metal staff gages of the German or Swiss type are used at a majority of the gaging stations, although a few Stevens and Friez recorders are in use. A recorder having the advantages of the various types of existing recorders is being developed by the Bureau of Meteorology, Geophysics, and Hydrology for the use of all the government agencies.

A copy of the instructions for making measurements has been furnished the author by Mr. Alfredo G. Galmarini, Director of the Bureau of Meteorology, Geophysics, and Hydrology, and these stress the importance of a thorough reconnaissance before establishing a station, and also great care in making the measurements. Referring to the latter the instructions state:

> The number of verticals will vary between 10 and 20 depending on the width during the high water. It is never advisable to take less than 10 verticals when the stream course is not less than 10 meters wide and where the flow is very regular.

Measurements are made by two engineers with the assistance of two laborers.

Uruguay.- In 1916, the Bureau of Hydrography began to measure the streams in the interest of irrigation, and later of water power. Apparently, the program consisted in making current-meter measurements only, and did not include the maintenance of gaging stations with daily gage heights. The "Salmoraghi" current meter of a type not known to the author, was used and mean velocities obtained by applying a coefficient to the surface velocities. The summation of the discharges in each section gave the total discharge at the time of measurement.[546]

[546] Letter from Sr. Mario Gil Nin, Engineer-Inspector, Geological Institute of Mines, to author.

Brazil.- After the close of the World War I, Brazilian engineers became interested in the water resources for power, irrigation, flood control and navigation. The Government, through the Division of Water in the National Department of Mineral Production, in the Ministry of Agriculture, started a stream-gaging program which has grown to 1,700 or more stations at the present time, most of which are equipped with staff gages. The Ott meter is used chiefly, although some Price meters are also in use. Mean velocities are obtained from vertical-velocity curves, and the discharge is computed either graphically by the European method or by the Survey method of summation of the discharges in each section obtained by the average-end-area method. Daily discharges are computed from rating tables in rating curves. The daily and monthly records are published biennially on the calendar-year basis by the Government. In addition, the State of Minas Geraes also publishes stream-flow records, through the Office of Agriculture Industry, Commerce and Labor. Measurements of the large rivers are made either from bridges or from boats, operated between two parallel cables stretched across the stream, one of the cables being tagged for distance. In their measurements the meter is suspended from a cable operated by reel and short boom on the side of the boat. Measurements of small streams are made either from footbridges or by wading, with the meter attached to a rod. Field parties consist of an engineer with several assistants.[547]

[547] Letter from Close Olinto Carneiro Vilela, Brazilian Government Engineer to author.

Chile.- In connection with irrigation investigations, the Department of Irrigation started a stream-gaging program about 1915 and has maintained about 35 gaging stations. In 1939, a new president with the aid of a loan from the United States, started a movement to develop the

natural resources, which included a widespread program of electrification, largely by means of water power. For that purpose, the Commission for the Encouragement of Production was created, and within it, the hydrological section was given charge of stream-gaging and related meteorological studies. Private interests maintain five gaging stations, which with the government stations make a total of 120 stations in Chile.

The rivers drain the western slope of the Andes, and as the average width of Chile is 100 miles, the rivers are all short with steep gradients. The height of the mountains decreases toward the south and as the precipitation increases, the southern rivers have flatter gradients and greater volumes. In northern and central Chile, the stream flow depends almost entirely on melting mountain snow, and as there is very little rain during the winter, there is a long period of very low flow, followed by the prolonged summer high water. In southern Chile, the winter rainfall is much greater, and this causes frequent floods which are greater than the summer high water from melting snow. The largest stream measured, the Puelpo River has a mean annual discharge of about 8,800 second-feet.

With a few exceptions, where water-stage recorders are installed, the gaging stations are equipped with staff gages which are read from 2 to 4 times daily. On the northern streams which are small with shifting channels, the discharge is measured by 6 weirs. Streams in other parts of the country are measured from boats, cableways, or bridges. The smaller streams are measured from footbridges or by wading and the measurements are made by parties of several men, including laborers to do what is termed "the physical work". The Ott meter is used, and mean velocities are determined by vertical-velocity curves. The discharge is computed by the graphical method. Daily discharges are computed by means of rating curves. In addition to the regular gaging stations, periodic measurements are made at a hundred or more points where it is not feasible to obtain daily gage heights. The records are not published.[548]

[548] Information obtained from Paul Matus, engineer, Chilean Department of Irrigation, and Enrique Elgueta, Chief, Engineer, Hydrological Section, Bureau of Industrial and Electrical Development.

Peru.- Peru was one of the first South American Countries to establish and maintain a stream-gaging program. About the turn of the Century, the importance of irrigation on the Pacific Coastal lands became a live subject, as the growing of sugar cane on which the fiscal export policy was largely based, required such irrigation, and a code of water laws was advocated to correct the disorder existing in the administration of water rights. Also, the creation of the U. S. Reclamation Service in 1902, and the conservation policies proposed, appealed strongly to a group of engineers who, although educated in Europe, were attracted by the creation of that service and its objective. The interest aroused resulted in the creation of the Peruvian Corps of Engineers of Mines and Waters, having the same purpose as that of the Reclamation Service. Soon afterward, in 1904, the Peruvian Government requested the U. S. State Department to recommend an engineer who would be employed by Peru to study the water resources of the coastal lands. C. W. Sutton was selected and he started a small stream-gaging program in 1904. Regarding the methods used he states[549] that he introduced Survey methods and

[549] Letter to author.

Price meters, as those were the only methods and equipment with which he was familiar. Both are still in use. The stations are equipped chiefly with staff gages. In 1908 the program was expanded by the establishment of stations north of the River Ica in lat. 15°S. About 1924, the Bureau of Water and Irrigation took over the water resources investigations. The Peruvian Rivers drain the western slope of the Andes, and about 80 per cent of the yearly flow occurs during the summer months, due to the melting of the high altitude snow.

Ecuador.- No sustained stream-gaging program is followed in Ecuador. Whenever a specific project requires stream-flow records the agency interested makes discharge measurements by means of floats, using a coefficient of .80 to obtain the mean velocity. As an Ecuadorian engineer writes:550/

550/ Letter from Ing. José A Ordonez G. to author.

> Flows of our rivers are pretty regular all year around, due to our uniform weather. The dry season lasts three months yearly in the mountains and six in the coast.
>
> We do not worry about hydro-power sources because we are very far from facing any scarcity of them. * * * it is estimated we have 17,000,000 H.P. hydro-power available, and only 10,000 of them are developed.

Colombia.- Floods during the winter months and the need for storage for irrigation during the dry season resulted in the beginning of stream-gaging about 1930, and this has been rapidly expanded during the past few years. The work is under the Water Commission of Colombia. Ott meters are used.

Venezuela.- Unsettled conditions in Venezuela and the prevalence of malaria in the most fertile region had retarded agricultural development to such an extent that food prices were higher than in any other South American country, and that condition was aggravated by the development of the oil industry with its relatively high wages which attracted many workers. To remedy that situation the Government started a mosquito-control project, and also an investigation of possible irrigation projects under the Ministry of Public Works, in 1939. J. B. Bond, a former member of the U. S. Bureau of Reclamation, accepted a position with the Venezuelan Government in charge of irrigation investigations. He started a stream-gaging program which included 25 stations and introduced American methods. Prior to 1939, no stream gaging has been done in Venezuela except the maintenance since 1935 of one station on the Rio Macarao, from which the city of Caracas obtained a portion of its water supply551/

551/ Letter from J. B. Bond to author.

In 1945, Mortimer R. Lewis formerly an irrigation engineer in the United States was head of the Irrigation Division of the Ministry of Public Works and realized the necessity for continuing and expanding the stream-gaging program. He was acquainted with R. C. Briggs of the Survey and learned that the latter would be willing to accept a year's assignment in Venezuela. Thereupon, the Venezuelan Government, through its Embassy in Washington, and the U. S. State Department, obtained

Briggs' formal assignment to Venezuela as a technical advisor in hydrology in the office of the Director of Irrigation Work and National Crtography of Venezuela. As such, his duties were to organize and put into operation a nation-wide stream-gaging program. As the plans had not been completed by the end of Brigg's assignment, the same diplomatic process was repeated and A. R. Peracca of the Survey was assigned to Venezuela for a year, beginning about July 1, 1946.

In passing, it may be stated that the Government's income from the fabulous Maracaibo oil field within recent years, has made possible an ambitious program of internal improvements of which irrigation was only one objective.

Mexico.- Two governmental agencies are engaged in stream-gaging in Mexico. One is the Mexican Section of the International Boundary Commission, which works closely with the American Section and operates 15 stations on the Rio Grande and tributaries; the other is the National Commission of Irrigation. As its name implies, this latter agency is charged with constructing irrigation works and, like the U. S. Reclamation Service in its early days, finds it necessary to maintain gaging stations to determine available supplies for irrigation. About 400 stations are maintained, at 61 of which salt samples are collected. The methods used by both agencies are substantially the same as those of the Survey. In 1939, the National Commission of Irrigation began to publish by calendar years, the stream flow records in Boletin Hidrologico. In 1946, through a governmental reorganization, the work of the National Commission of Irrigation was taken over by the Ministry of Hydraulic Resources.

Haiti.- As described elsewhere in this history,[552] stream gaging in

[552] pp. 113 to 117, 1919-1928.

Haiti follows methods and equipment similar to those of the Survey.

Cuba.- Practically no measurements of Cuban streams were made until 1938. As an engineer of that government writes:[553]

[553] Letter from Acosta H. Roberto to author.

> There are no large rivers in Cuba due to the Island's long and narrow form. Besides, the generally employed extensive agricultural methods are not taking advantage of irrigation. Finally, majority of population is located on the lowlands and for that motive the private utilities have developed only two or three little and medium sites.

In 1938 the government began to plan for irrigation of rice crops in several areas and the Comision de Fomento, Direccion de Riego was given charge of measuring the streams from which the lands are to be irrigated. Survey methods are used.

Canada.- As described in this history,[554] the Canadian Government

[554] Follansbee, Robert, History of the Water Resources Branch to June 30, 1919, pp. 348-51. See pp. 54 - 55 (period 1919-1928).

since 1910 has followed closely the methods of the Survey, and has used similar equipment. In 1943, the stream-gaging investigations were conducted by the Dominion Water Power and Irrigation Service, which was maintaining about 600 gaging stations, 90 being stage stations and about 35 International gaging stations. The largest stream measured was the St. Lawrence River at Montreal, which has an average discharge of about 295,000 second-feet.

Soviet Union.- The first stream gaging in the Soviet Union was done in the early days of the 19th century. Alexander I, desirous of establishing an engineering school in Russia, called upon the École des Ponts and Chaussées, the leading engineering school in Europe, for help, and a number of French professors and engineers were sent to Russia. One of them, Raucourt, made on the Neva River the first recorded measurement under ice.[555] A few stations were established and records obtained for

555/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 135.

a few years, but through lack of interest the program gradually died out. Between that period and the early part of the 20th century very little attention was paid to the flow of the rivers, although at least one station was operated. That station was on the Dnieper River where records were started in 1878 and continued until 1923,[556] when they were

556/ Engr. News-Record, June 23, 1932.

discontinued as a result of the revolution. The station was maintained near the present town of Dnepropetrovsk where rapids in the river made it non-navigable. As plans had long been prepared for a canal around those rapids it is probable that navigation was the original purpose of the records. Later water power came into the picture, with the result that in the late nineteen-twenties, Col. Hugh Cooper, the builder of the Keokuk dam on the Mississippi River, was employed to construct the Dneprostroy hydro-electric and navigation project and the Dnieper station was reestablished.

The real beginning of stream gaging was made about 1910 when the people's representatives in the Duma looked forward to the industrial development of the country. Two government departments became interested in the streams, that of Ways of Communications in connection with navigable rivers, and the Bureau of Land Improvement in connection with irrigation, particularly in Siberia and Turkestan. With this revival of interest in the rivers, instruction in the engineering schools followed. The only text book available was Hoyt and Grover's "River Discharge" which was used, together with Murphy's "Accuracy of Stream Measurements" (Water-Supply Paper 95). As a result, Survey methods were generally followed, but as German meters, chiefly Ott and Amsler, were cheaper and could be more readily obtained, those instruments were used. Another reason for adopting Survey methods which required smaller field parties and were less expensive, was that such methods were more suitable to the vast area to be covered than the general European method of large field parties, that were applied where the number of streams and the areas were very much smaller.[557] One investigation in the Crimean Peninsula started

557/ Statement of Boris A. Bakhmeteff to author.

in 1913 required the intensive measurement of 150 streams and 1,500 springs. In that Peninsula, the normal flow of the streams is so small that buckets, weirs, and flumes are used in measuring. For high flows, floats and current meters are used for measuring velocities, and automatic gages indicating maximum stages are used for recording flood stages.[558]

558/ Eng. News-Record, Apr. 4, 1918, p. 657-8.

This program was interrupted by the first World War and the resulting revolution which changed "Russia" to "the Soviet Union," and the work was later resumed but limited chiefly to central Asia, under the direction of the Central Asiatic Water Economy Department. At first, German meters, probably holdovers from the previous regime, were used, together with a few Price meters. About 1927, owing to the difficulty of obtaining foreign meters, the Experimental Research Institute of the Water Department experimented in designing its own meter, and as the Price meter had shown marked superiority over the other types, it was used as a model;[559] in other words, the Soviet government made its own

559/ Tolstoff, V., On the present work of the Experimental Research Institute of the Water Department: (Translated from) Journ. of Irrig. Tashkent; No. 9, 1927.

Price meters. The unit of volume used is the cubic sagan equal to 49 cubic feet.

The following quotations from a paper by Major M. Lvovich[560] are of

560/ Lvovich, M., Hydrology in the Union of Soviet Socialist Republics, National Research Council, A. G. U. 24th Annual Meeting, Apr. 23-24, 1943, Part II, pp. 737-742.

interest:

> "The water-measuring network in the eighties of the last century consisted of some hundred water-gaging points, where systematic observations were made of the water-levels and ice-conditions in rivers and lakes. The results of these observations have been periodically published in the form of 'Water-level information' since the year 1880.
>
> "A particularly active work was undertaken by the Hydrometrical Section of the Turkestan Region, established in the year 1910. There the development of irrigation had set some important tasks which differed from those directed towards the fulfilment of navigational aims. It proved necessary to determine the water-discharge on the rivers for computing the runoff needed in the calculation of irrigation-water resources. In this period, and for the first time in its history, the widely developed measures were started for determining the rate of water-reservoir silting.
>
> "In 1919, on the initiative of the Academy of Sciences of the Union of Soviet Socialist Republics, the Soviet Government decreed to establish the State Hydrological Institute. This Institute, being an All-Union Institution, had to tackle the tasks of many-sided investigations of the waters throughout the whole country

as well as the reestablishment of hydrological works in the Union of Soviet Socialist Republics which were discontinued during the first World War and Civil Wars. These efforts are now directed wholly to the fulfilment of the demands of the economical building up of the young Soviet State.

"The hydrometeorological network of the Union of Soviet Socialist Republics to January 1, 1941, consisted of 4,644 stations, including 3,362 basic stations controlled by the Central Office of Hydrometeorological Service and 1,282 temporary hydrological stations under various departments for satisfying the particular needs of a number of construction-projects. This number does not include gaging-stations functioning on the navigation-canals and in the power-plants and irrigation-systems.

"While considering the development of the network of the permanent hydrological stations we get the following picture: In 1917 there were 1,508 stations; in 1927, 2,000 stations; in 1931, 3,000 stations; in 1935, 3,600 stations; and in 1940, 4,641 stations.

"On the average, in all the territory of the Union of Soviet Socialist Republics, there is one hydrological station for each 4,524 square kilometers and in the European part of the Union of Soviet Socialist Republics one station per 2,000 square kilometers. The density of gaging-stations in the United States is about one station per 1,800 square kilometers."

Great Britain.- No systematic measurements of stream flow have been made in Great Britain. When special problems arise, various local agencies maintain records at particular sites, usually by means of existing weirs. The longest record of that type relates to the Teddington weir operated by the Thames Conservancy District.[561] One of the few records of discharge made by the standard type of station is that on the Severn River at Bewdley. This station has been maintained continuously since 1921 by Prof. S. M. Dixon of the Imperial College of Science as a laboratory in which he has taught his students stream gaging. The station is equipped with a water-stage recorder and measurements are made either by an Amsler meter used on a rod from a boat or by a Price meter suspended from a cable stretched across the river and operated from the bank by means of a traveller similar to that designed in the days of the Irrigation Survey.[562] Vertical velocity curves are developed at 10-foot intervals across the 160-foot channel, and the discharge determined graphically by planimeter.[563]

561/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 42.

562/ Op. cit.

563/ McClean, W. N., Practical river flow measurement and its place in Inland Water Survey, as exemplified in the Ness (Scotland) Basin: Inst. Water Engrs. (reprint) London.

For years, engineering and scientific societies had called attention to the need for an Inland Water Survey by the Government and early in the twenties the Department of Scientific and Industrial Research appointed a committee to investigate existing methods of measuring river discharge applicable to Great Britain. Various types of meters, all

screw type except the Price, were tested under varying conditions. In the report covering the investigation which included various methods of stream measurements, the committee, in reference to current meters, stated:564/

564/ Hogan, M. A., River gauging: Dept. Scien. & Indus. Research; His Majesty's Stationery Office, London, 1925, p. 4.

> On account of its robust construction and reliability in use, the writer is of the opinion that the small Price electric current meter is the most generally suitable instrument for the work of the Survey.

No further action was taken by the Government but the agitation for an Inland Water Survey has continued.

This was the only definite recommendation regarding current-meter measurement procedure.* Measurements of the Severn and Liffey Rivers were made and the method used by Prof. Dixon at the Bewdley station was followed.

* A by-product of that investigation was the later manufacture of the Watt meter which is similar to the Price meter.

Egypt.- The annual rise of the Nile was perhaps the most important event in ancient Egypt, and records of flood stages were marked on cliff walls at various points. Among the oldest records known, are those at Semna near the Second Cateract, where 179 distinct markings have been discovered dating back to the period 1750 to 1800 B. C., or earlier. A few older markings during the period 3000 to 3500 B. C. are also known.565/

565/ Jarvis, C. S., Flood stage records of the River Nile: Am. Soc. C. E., Trans. Vol. 101, p. 1017, 1936.

The flood stage was an index of the area inundated in the Nile Valley and as flooding irrigated the land, the annual taxes were based on the area inundated. Hence, the tax gatherer, cursed since earliest times, had a direct interest in recording the maximum stages; if he "fudged" to make the area appear greater, his percentage of the taxes was correspondingly increased. Readings on nilometers (masonry pillars set in wells connected with the river) were maintained at various points. The most complete record known is that of the Roda nilometer at Cairo, which extends back with some breaks to 622 A. D. After the Arab conquest about 641 A. D., the record was more complete, there being some gaps due to uprisings and other internal strife.

With the increase of British influence in Egypt, systematic readings of a staff gage at Aswan were begun about 1870, and occasional float measurements of the discharge were made. But the scientific study of the hydrology of the Nile began with the introduction of current meters in 1902. The reconquest of the Sudan had again opened the upper river to investigations, and had expanded greatly the field of endeavor. By 1912, permanent gaging stations had been established at some of the most important points on the river and since 1923, stations have also been maintained on the more important tributaries in the Sudan. These stations are equipped with staff gages, the usual type being a marble scale on a concrete or masonry pillar. No recorders are used. The gages are tied to sea-level datum by means of levels carried along the

Nile and its tributaries.

Measurements are usually made by means of Price meters suspended from boats. The velocity is observed at mid-depth and a coefficient of .96, determined from vertical velocity curves, is applied to obtain the mean velocity. This is practically the method developed by Humphrey and Abbot.[566] In making measurements, observations are made at 20 equally-

[566] Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 42.

spaced points in a width of some 1600 feet. As the measurements are made from boats and as the velocity is very low, from less than 1 foot to 5 feet depending on stages, heavy weights are not needed even at flood stages. The discharge through each partial area is computed by average-end-areas and the total discharge from the total of the partial discharges. All units are in the metric system. At the more important stations measurements are made every few days. Rating curves for rising and falling stages are constructed and the discharge computed by 10-day intervals based on the average stage for 5-day intervals. Results of measurements, gage heights of 10-day intervals, and discharge for 10-day intervals, expressed as millions of cubic meter per days, from the beginning of the modern investigations through 1927 have been published.[567]

[567] The Nile Basin, vols. II, III, IV; Ministry of Public Works, Physical Rept. Paper 26: Cairo, 1931.

Discharge records for 26 stations are presented. Thirteen of the stations are located at dams, which have been calibrated by current meter and the daily discharges computed from the head in the drains as read from staff gages.

The mean annual discharge of the Nile at Awan for the period 1870 to 1930 was 109,000 second-feet and the maximum about 500,000 second-feet. The Egyptian work is under the direction of the Physical Department of the Ministry of Public Works. Very considerable experiment on the rating and use of meters has been done and a low-velocity meter has been developed. With reference to the performance of the Price meter under all, but lowest velocities, the investigator writes:[568]

[568] Wade, E.B.H., Report on investigations into the improvement of river discharge measurements, Part V; Physical Dept. Paper 13, p. 1. Ministry of Public Works, Cairo, 1924.

> the longer I work at the subject (development of low-velocity meter), the more I am impressed with the excellence of the Price.

Iraq.- Influenced doubtless by the success of irrigation in Egypt under Sir William Willcocks, the Turkish government of what was then the Turkish province of Mesopotamia, about 1906 called him to plan for a system of irrigation from the Euphrates and Tigris Rivers. At that time the only stream-flow records were a short series made in 1837 by the Chesney Expedition for the Survey of the Rivers Euphrates and Tigris.

Having devised a plan of irrigation, Sir William Willcocks started a few gaging stations in 1906. It was not until after World War I, when Mesopotamia became Iraq under British Mandate from the League of

Nations, that the stream-gaging program was expanded by the Irrigation Department and placed on a solid foundation. The number of stations was increased to 22, one being at Baghdad of Arabian Nights fame. The gages which are read once a day in the morning, are either vertical posts with scales attached, or masonry or concrete steps, to the face of which scales are attached. Although the step-type gage is more durable, silt collects on the steps. In the case of remote stations, which are not visited frequently by an engineer, such silt may remain for months, the observer guessing at the readings instead of going to the trouble of removing it. (Unfortunately comparable indifference of observers is not unknown to the Survey.) So far as possible the gages are related to sea level datum by means of the Great Trigonometric Survey.

Prior to 1921 discharge measurements were made by floats but in that year 6 Price meters were purchased, and by 1933 that number had been increased to 33. Discharge measurements are made from boats kept in position by a 3/4-inch cable stretched across the river and suspended from posts. One end of the cable which is marked at 10-meter intervals, is equipped with a windlass by which the cable is lowered to permit the passage of river craft.

Following the Egyptian methods which are generally used, the mean velocity is assumed to be .96 of that at mid-depth. For sounding, a 110-pound weight is attached to piano wire, and for velocity measurements, the meter and weight are suspended by a small cable similar to that used by the Survey, and probably purchased from Gurley. The daily discharge is computed from the mean of 5-day gage heights, or for less important stations from the monthly mean gage heights, by means of a rating curve.569/

569/ Ionides, M. G., (formerly with Irrigation Dept.) The Regime of the Rivers Euphrates and Tigris: E. & F. N. Spon, London, 1937.

In commenting on the methods used, Ionides writes:570/

570/ Letter to author.

> Our methods had necessarily to be adapted to a rather superficial type of observer, and the greatest possible simplification was always considered to be the best way to reliable results, even though they introduced technical errors.

Siam.- During the Japanese occupation, Siam became Thailand, but afterward became Siam again. Stream gaging which was started in the early days of the century is carried on by Royal Irrigation Department in the interest of rice irrigation and flood control. About 200 gaging stations are being maintained most of which are equipped with water-stage recorders, chiefly of European manufacture. Discharge measurements are made by German screw-type meters. However, the American method of making measurements and computing the records are employed, the 6-depth being used chiefly for mean velocities.

Federated Malay States.- The need for power chiefly in connection with mining, caused the Government of the Federated Malay States to install a staff gage on Perak River at the Enggor pontoon bridge in 1916. Occasional current-meter measurements were made at the .6 depth and a rating curve was developed from which the daily discharges were computed.

In 1926, an additional station was established at Chenderoh, and at that time, vertical-velocity curves were obtained by meter, presumably at both stations. These vertical-velocity curves showed that the velocities so obtained were 8 percent less than the earlier cones from the .6 depth method. By means of overlapping records in 1926, the discharge at Chenderoh was computed for the period 1916 to 1926 and the mean discharge found to be 7,380 second-feet from 2,340 square miles. This runoff was from a mass of jungle-clad mountains rising to 7,000 feet elevation, where the average rainfall varied from 50 inches near the plains to possibly 250 inches in the mountains.571/

571/ Proc. Inst. C. E., vol. 239, pp. 259-62, London, 1936.

Afghanistan.- Within the past few years, the Government of Afghanistan has embarked upon a program of modernization and has appointed as Royal Minister of Public Works, Kabir Ludin, who was educated in engineering at Cornell University, and later spent a year with the Bureau of Reclamation in the Denver office. Lacking the trained personnel itself, the Ministry of Public Works has contracted with an American Engineering Corporation to investigate, design and construct a number of irrigation and water power projects. In that connection, one gaging station equipped with a water-stage recorder is in operation and measurements are made by current meter. The Government expects to employ an American "hydrologist" to carry out a program of stream-gaging on a dozen or more streams.572/

572/ Letter from Kabir Ludin to author.

India.- Stream gaging in India is carried on chiefly in connection with irrigation in the central and northern sections of that subcontinent. Each province in that area has its Public Works Department with an Irrigation Branch which is charged with the construction and maintenance of the irrigation works. To afford a common meeting ground for the exchange of ideas, and the coordination of irrigation research, the Central Board of Irrigation composed of the chief engineers of the Provincial Irrigation Branches was created.573/ That this exchange of

573/ Ann. Rept. (Technical) 1934-35: Central Board of Irrigation, Pub. 11, p. 1, Simla, 1936.

ideas does not necessarily mean uniformity of methods is shown by the description of stream-gaging methods employed.

The first records were those of stage on the Indus River which drains the provinces of Punjab and Sind: such records were started at Sukkur in 1848 and at Kotri in 1863 in what is now Sind Province. In the seventies, half a dozen similar records were started in Punjab Province. In 1901, Sind Province created the Indus River Commission, and that agency increased the number of stations to 12 and started current-meter measurements. In Punjab Province about the same time one or two measurements per month were made at each station. By 1920, irrigation diversions from the Indus had increased to such an extent that over-appropriation was feared, and Sir Thomas Ward, Inspector-General for Irrigation for India, recommended a more complete study of the water resources.574/ In 1921, a program of daily current-meter measurements was started in both provinces, and in 1926 the number of stations in Punjab Province was increased to about 30.

The methods used are substantially the same in both provinces except that in Sind Haskell, meters are used and in the Punjab area Price meters are used, the measurements being made generally from boats or launches with parties of half a dozen men. It was found that the cable suspension was unsatisfactory due to the bowing effect of the current and in 1924 a special rack-and-pinion device for lowering the meter on a rod was adopted. It was also found that at lower velocities the Haskell meter was not accurate, and since 1925, the Price meter has been used for velocities less than 6.5 feet per second.[574] In the Punjab, a description of

[574] Memorandum of K. M. Bhatia., Executive Engineer, Development and Research Division, Karachie-Sind, 1944.

current-meter measurements written by an employee of the Irrigation Branch contains the following:[575]

[575] S. L. Malhatia, Methods of discharge observations, Paper 27_2 Punjab Engineer Congress; Lahore.

> "The Gurley (Price) meter possesses reliability in service under the most trying conditions in the field, simplicity in design, rigidity in construction, adaptability for use in all sizes of streams, compact size, and is now used to the exclusion of all other meters in the Punjab".

Many 10-point vertical-velocity curves were obtained, and from those, it was found that the mean velocity was at the six-tenths depth and that method was adopted. The .2 and .8 depth relation was also noted but that method was not used on account of the longer time required. The total discharge for each measurement is obtained by totaling the flow through each section. So severe is the use of meters in making daily measurements in the heavily silt laden streams, that in Sind Province, two meters are provided, one for daily use and the other for making check measurements every two weeks. Whenever the results differ by 2 percent or more, the service meter is rerated, as it is after 180 measurements. A somewhat similar practice prevails in Punjab Province. To eliminate the effect of high temperatures on meter operations, all measurements are started at sunrise, and the meters are rated at sunrise at the rating station. The Sind Province records have been published since 1901.[576] In passing it may be added that as a

[576] Indus River Commission Records 1921-25, Parts I-IV. Public Works Dept., Sind, Karachi, 1930.

result of an inter-province lawsuit, the engineers of each province visit stations in the other, and make occasional check measurements.

The Indus River rises in the Himalaya Mountains, and has its first high water period in May due to the melting snow. In July and August the high water is augmented by the rains during the monsoon period; the low water period occurs during the winter months. The mean annual discharge of the Indus River at Sukkur for 41 years is 155,000 second-feet.

In the United Provinces, the government maintains two gaging stations on the upper Ganges River. At Raiwala, gage heights have been observed since 1854 at which time the British Government took over from the British East India Company, the administration of India following

Sepoy Rebellion. Discharges during the cold weather (low water season) are obtained by means of float measurements, and during the remainder of the year are based on the flow over the diversion dam for the Ganges Canal, five miles downstream. At Nanora, observations were started in 1878 at a masonry diversion dam, where gage heights above and below the dam are observed from a staff gage and the discharge computed. At about 30 other points on rivers, staff gages read three times daily are maintained at the diversion dams for the irrigation canals and the flow of the river computed. Staff gages are maintained in the canals and the flow is measured by means of Price meters, the mean velocity determined by the .2- and .8-depth method.

In the province of Bihar, the Irrigation Department maintains 11 gaging stations in the interest of irrigation and flood protection. Records of stage on the River Son are available since 1898, and on the River Gandak since 1906, which is apparently the date when discharge measurements were begun by means of floats. Two stations are equipped with water-stage recorders and the remainder with staff gages.[577]

577/ Letter from W. G. Came, Chief Engineer, Irrigation Dept., to author.

In West Bengal, the Irrigation and Waterways Directorate maintains 133 gaging stations, some of them established many years ago. Various purposes are served by the records, among them flood prevention for which 16 stations have recently been established. The stations are equipped with staff gages read more than once daily. Discharge measurements are made by floats, a coefficient being applied to obtain the mean velocities. Where sufficient measurements have been obtained to define the rating curves, those are used to complete the daily discharges. The records are not published.[578]

578/ Letter from Chief Engineer to author.

In Orrisa Province, the principal stream is the Melhanadi River and a station with daily staff gage readings has been maintained at a diversion weir since about 1894. In 1936, flood control and power came into the picture, and an emergency flood control division was set up by the Public Works Department. In a 400-mile stretch of river both in Orissa Province and the bordering native states, gaging stations have been established at each important city, about 30 in all. Staff gages are read once daily except during the monsoon season where 3 daily readings are obtained. Measurements with a Price meter using the .6-depth or .2- and .8-depth method are made from boats; at ordinary stages, the river is about 3,000 feet wide, and depths and velocities are observed at 100-foot intervals. Stations with staff gages are also maintained on the tributary streams and measurements are made by means of floats.[579]

579/ Statement of B. Behera of the Public Works Department to author.

In Bombay Presidency, records of the Girna River have been kept at the Jamda weir since 1871. In 1902, river gaging on a larger scale was started, and the discharge was measured either by means of floats or by weirs. In describing the work, the official report[580] stated that

580/ Stream gaging in Bombay Presidency: Public Works Dept. Tech. Paper 30, 1930.

"current meters could not be used as the cost would have been prohibitive." In that connection, it may be added that native labor is cheap and can be taught to make float measurements, but current-meter measurements required trained operators of a much higher order.

In the Native State of Mysore, the flow of the Cauvery River is regulated by the Krishnarajsagar Reservoir, and the Office of Chief of Engineer for Irrigation maintains three stations on streams entering the reservoir, and three on irrigation canals leading from the reservoir. These stations which were started in 1914 are equipped with water-stage recorders, and in addition with staff gages read three times each day. Discharge measurements are made with Price meters either from bridges or from cableways. The mean velocities are obtained by the .2- and .8-depth method and the computations made by average-end-areas for each section into which the river cross section is divided. Daily discharges are computed from rating curves. The stations have hard-rock beds and once rated, check measurements are made every three years. Since establishment of the stations, the changes in area have been less than 5 percent. As the records are used solely for the daily regulation to compute the amount due Madras, they are not published.

In Madras Presidency, stream gaging was started in 1909. By that time, irrigation demands on the Cauvery River, which rises in the State of Mysore and flows into the Madras Presidency had made it necessary to agree to a division of the water between the two political units, and this required the establishment of gaging stations on the Cauvery River and seven of its tributaries, to be maintained by an engineering organization composed of personnel of both Mysore and Madras Presidency. The principal station is equipped with a Stevens recorder, and the stations on tributary streams with staff gages. Discharge measurements are made from boats by means of a Price meter, using the .2-.8 depth method. The other principal streams in the Madras Presidency are measured at weirs.

Madras States occupy the Southern part of Indian peninsula, extending to Cape Cormarin. In Travancore, the area is mountainous and the rainfall increases from 20 inches at the Cape to more than 300 inches at an elevation of 8,000 feet, with an average of about 130 inches. Farther north in Cochin, the rainfall is less and irrigation is required. About 1940, a gaging station was established on one river which rises in Cochin and flows into Travancore. The station which is maintained by the Travancore Public Works Department is equipped with a water-stage recorder and the discharge is measured by means of a V-notch weir.

An exception to the general statement that stream gaging is carried on in the interest of irrigation, occurs in the province of Assam which lies between Burma and Bengal, in the extreme northeast corner of India. There the problem is one of navigation and drainage, in a region having very heavy rainfall. A range of mountains intercepts the southeast and southwest monsoons with the result that at Cherapungi, with an altitude of 4,000 feet, the mean annual rainfall is about 350 inches, with a recorded maximum of 870 inches. About 1880, in the interest of navigation, a number of staff gages were installed on the Brahmaputra River, one of India's largest river rising in the Himalayas. Records of stage have since been kept, and float measurements of discharge have been made from time to time, but no attempt made to compute daily discharges. Rice growing is an important industry; one that requires water on the rice at certain times and an adequate drainage system to remove the water at

other times. The area devoted to rice is so flat that drainage channels are blocked by high water at times. Early in World War II, this problem became acute, and the Department of Public Works turned its attention to the smaller streams, establishing about 50 gaging stations on the streams and 150 on drainage canals; the stations are equipped with staff gages read once daily. The Price meter is now being used and measurements are made from boats using the vertical-velocity curve method to determine mean velocities. To give closer attention to flood control and drainage, a division of the Department of Public Works known as the "Embankment and Drainage Circle" has been created.

No governmental gaging station is maintained on the lower Ganges, India's largest river. However, the Bengal and Assam Railway, in the interest of flood protection, has maintained a station at the Hardinge Bridge at Sara since 1934, where measurements are made by means of a Watt (cup-type) meter used from a boat. The meter is held 1 foot below the surface and the mean velocity taken at 85 percent of the observed velocity; the depth is measured at each point. The discharge is computed by the Survey method of average-end-area in each section. The average annual discharge at Sara is 351,000 second-feet.

It will be noted that water-stage recorders have been installed at only a few stations. A British engineer engaged on Indian work has stated that it is much cheaper to hire a native to squat on the bank and read the gage at frequent intervals than it is to purchase a relatively expensive recorder.

The foregoing descriptions of stream gaging refer chiefly to river measurements. Many canals also are measured usually at weirs or by means of floats. It was in the seventies that from float measurements in the Ganges Canal the relation of the .2- and .8-depth method to the mean velocity was first pointed out.[581] It is of interest to note that

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581/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 45.

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the Ganges Canal, having a capacity of about 8,000 second-feet, is only exceeded in size by the All-American Canal with a capacity of 15,000 second-feet.

Ceylon.- The first stream gaging in Ceylon was started in 1910 when a few streams draining into reservoirs were measured, the method of measurement not being available. A general program of stream gaging was started about 1939, the records being needed for flood control, storage for irrigation, drainage, and more recently for power development, and water supply. At certain seasons, very heavy rainfalls cause severe floods in the relatively small drainage basins. Precipitation of 30 inches in 24 hours is a fairly common occurence, and during a storm lasting from 10 to 15 days, the rainfall may vary from 50 to 75 inches. If such a storm occurs in the mountainous areas where the elevation ranges from 7,000 to 8,000 feet, much of the low country is flooded. In August, 1947, a flood in the Kelani River which enters the ocean near Colombo had an estimated peak discharge of 222,000 second-feet from 860 square miles. Records of the Kelani River at Victoria Bridge for the 23-year period 1925 to 1947 show a mean annual discharge of 4,720,000 acre-feet from a drainage area of 805 square miles. The unit runoff of 5,860 acre-feet per square mile is only exceeded in the United States by that of a

few streams on the Olympic Peninsula in Washington.

The Irrigation Department maintains 73 river gaging stations, 8 being located at dams. The stations are equipped with staff gages, to be replaced by water-stage recorders at a later date, when the type most suitable to local conditions is determined. Discharge measurements are made from boats chiefly by the English Watt meter similar to the Price meter, using the .6-depth method as being the quickest method for reasonably accurate discharges. At flood stages, the velocity is measured by floats, as the type of boat and the unskilled men available, makes boat measurements too hazardous. The discharge is computed by the average-end-area method.582/

582/ Letter from R. V. Burns, Irrigation Department to author.

China.- Prior to about 1930, stream gaging in China was performed chiefly in connection with studies of flood control of various rivers, which were carried on by commissions appointed by the Chinese Government, either central or provincial, and headed by foreign engineers. Later, attention was given to irrigation. About 1930, most of the river commissions were taken over by the Chinese National Government under the Ministry of Economic Affairs, and reorganized with wholly Chinese personnel; a few foreign engineers were retained as consultants. This supervision continued until 1941 when it passed to the National Conservancy Commission. The actual operation, however, continued to be performed by the various commissions. Engineers generally trained in the United States, and engineers trained at Pei-yang, University at Tientsin by American engineers, continued and even expanded the stream-gaging programs, until halted by the Japanese invasion in 1937. American methods have been followed, and Price meters generally used. Stations are equipped with staff gages which are read twice daily. In addition to the various river commissions, the foreign interests in Shanghai maintain, or did until the capture of Shanghai by the Japanese, the Whangpoo Conservancy Board in the interest of the port of Shanghai.

In point of time the Whangpoo Conservancy Board is the oldest, having been organized in 1906. Beginning in 1912, a hydrographic service was established on the Whangpoo River, on which Shanghai is located the river channel forming the harbor. The hydrographic service was concerned chiefly with measuring the flow of the Whangpoo River, a tidal stream, and in keeping continuous records of the tides at various points. For the latter purpose, water-stage recorders, chiefly of foreign make, were used. Both Ott and large Price meters were used in measuring the river discharges.

As the Whangpoo River is about 2,000 feet wide, with no bridges, the measurements were made by means of specially equipped launches, house-boats, and sampans. Soundings were taken at or near slack water, and the cross-sections divided into six or more areas, in the center of which simultaneous velocity measurements were made at .2 depths. By means of vertical velocities, the observed velocities were reduced to the mean velocity. Continuous velocity determinations and discharge measurements were made, sometimes during only one ebb or one flow period, but generally for 13 or 25 hours at a time. Such measurements were taken periodically, generally from two to four per month at different stations. Silt measurements were also made.583/

583/ Report on the hydrography of the Whangpoo; Whangpoo Conservancy Board Shanghai, July 1916.

Following the great Tientsin flood of September 1917, the Chinese government organized the Chihli River Improvement Commission, composed of both Chinese and foreign members, and under the guidance of English, American, and Chinese engineers made topographic and hydrographic surveys in northern China. In 1918, two gaging stations were established on the Yellow River, one at the Tientsin-Pukow railroad bridge near Lokou, 152 miles from the mouth, and the other at Shanchow in western Honan Province, 472 miles farther upstream at a point where the stream bed was believed to be free from scour, and where a rating curve could be established. The work was gradually broadened in scope with the establishment of a few additional stations. About 1933, the Yellow River Commission was organized and in addition to taking over the stations then in operation, increased the number to 31, of which 16 were on the Yellow River and 15 on tributaries. Some of the latter had been maintained previously by the Hai Ho Conservancy Board, similar in mixed personnel to the Chihli River Commission.584/ As a matter of passing

584/ Letter from O. J. Todd, formerly cons. engr. Yellow River Com. to author.

interest it may be stated that the highest discharge of the Yellow River recorded at Shanchow was 1,040,000 second-feet, with nearly 40 percent silt by weight; this from a drainage area of 290,000 square miles.585/

585/ Letter from H. Y. Chang, Commr. National Conservancy Com., to author.

The stations were equipped with staff gages read twice a day, and discharge measurements were made by means of a large Price current meter. The .2- and .8-depth method was used in measuring velocities and the method of average-end areas used by the Survey was used to compute the discharge. Discharge measurements were made from railroad bridges or from boats except at one station where a cableway was used. The Yellow River is so unstable that frequent measurements were necessary for the construction of rating curves.

The chief obstacle to the navigation of the Whangpoo River, a tributary of the Yangtze, is the bar at the mouth of the latter stream, and in 1921 an International Committee of Consulting Engineers was called to report on the problem. As a result, the Yangtze River Commission was created by the Central Government in 1922 and eight gaging stations were established on the main river. These stations were equipped with staff gages read twice a day. Price current meters were used and the measurements were made from boats. Vertical-velocity curves were used to obtain the mean velocities. At Hankow, where the width at high water is 5,000 feet and the depth about 75 feet, the cross-section was divided into eight equal sections and a boat was anchored in the middle of each section. The mean velocity obtained at each boat was considered to apply half way to the boat on either side. By means of frequent discharge measurements, it was possible to construct rating curves and compute the daily discharge. The mean annual discharge of the Yangtze at Hankow is about 950,000 second-feet, and the maximum, about 2,700,000 second-feet

near Nanking.[586]

[586] Letter from G. G. Stroebe, formerly in charge of Yangtze Commission Engineering work, to author.

In 1921, the Shansi provincial government appointed the Shansi Conservancy Commission, chiefly for the purpose of irrigation development. About 30 gaging stations, all equipped with staff gages established.

In addition to the Commissions, the work of which has been described, most of the provinces have agencies concerned with water conservation, and some of those undoubtedly have stream-gaging programs, but specific information is not available.

Japan.- The stream-gaging program which was started in 1910, was based on the need for power, and was started in a small way by the Department of Communications in connection with a survey of power sites. It was suspended three years later and was not resumed until 1918. At that time World War I had so increased Japan's industries that a very great demand for additional power existed and the survey of power sites, with accompanying establishment and maintenance of gaging stations, was resumed on a wider scale. The Survey was completed in 1923, and thereafter the operation of most of the gaging stations was turned over to the power companies. The government suspended field work and itself only maintained a few stations at the more important power sites, under the direction of the Electric Bureau.[587]

[587] The Water-power survey of Japan: Trans. First World Power Conference Vol. I, p. 1004, London, June 30 - July 12, 1924.

At each gaging station, the power company directly interested makes the measurements and computes the records using the metric system. The Electric Bureau furnishes standard instructions for operating the station and making measurements, standard computation forms, rates the meters and publishes the records on the calendar year basis.

As would be expected from the visits to the United States of many Japanese engineers during the "inter-war" years, the field and office methods of the Survey are generally followed. Perhaps, the most notable exception is the size of the parties making the measurements. As an illustration, it requires four men to make a cableway measurement; two in the car, one to handle the meter, and a second to count the clicks, a third and fourth man on the ground, one of whom handles the stop watch and the other, the chief of party who is in charge of operation, calls out frequent instructions. A boat measurement requires five men.

Price meters of Japanese manufacture are generally used. The .6 and .2- and .8-depth methods of obtaining the mean velocities which were formerly used, been generally superceded by the vertical-velocity-curve method in the interest of what is considered to be greater accuracy. As equipment is inadequate to make measurements at flood stages, it is sometimes necessary to extend the rating curves 15 to 20 feet; this is done by means of the equation which is developed for each rating curve. A few American-made recorders are in use, but in general, native instruments are used. These are weekly-recorders of the cylindrical type having a reversing screw not unlike that on Friez recorders, and probably suggested by the latter.

A comprehensive manual has been prepared which gives exact instructions for the installation and operation of gaging stations. For the location of a station, the following requirements are specified:

(a) Flow should not be too fast or too slow.
(b) Change in river course and river bed should be small.
(c) There should be no undercurrent, counter flow, nor stagnation.
(d) There should be no irregular changes in the water level due to inflow of tributary water.
(e) There should be no danger of movement, loss nor damage due to floods and floating objects.
(f) A suitable water-level observer should be available in the vicinity.
(g) It must be convenient for observations.

At the present time (1946), about 250 gaging stations are in operation, chiefly in the mountainous sections of the streams, where power is to be developed. Frequent floods have made it necessary to study food problems and about 1940, the Department of Public Works enlarged its program by establishing additional gaging stations, which number about 120, chiefly on lower sections of the rivers where flood damages are greatest.

The author is indebted to F. M. Bell, who for six months was attached to the Military Geology Unit of the Geologic Branch in Japan, for much of the information on Japan. In closing his description of stream-gaging in Japan, Mr. Bell stated that before his departure from Japan he left several copies of Water-Supply Paper 888 where they would do the most good.

Union of South Africa.- Since about 1910 the Irrigation Department of the Union of South Africa has carried on a stream-gaging program. In addition, silt-sampling, evaporation, and reservoir stations have been maintained, the total number being about 200 in all provinces of the Union. In describing the work, the Acting Hydrographic Surveyor writes:588/

588/ Letter to author.

> Owing to the rapid rise and fall, and uncertain dates of flood occurrences in S. Africa, current meters are used for low flows only; position of meter being generally at 0.5 to 0.6 of depth, cross sections being observed simultaneously. In times of flood surface floats are used. If possible, water surface gradients are taken and used as a check. The Ott screw-type meter is used.

Computations are made by the Harlacher (graphical) method.

At particularly important stations weirs are constructed. Stages in open channel are measured by enamel steel scales graduated to feet and tenths, and at weir stations by similar scales graduated to feet, tenths, and hundredths. Some of the stations are also equipped with water-stage recorders either of English or American (Gurley) type.

Northern Rhodesia.- The only gaging station maintained in Northern Rhodesia is on the Lunsemfwa River, a tributary of the Zambesi River.

In 1932, to determine the relation between rainfall and run-off, a water-stage recorder was installed at an old pontoon crossing between Broken Hill and Mkush and a cableway was erected. During four rainy seasons, an engineer was stationed at that point and made frequent current-meter measurements covering the complete range of stage from which a rating curve was determined. Measurements have not been made since that time, but the records of stage have been continued. As the water-stage recorder was being constantly tampered with by the curious natives, its use was discontinued in 1937, and daily gage heights from a staff gage substituted.[589]

589/ Letter from Water Engineer, Public Works Dept. to author.

Southern Rhodesia.- Records of stage of the Zambesi River above Victoria Falls were maintained by the Beira, Mashonaland, and Rhodesia Railways during the period 1907-1925, but few if any discharge measurements were obtained. In 1924, the Irrigation Department began observations at that site, and from the rating curve subsequently developed, the mean annual discharge was computed as 82,000 second-feet.

In 1920, the Irrigation Department started a stream-gaging program to obtain general hydrographic data for the colony. Stations were established on seven streams, and as these are small, weirs were installed and the records of stage obtained from water-stage recorders. Wading or boat measurements are made by current meter, the mean velocity being obtained by vertical-velocity curves. High stage measurements are obtained by floats, as adequate equipment for making current measurements is not available. The discharge is obtained by multiplying the mean velocity by the cross-section area.

Describing the work, the Director of Irrigation, P. H. Haviland writes:[590]

590/ Letter to author.

> ...very few funds were made available for the purpose and it has been only during the last few years that the value of data so obtained has been appreciated outside official circles. Increased Hydrographic staff has, however, now been asked for and it is intended to obtain information from 100 river stations, (the stations) being situated in the existing and immediately potential industrialized mining and farming areas.

Australia.- Stream-gaging in Australia is carried on by the States with no participation by the Commonwealth Government.

Victoria: The earliest river gages in Victoria were installed in 1865 at Mildura and Echuca, on the Murray River, the great inland stream of Australia. As large irrigation reservoirs were later constructed on that river, it is probable that proposed irrigation was the reason for the installation of those stations. A third station was installed at Albury in 1877. It is believed that few or no discharge measurements at those stations were made until later as computations of discharges of the Murray River began in 1891. Those records are not now being obtained and the longest record is that of the Goulburn River at Murchison which has been continuous since 1881. As 18 stations were established during the eighties, that period may be considered the start of the

stream-gaging program. Except for a few stations on coastal streams, the stations are in the Murray River Basin. At the present time The State Rivers and Water Supply Commission and the State Electricity Commission both conduct stream-gaging programs, the latter in the interest of water-power development.

The former agency uses both Price and Amsler (screw-type) meters, and the latter, Price meters. The mean velocity is obtained by the vertical-velocity curve method. Small streams are measured by wading or by means of a traveller on a cable by means of which the meter is operated from the bank. Large streams are measured either by cable car equipped with a reel for operating the meter or by means of a boat. Some recorders of local make are in use but most of the stations are equipped with some form of staff gage. All records of Victorian streams are published at intervals by the State Rivers and Water Supply Commission.591/

591/ River gagings State Rivers and Water Supply Com. Melbourne, 1939.

Monthly maximum, minimum, and mean values are presented together with values in acre-feet. An annual report published for the year ending June 30, 1939, shows that 61 gaging stations were being maintained.

New South Wales: In New South Wales an extensive stream-gaging program is carried on by the Water Conservation and Irrigation Commission. Without definite information, it is assumed that the methods in use are similar to those used in Victoria. In 1937, 257 gaging stations were in operation, of which more than half were for irrigation and water rights. The remainder were operated for power investigations (29), municipal water supply (17), flood warning and flood prevention (13), and miscellaneous uses.592/

592/ Rept. Water Cons. & Irrig. Com. for year ending 30 June 1937, Sydney, 1938.

South Australia: Stream gaging was started in 1878 when small streams were measured by weirs to determine whether their flow was suitable for municipal supplies. At the present time, the State Engineering and Water Supply Department maintains 22 gaging stations. Of these, eight are on the River Murray, six being weir stations at the locks, and 2 river stations for use when the locks are opened to pass floods. Twelve stations are equipped with water-stage recorders and the remainder with staff gages read once daily. At 20 stations, the discharge is computed by a weir formula, but at the 2 flood stations on the River Murray, the discharge is measured from boats, using Price meters. The mean velocity is determined from vertical-velocity curves and the discharge is computed by the graphical method. The monthly records of the River Murray are published in the annual reports of the River Murray Commission.

Quennsland: In 1909, stream gaging was started for the purpose of determining the relation between precipitation and runoff in the interest of flood control, water power, irrigation, municipal water supply, design of dams and information needed in the administration of the laws relating to the use of water.

The stream-gaging program is operated by the Department of Irrigation and Water Supply, and at the present time consists of 275 stations, one being equipped with a 60-day water-stage recorder, and the others

with staff gages. Daily gage heights are obtained at 108 stations and observations during floods at the remaining 167 stations. Discharge measurements are made by the Price accoustic meter when the streams can be waded, and by Laffon and Amsler screw-type meters, used from boats and bridges. Where those means are not available, flood measurements are made by floats. Prior to 1942, the mean velocity was obtained by means of vertical-velocity curve, but subsequently, the .2- and .8-depth method has been used exclusively. The discharge in each section is computed and the discharge in each section added to obtain the entire discharge. Daily discharges are computed from rating curves. The records are not published, but are available upon request.

Western Australia: Stream gaging in Western Australia which is carried on by the Department of Public Works was started in 1939 for the purpose of obtaining water resources data in the southwest part of the state. Twenty gaging stations are maintained, all equipped with water-stage recorders, of which two are at irrigation dams where the discharge is measured over the spillways. At the other stations, the discharge is by the English Watt meter operated on a "flying fox" or traveller similar to that in the Severn River at Bewdley, England.593/ Regarding the method

593/ p. 265.

of measurement and computation, Mr. R. G. Dumas, Director of Works writes:594/

594/ Letter to author

> The mean velocity is obtained in the following measure: Cross sections of the stream were taken and discharge curves were obtained from the velocity contours obtained by the use of a current meter at different stages of flood. These cross sections are periodically checked and if necessary a new discharge curve is prepared for the station. Chemical analysis are made regularly at the gaging stations. The stream flow records are not published.
>
> An additional quotation from Mr. Dumas letter is worth recording in this history.
>
> The Governments of the various States in Australia have sent engineers to American to acquaint themselves with your practices, which are recognized by us in the most advanced of any country.

New Zealand.- Prior to 1946, stream gaging had been carried on in a more or less haphazard fashion by various governmental agencies for special purposes with no national program. The agencies had realized the need for records and where a project could justify the expenditure, a gaging station was established. The Hydroelectric Department installed water-stage recorders on nine lakes and one river, and the Irrigation Branch of the Public Works Department installed eight recorders on rivers. The Public Works and Lands and Surveys Departments operated about 20 recorders for a few years to obtain run-off data for design of land drainage.595/

595/ Letter from E. C. Schnackenberg, New Zealand Soil Conservation and River's Control Council to author.

About 1930, an engineer of the Public Works Department on a travelling fellowship visited the Bureau of Reclamation to study irrigation investigations and became familiar with American stream-gaging procedure. On his return to New Zealand, a modest program, chiefly for irrigation was started. American methods and equipment are used, except recorders, where the Kent recorder of British manufacture, having a vertical cylinder designed for a month's operation, is used.[596]

[596] Statement of J. O. Riddell, Irrigation Engr., Public Works Department to author.

In 1941, the Soil Conservation and Rivers Control Council was created by law, empowered to expend public money "for the conservation of soil resources and for the prevention of damage by erosion, and to make better provisions with respect to the protection of property from damage by floods". Gradually, all hydrologic investigations are being brought under one head and nation-wide programs developed.

Describing the need for stream gaging in New Zealand, Mr. Schnackenberg writes:[597]

[597] Letter to author.

> New Zealand has strongly broken topographical features with high rugged ranges which exercise a controlling influence of the distribution of rainfall and consequential runoff. Our total area is 103,000 square miles, the North Island being 44,000 square miles with average width of about 80 miles and South Island 58,000 square miles with an average width of about 116 miles. We have 22 rivers of drainage areas between 1,000 square miles and 8,160 square miles and at least 15 with flood discharge of over 100,000 cusecs. at average flood velocities above 10 feet per second. Practically all the beds of the rivers, which rise at altitudes of up to 12,000 feet are shifting shingle.
>
> From a Hydrologic point of view, therefore, we would require as intense a cover of stations as any country in the world if our data was to be adequate.

Tasmania.- A stream-gaging program was started in connection with water power by the Hydro-electric Department of Tasmania in 1917, when gaging stations were established on a majority of the principal streams. The stations were equipped with staff gages, read daily, except at remote sites where recording gages were installed.[598] This program has

[598] Trans. First World Power Conference, vol. I, p. 28, London, June 30-July 12, 1924.

been continued.

Puerto Rico (An American possession)

Like stream gaging in Haiti,[599] the measurement of Puerto Rico's

[599] p. 113, 1919-1928.

streams were started by Survey engineers, and continued after a few years by an independent Puerto Rican organization.

In March 1908, B. M. Hall, who had been in charge of the early stream-gaging work in Georgia[600] went to Puerto Rico as Chief Engineer

600/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geological Survey to June 30, 1919, p. 111.

of the recently created Puerto Rico Irrigation Service. He took with him as assistants, J. M. Giles, B. S. Drane, Warren Hall and B. M. Hall, Jr., all of whom had been employed by the Survey in stream-gaging. A number of gaging stations were established on streams within an area of about 500 square miles, comprising the proposed irrigation system. Most of the stations were maintained until 1914 when the system was placed in operation. At that time, the stream flow was either stored or diverted for the system's use, and the gaging stations were discontinued as the records of run-off were kept as a part of the System's operation.[601]

601/ Letter from Antonio Lucchetti, Executive Director, Puerto Rico Water Resources Authority, to author.

Between 1916 and 1924, a few gaging stations were maintained in connection with two small irrigation projects. Records of flow of streams in areas where irrigation was not needed, were not considered necessary.

The major irrigation project had a hydro-electric system and in 1924, the people in other parts of the Island began to demand a hydro-electric system also, and the "Insular Legislature (in that year) passed a law providing for the development of water power sites at all other points of the Island capable of being developed economically.[602] As a

602/ idem.

result, a new program of stream gaging was started and enlarged to a total of 111 stations, all equipped with staff gages, Survey methods are followed. The stream gaging program now is carried on by the Puerto Rico Water Resources Authority.

Although Congress has provided for the extension of cooperative stream gaging to Puerto Rico,[603] and although consideration has been

603/ 49 State L, 386.

given to it, such extension has not yet (1946) materialized.

Discharges of some foreign rivers

While compiling data on stream gaging in foreign countries, a considerable number of government reports were obtained. From those reports chiefly, the average discharges of some of the outstanding rivers were obtained and are presented in the following table:

Average discharges of some foreign rivers

River	Average Discharge sec.-ft.	Drainage Area sq. miles	Number of years' record
Congo near mouth	1,380,000	1,475,000	several years *
Yangtze at Ta Tung, China	1,000,000	755,000	1922-23; 1935-37
Parana near Corrientes, Argentina	544,000	744,000	1901-1930
Ganges at Sara, India	351,000	361,000	1935-1943
Volga at Syzran, U.S.S.R.	349,000	500,000	Meyer's Lexikon
Danube, near mouth, Rumania	283,000	327,000	1894-1923
Indus at Sukkur, India	155,000	310,000	1902-1942
Nile at Aswan, Egypt	109,000	670,000	1870-1930
Zambesi at Victoria Falls, Rhodesia	82,000	132,000	1907-1925
Rhine at Emmerich, Germany	77,700	61,700	(10-year mean (Meyer's Lexikon)
Yellow at Shanchow, China	62,700	290,000	25 years
Tigris at Baghdad, Iraq	43,800	30,900	1906-1932
Euphrates at Hit, Iraq	25,000	42,300	1924-1932
Syr Daria at Begovat, Turkestan	20,000		1899-1925
Murray at Lock 15 Euston, Victoria	11,100		1930-1936
Kelani at Victoria Bridge, Ceylon	6,525	805	23 years
Thames above Teddington (London)	1,357	3,812	35 years
Jordan above Dead Sea, Palestine	1,100		7 years

* Based on 15 years' gage heights and a few discharge measurements (official estimate).

By far the largest river is the Amazon, which drains about 2,370,000 square miles, exclusive of the Tocantins Basin. No discharge records are available, and estimates of average flow range from 3,000,000 to 15,000,000 second-feet.

During the present period O. E. Meinzer gave a vivid picture of the important part played by ground water in the nation's life, and from his writings[604] the following has been summarized:

604/ Water-Supply Paper 836-D, pp. 158-9, 1939

> About 10,000 communities with about 75,000,000 inhabitants (1930 census) have public water works of about 6,500 with 20,000,000 inhabitants are supplied with ground water from wells. The total yielded by wells for public supplies is estimated at 2,000,000,000 gallons per day.
>
> Numerous large and small private water supplies have been developed from wells for industries and institutions in areas not reached by public water works, and also to a considerable extent in the large cities.
>
> Over 2,100,000 acres were irrigated in 1929 with water from wells, about two-thirds of which was in California. The area irrigated from wells is about 11 percent of the total irrigated area.
>
> A total of 184 thermal springs are reported to be used for resorts including sanitariums.

The keynote of the work of the division during the present period was sounded by Mr. Meinzer at a meeting of the Society of Economic Geologists in New York City on December 29, 1928. This was that

> The most urgent problems in ground-water hydrology at present are those relating to the rate at which rock formations will supply water to wells in specified areas -- not during a day, a month, or a year, but perennially.[605]

605/ Water-Supply Paper 638-C, p. 99.

Increase in activities

The period 1928 to 1939 was one in which increasing use of ground water supplies occurred. This development was due to several causes. The improvement in methods of well construction and in pumping and power machinery made the use of water from wells more feasible and economical. The work that the Ground Water Division had done in previous years had furnished a large amount of reliable information on the occurrence and quantity of the ground-water and had called attention to the value of aquifers if properly utilized and controlled. The ensuing drought years and the aid given by the Federal government resulted in large

increase in use of ground water for new or enlarged developments of public supplies and irrigation. Moreover, new uses for water were found in the industries and for air-conditioning and ground-water supplies were sought especially for cooling and for other purposes where uniform temperatures and chemical quality were desired. The increase in use naturally caused an increase in interest regarding available supplies. The Ground Water Division under the able leadership of Dr. Meinzer, has become recognized as the leading authority in the world on the subject. Hence, a great increase resulted in State cooperation,[606] which was stimulated by the

[606] p. 286.

Survey's ability to meet such cooperation substantially on a 50-50 basis. There was also a gradual increase in the service rendered to the various Federal agencies that required ground-water investigations. Annual expenditures from all available funds were:

1929	$ 55,034	1933	$157,746	1937	$176,506
1930	83,346	1934	144,832	1938	243,434
1931	129,291	1935	149,429	1939	
1932	172,927	1936	155,986		

As a result of the great increase in funds, the full-time scientific personnel was increased from 11 to 47. Seven geologists and four engineers constituted the full-time personnel at the beginning of the period, whereas 25 geologists, 21 engineers and 1 physicist, that at the end of the period. Two additional physicists were detailed to the Division near the end of the period to study the application of geophysical methods to the ground-water work. During the last four years of this period, 26 full-time technical men were added and there were no separations of any kind. In addition to the Survey personnel, a number of State employees were engaged on some of the cooperative investigations.

Organization

O. E. Meinzer continued as chief of the division during the period.

In previous years, it has been the practice to make Washington the headquarters for most of the members of the division, but during the present period, continuing cooperative State programs made it advisable to establish permanent field offices. At the beginning of the period, there were three field offices; by the end of the period, 14 field offices were in existance. The location of the offices with the periods of their existence, were: →

Work was performed by the Portland Office in Washington and Oregon
Work was performed by the Trenton office in N. J., Pa., Md & Del.
Work was performed by the Jamaica office in N. Y., Me., N. H., Vt., Mass., R. I., & Conn.

Portland, Oreg.	Sep. 1935 to June 1939
Trenton, N. J. 1/	Aug. 1923 to June 1939
Jamaica, Long Island, N. Y.	June 1933 to June 1939
Lodi, Calif.	Apr. 1926 to Sep. 1935
Idaho Falls, Ida.	May 1928 to June 1930
Minneapolis, Minn.	Aug. 1928 to June 1931
Honolulu, T. H.	July 1930 to June 1939
Salt Lake City, Utah	July 1931 to June 1939
Albuquerque, N. Mex.	Feb. 1936 to June 1939
Austin, Tex.	Mar. 1936 to June 1939
Norman, Okla.	Nov. 1937 to June 1939
Baton Rouge, La.	May 1938 to June 1939
Wichita, Kan.	Sep. 1938 to June 1939
Oxford, Miss.	Sep. 1938 to June 1939
Savannah, Ga.	Oct. 1938 to June 1939
Tallahassee, Fla.	Jan. 1939 to June 1939
Iowa City, Ia.	May 1939 to June 1939

1/ The Survey has had a ground-water office in Trenton, N. J. from Aug. 1923 when Mr. Thompson established himself there, until the present time. There was no formal cooperation from July 1, 1927 to June 30, 1931 but there was active informal cooperation. Mr. Thompson kept contact with the work, maintained an active file on N. J. Barksdale reported to him regularly and frequently while on a W.A.E. basis with the survey and on state pay roll, at the behest of the cooperating official.

State cooperation

At the beginning of the period, cooperation was effective with eight States; by the end of the period twenty-five States and the Territory of Hawaii were cooperating in ground-water investigations.

Annual expenditures from State, County and Municipal funds were:

1929	$34,700	1933	$81,652	1937	$ 63,516
1930	45,692	1934	51,479	1938	111,539
1931	56,646	1935	45,259	1939	159,908
1932	77,973	1936	61,351		

Note: The annual expenditures in each State are presented with the description of the work in that State.

Federal cooperation

For many years the ground water division had considered one of its chief activities to be that of consultant to other Federal agencies in problems involving ground water. In general, such service was for specific projects requiring days of field work and a comparatively short time for preparation of the resulting report. Most of the work for

Federal agencies was financed by the agency concerned, but there was no uniform rule and many of the smaller jobs were performed with Survey funds. There were, however, a number of agencies, cooperation with which was both extensive and intensive. The Rio Grande Joint Investigation, sponsored by the National Resources Committe, lasted for a year or more; funds allocated by the Public Works Administration required for the various project field work continued for nearly two years; cooperation with the Soil Conservation Service continued on some projects for 4 years or more; and investigations for the Army engineers lasted several months.

The expenditures from funds of various other Federal agencies, including minor expenditures, were:

1929	$1,334	1933	$ 93	1937	$24,400
1930	2,211	1934	55,100	1938	1,850
1931	2,911	1935	53,800	1939	9,160
1932	707	1936	23,500		

Emphasis on quantitative investigations

The quantitative methods which had been developed by the Survey were described in considerable detail by Meinzer [607] early in the present period.

[607] Water-Supply Paper 638-C.

With the development of the division's activities, more and more attention was given to quantitative investigations. In fact, the methods developed were so varied that at least one was usually applicable even to those investigations covering but a few months in the field; consequently the systematic areal survey designed to cover by separate units a large area, such as a State, usually contained some quantitative data regarding recharge or safe yield. Continuing periodic measurements of observation wells, which were greatly expanded, furnished valuable data for quantitative studies. (See under "Observation wells".)

The opportunity to exchange ideas with hydrologists of other agencies, and those working independently, that was afforded by the meetings of the American Geophysical Union's Section of hydrology, organized in 1930, undoubtedly was a factor in the development of new methods in quantitative investigations. Meinzer took an active part in the organization of this Section, and became its first president (1930-33).

Development of methods and instruments

Of the four general quantitative methods,[608] particular attention

[608] Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 432.

was given to the water-table and underflow methods, and to adaptations and combinations of these methods. In order that recharge to and discharge from aquifers can be evaluated by the water-table methods, there is required a record of the change in stage of the water table, and a knowledge

of the volume and specific yield of the water-bearing materials. The changes in stage are determined by periodic measurements of the water levels in observation wells and the specific yield of the materials are determined by laboratory or field tests. Laboratory tests had been started with the establishment of the hydrologic laboratory in 1923, and were continued during the years now being reviewed. Much work of this nature, however, was done at the field offices.

The underflow method requires the determination of the permeability, thickness, and cross-sectional area of the aquifer and a knowledge of the hydraulic gradient of the water in the aquifer. Underflow tests of ground-water velocity by the Slichter method were replaced by the more reliable discharging-well tests to determine permeability (which in turn could be used to compute effective ground-water velocities). The discharging-well methods are based on the continuous pumping of a well for a period of hours or days and observing in other wells at varying distances away, the drawdown of the ground-water level; also the recovery of the water level in the pumped well or in another well. A German investigator, Gunter Thiem, had developed a formula based on the difference in drawdown in two observation wells near the pumped well, and this method appeared worth investigating. The first field test by the Geological Survey using the Thiem method was made in about 1929 by R. M. Leggette near Meadville, Pa.[609] In 1931, L. K. Wenzel made two rather

609/ Penn. Geol Survey, 4th Ser., Bull. W3, pp. 117 - 119, 1936.

elaborate pumping tests near Grand Island, Nebr., in order to determine the validity and applicability of the Thiem method. The behavior of the ground water around the pumped wells was observed over a large area by measuring the fluctuations of the water levels in 81 observation wells during the 48-hour period of pumping, and for 24 hours afterward during the recovery period.[610] The thickness of the saturated sand and gravel

610/ Water-Supply Paper 679-A, p. 1.

was determined from a test well drilled nearby. A study of the results indicated that the Thiem method was applicable to natural conditions, and could be used for the determination of both permeability and specific yield, but that some modification of the original procedure and of the use of the formula was required.

From November 1931 to January 1932, tests were made by H. C. Barksdale and R. W. Sundstrom in connection with the ground-water investigations in the vicinity of Atlantic City, N. J. At the beginning of the tests, three wells had been pumped continuously for several weeks. Before changing the operation of the pumps, observations were made in 23 wells, and during the changed rates of pumping frequent observations were made. At the conclusion of the first test, the pumps were shut down and the water level in the sand allowed to recover. Later, one well was operated for a period of more than 24 hours. The tests were concluded January 9, 1932.[611]

611/ N. J. State Water Policy Com. Special Rept. 6, 1936, pp. 43-52.

A pumping test was made near Nearney, Nebr., in 1933 using the procedure developed by the tests near Grand Island. Ten observation wells were constructed on a straight line different distances from the pumped well. The latter was operated continuously for 24 hours and the water levels in the observation wells made at 2-hour intervals. Also, in 1933 similar pumping tests were made near Gothenburg, Nebr., and Elizabeth City, N. C. to determine the permeability of the water-bearing material at those localities. Other tests based on this procedure were made near Scottsbluff, Nebr., and near Wichita, Kans., both in 1937. The results of the Nebraska and Kansas tests and the comparative computations based on several formulae are given in Water-Supply Paper 887, and the results of the North Carolina test are given in Water-Supply Paper 773-A. In 1936, during the investigation of Croton Valley, in New York State, pumping tests were made on a dug well for the purpose of testing the applicability of the Thiem method to narrow valleys.[612] During the Tacoma investigations in 1937, exten-

[612] Am. Geophysical Union Trans. pt. I, p. 420, 1938.

sive pumping tests of one well were made during the periods Sept. 20-25 and Oct. 4-11, and levels in nearby wells were observed at frequent intervals in order to determine the permeability by the Thiem method.[613]

[613] Ground water in the Tacoma area, Wash.: prog. rept., Nov. 1, 1938.

Unquestionably the most important contribution to the hydraulics of ground water during this period was the development of the non-equilibrium formula by C. V. Theis[614] in 1935. By reasoning that Darcy's law governing the movement of water through permeable materials is analogous to the law of the flow of heat by conduction he developed a formula, and later a graphic method[614], for determining the coefficients of transmissibility and

[614] Water-Supply Paper 887, pp. 88, 89.

storage under non-equilibrium conditions. This formula involves time as a variable, and when applied to artesian aquifers, it involves also the compressibility, or elasticity, of the aquifers. C. E. Jacob[615] later

[615] Am. Geophysical Union Trans. pp. 575-586, 1940.

developed the same formula directly from hydrologic concepts.

Using this fundamental formula, it became possible for the first time to determine one or both of the coefficients under either water-table or artesian conditions and under either equilibrium or non-equilibrium conditions using a wide variety of layouts of pumped and observation wells or by observing the recovery in water level in only one well after it had stopped discharging. Use of this formula also made it possible to compute the drawdown at any distance from a pumped well and at any time after well began pumping.[616] Because of its adaptability as well as its demonstrated

[616] Econ. Geol., Vol. 33, No. 8, pp. 889-902, December 1938.

reliability, the Theis non-equilibrium formula, in its various forms, found immediate and extensive use in quantitative ground-water problems.

A problem met in field investigations is that of determining leaks in artesian wells, and during the previous period, the deep-well current meter had been devised for that purpose.[617] To determine the change in

617/ Water-Supply Paper 596-A.

salt content at various depths, and hence locate the point of leakage into the well, it had been necessary to sample the water at those depths. To eliminate that tedious process and locate the leaks more accurately, Penn Livingston and Walter Lynch, while searching for well leaks in the Winter Garden area in Texas in the fall of 1930, developed the electrical-conductivity methods for use in wells.[618] C. H. Au devised the necessary

618/ Water-Supply Paper 796-A, p. 3, 1937.

electrical equipment, consisting of a Wheatstone bridge with two electrodes arranged in one unit that could be lowered into the well to various depths. The relative conductivity of the water between the electrodes was measured by the Wheatstone bridge and as salt water has a higher rate of conductivity than fresh water, the difference in conductivity indicates an increase or decrease in the salt content. For water low in chloride a direct current of low voltage was applied and the current flowing between the electrodes was measured by a milliameter.[619]

619/ Op. cit. p. 1.

At first the instruments were lowered into the well by means of a hand line, but to reduce the manual labor, a hand reel was used in Hawaii beginning about 1927. In 1925, A. G. Fiedler was conducting tests near Roswell, N. Mex. and mounted a winch on the rear of a truck, and obtained power through the rear wheel. Three sets of power-driven winches were in use at the end of the period.

During investigations near Salt Lake City in 1931, it was necessary to determine the height to which the water would rise in flowing wells having no means by which the flow could be shut off. George H. Taylor placed in the top of the wells standard soil-pipe test plugs connected to garden hose leading to indicating pressure gages.[620] Later it was found that the indicating pressure gages were not satisfactory as they

620/ Water-Resources Bull., Mar. 10, 1932.

required frequent calibration, and the Salt Lake City engineering department constructed a mercury manometer pressure gage which was contained in a small wooden box.[621]

621/ Water-Resources Bull., Dec. 11, 1933.

At times recording gages are needed on wells which are pumped intermittently, and in 1934 Barksdale and Sundstrom devised a float which enabled recorders to be placed on two such wells at the Atlantic City water works. The openings through which the floats had to be inserted were $1\frac{1}{4}$ inches in diameter and the distance between the outer casing and pump column was only 3 inches. As the ordinary recorder float was too

large, special floats were made from rubber hot water bottles having an attachment for inflation by means of a tire pump. A similar float was used in connection with one Long Island well.[622]

622/ Water-Resources Bull., June 10, 1934.

In connection with investigation in New Mexico, during 1934, C. V. Theis devised an apparatus to make field tests of the permeability of unconsolidated water-bearing material. Later, V. C. Fishel prepared a somewhat similar apparatus for use in New Jersey, and in 1935 V. T. Stringfield had constructed in the Division of Field Equipment an apparatus similar to the one devised by Theis, for use in connection with the ground-water investigation in Michigan. The apparatus as described by V. C. Fishel and V. T. Stringfield,[623] consists of a

623/ Water-Resources Bulletin, pp. 36-38, Apr. 19, 1937.

vertical brass cylinder open at the top, a screen at the bottom, connected with a manometer tube. The tube is graduated to centimeters with the zero at the elevation of the top or overflow level of the cylinder, in which the material is placed. By filling the tube with water, the water is forced upward through the cylinder and the time required for a given decline in head, as indicated on the tube's scale is determined by a stopwatch. From these data, the coefficient of permeability may be computed using a formula devised by Theis. This equipment was immediately adopted for use in the Washington laboratory and several of the field offices.

Hand-operated equipment for rapidly putting down shallow wells by the jetting method to supply water for fighting forest fires, as suggested by A. G. Fiedler was devised and used successfully in Michigan in about 1931 by G. J. Stewart of the Michigan Forest Fire Equipment Station, and is described on p. 72.

With geophysical methods in geologic investigations coming to the front, Prof. M. K. Hubbert, of Columbia University was requested to present at the technical meeting held in Washington January 24, 1935, a paper on geophysical methods and their use in ground-water investigations. To determine the practical use of geophysics, the Geophysical Section of the Survey made tests of the resistivity methods to determine the presence of faults and of salt-water bodies in the El Paso area during 1935 and 1936[624] and later to determine the depth to the contact between fresh and

624/ Trans. Am. Geophysical Union, Pt. II, pp. 393-396, 1937.

salt waters in the Hawaiian Island.[625] The results of the test in Hawaii

625/ Division of Hydrography, T. H., Bull. 6, pp. 97-115, 1940.

demonstrated the applicability of the electrical resistivity method for determining the depth to the salt-water contact.

In July 1936, D. G. Thompson, H. C. Barksdale and B. E. Jones, the latter a member of the Conservation Branch, investigated the possibility

of using earth resistivity methods to determine encroachment of salt water upon fresh ground-water supplies in the vicinity of Atlantic City.

Test drilling

During the present period, test drilling became a very important feature of the ground-water investigations. In that connection, Meinzer writes: 626/

626/ Am. Geophysical Union: Trans. 1937, pt. II, p. 386.

> Geologic work has depended chiefly on the device of studying natural exposures and artificial exposures made for other purposes and from these data inferring the geologic conditions in the intervening areas. In the ground-water work, we have long since realized that by trenching and by test drilling, we ought to lengthen our geologic picks. Field work and office study have often been severely handicapped by lack of adequate well data. In the past, the funds available have generally not been sufficient to permit test drilling but with the greatly increased appreciation of the value of ground-water and of ground-water investigations, the sinking of tests wells of some sort is now a part of the program of most of our investigations, for instance in the P.W.A. Coastal Plain investigation in New Jersey and in the investigations in Elizabeth City, N. C.; Long Island and Croton Valley, N. Y.; Michigan; Nebraska; Texas; Mokelumne, Calif.; Escalante Desert and Ogden Valley, Utah; the Rio Grande investigation in Colorado and New Mexico; and Hawaii. The deeper test wells are generally drilled by contract, but in several projects we now have light drilling equipment that may be regarded, with some poetic license, as lengthened geologic picks.

In 1931, a combination rotary percussion-tool, well-drilling rig for use on the cooperative ground-water investigations in Nebraska was purchased. The rig was used in the Platte Valley investigations from 1931 to 1934, for drilling test holes and was later used to great advantage on other ground-water projects in the State, including the construction of a State-wide network of observation wells. The value of the information obtained by the test drilling was so great that another drilling rig was purchased in 1939 for use on the cooperative project. Both rigs were in operation at the end of 1939, the period under review. A rig, larger but similar to those used in Nebraska, was purchased in Kansas in 1939, soon after the beginning of the cooperative ground-water work, and was used extensively on detailed investigations throughout the western part of the State. The rigs in both Nebraska and Kansas were operated most of the time by geologic students of the State universities, which resulted in the economical collection and interpretation of data.

A small gasoline-driven jetting rig was purchased in 1934 and used to drill numerous relatively shallow wells in Coastal Plain sections of New Jersey, Virginia, and North Carolina.627/

627/ pp. 348.

Observation wells

During the present period the value of periodic measurements to the water surface in so-called "observation wells," in connection with quantitative investigations was generally recognized, and the selection of such wells to give representative results in each area became a regular part of the ground-water program. Early in the period, Meinzer in describing methods in use stated:628/

628/ Water-Supply Paper 638-C, p. 143, 1931.

> It is becoming evident that the chief instrument of precision in ground-water hydrology is the water-stage recorder installed over a well. The water levels are sensitive to every change that takes place in the ground water, and they can be almost perfectly recorded by a high-grade automatic recorder. In the interpretation of such records lie possibilities of new and fruitful phase of ground-water hydrology. * * *

In 1936, D. G. Thompson in a paper before the American Geophysical Union's Section of Hydrology, stated:629/

629/ Trans. 1936, pt. II, p. 337.

> Studies of fluctuation of ground-water levels are probably of most importance in connection with quantitative studies. In such studies observation of fluctuations of the water table or artesian head give useful information as to the recharge of the formation, the discharge by seepage, spring flow, evaporation and transpiration, the permeability of the formation, the effects of pumping, and other factors involved in the determination of the safe yield.

That same year the National Resources Committee in its report on deficiencies in hydrologic data recommended a very considerable expansion of the observation-well program.630/

630/ p. 349.

The earliest periodic measurements of wells by the Survey appear to have been made in Southern California, where Mendenhall in 1903 began a series of observations of ground-water levels in various parts of Southern California.631/ Those were continued by the California district, which has

631/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 432.

made observations once or twice a year since. During that same year Veatch made periodic measurements of wells in connection with the Long Island investigations.632/ The first use of periodic measurement of ob-

632/ Letter from O. E. Meinzer to author.

servation wells in connection with quantitative investigations was in 1913, when at the beginning of the Pomperaug Basin investigations, A. J. Ellis selected a group of 29 wells and arranged for weekly measurements to the water surface. In 1923, at the beginning of the New Jersey investigation D. G. Thompson selected a group of 40 observation wells. Two of these were equipped with water-stage recorders, one in an area of heavy pumping and one in an area remote from any pumping. In each of the two following years four additional recorders were established on wells in areas of heavy pumping in New Jersey. Several observation wells equipped with water-stage recorders were also established by A. G. Fiedler in 1925 and about 100 wells were measured periodically in connection with the investigations of the Roswell artesian basin in New Mexico and in the Mimbres Valley, N. Mex., investigations in 1927. These were all in areas subject to heavy withdrawals. There were also two projects, the Kootenai and Flathead, in areas not subject to heavy withdrawals, but in limited areas seriously affected by river or lake stages, and hence the results were not representative beyond those immediate areas.

One of the first observation wells in an area not subject to heavy withdrawals, and which would show natural fluctuations of water level, was established by the ground-water division in the spring of 1927, but as pumping was not stopped until 1928, the records were not usable until that year. It was located in Arlington, Va., at the home of Clyde Ross, a member of the Geologic Branch.633/ Doubtless influenced by the results

633/ Letter from S. W. Lohman to author.

from the Ross well, R. M. Leggette, in connection with his investigations in northwestern Pennsylvania, established an observation well at Sligo in December 1928. Leggette was so impressed by the value of this well that when he turned over the Pennsylvania investigation to S. W. Lohman in 1930, he impressed upon the latter the desirability of finding at least one unused well in northeastern Pennsylvania which could be observed once a month by a local observer. The second observation was established at Montrose, in July 1930.634/ Just as the drought of the nineties in the

634/ Op. cit.

western States brought about the beginning of ground-water investigations by the Survey,634a/ so the drought of 1930 in the eastern States brought about a realization of the importance of a more thorough knowledge of ground-water supplies. On September 9, 1931, at a conference in Baltimore between State and Survey officials to consider future work in Pennsylvania, it was decided to suspend temporarily the series of areal investigations designed to cover the entire State, in order to start a State-wide program of "observation wells" embracing about 40 wells scattered throughout the State, for the purpose of making a systematic study of the fluctuations of the water table. The wells selected were

634a/ Vol. I, p. 93.

located near gaging stations in order that the gage observer could make well measurements weekly. One well was equipped with a recorder and 10 with float gages.[635]

[635] Water Resources Bull., Nov. 10, 1931, p. 19.

That same year a State-wide program was started in North Carolina at the suggestion of Thorndyke Saville, the State official cooperating with the Asheville district in stream gaging. This program, which included observations of wells, was carried on under the supervision of E. D. Burchard. In 1933 and 1934, three observation wells, each equipped with a recorder, were established in central New York by A. W. Harrington, cooperating with the State Department of Conservation in stream gaging. These wells were established in connection with a special investigation involving the effect of forestation on stream flow.[636]

[636] p. 184.

Beginning in 1931, a considerable number of wells in the North Platte Valley Nebraska were observed, the number increasing in the succeeding years. In 1932, periodic observations of wells in connection with the Long Island investigations were started. Referring to the early use of observation wells, Meinzer wrote:[637]

[637] Water Resources Bull. Apr. 10, 1935, pt. 51

> Our records showed that on January 1, 1933, there were about 3,000 observation wells in the United States that were being measured periodically by the Ground Water Division or cooperating parties, of which about 115 were equipped with automatic water-stage recorders. However, most of these wells were in areas of intensive ground-water development and therefore did not give any information on the general trend of the water table. Moreover, the observation wells that were valuable in this respect were nearly all in the East, South, or West-- almost the only wells of this kind in the drainage basin of the Mississippi River being some of those that we had recently established in Nebraska.

The year 1934 marks the beginning of what may be regarded as a nation wide observation well program. Although prior to that time about 3,000 observation wells were being measured under the direction of the Ground Water Division and about 115 recorders were in operation on wells. Cooperation with the Soil Conservation Service, which was started in that year, afforded an opportunity to extend the scope of the observation-well program. Leggette laid out a program of 213 observation wells, 24 of which were equipped with recorders, on 8 Soil Conservation projects.[638] The dry years were causing a decline in the water table,

[638] p. 355.

and to determine whether the decline was permanent, Meinzer in October 1934 appointed a committee on observation wells to promote the proper

and systematic development of a broad and (if possible) nation-wide program of observation wells; also, to establish uniform field and office methods.[639] This committee consisted of R. M. Leggette, Chairman

[639] Water Resources Bull., Feb. 11, 1935.

L. K. Wenzel, secretary, and R. C. Cady, S. W. Lohman, V. T. Stringfield, R. W. Sundstrom and S. F. Turner; all having had much experience with observation wells. The committee promptly took up its duties and decided that a program of national scope should include wells not only in areas unaffected by heavy withdrawals, but also in areas of heavy withdrawals; in areas of water-table conditions, and in artesian areas. The program should also include collection of records of withdrawals from both pumped and artesian wells, and the correlation of such withdrawals with water-level fluctuations. A more or less standard procedure for establishing and maintaining observation wells was developed, and recommendations were made for the publication of the records. At the time of the report, the committee pointed out that more than 1,300 observation wells unaffected by heavy withdrawals were being maintained on 13 projects, and nearly 3,000 observation wells were being maintained in areas of heavy withdrawals.[640] A preliminary manual of methods was issued in mimeograph

[640] Water-Resources Bull. Feb. 11, 1935, pp. 43-46.

form in May 1935. That year, to show his personal interest in the program, Meinzer started observations on a well located on his property near Catlett, Va. With the expansion of the work during the remainder of the period, the number of observation wells was greatly increased, being 6,000 in June 1939, of which about 250 were equipped with recorders.

Following the recommendations of the committee, the records of a large number of wells were published annually on a calender year basis, beginning in 1935, the annual Water-Supply Papers being 777, 815, 840, 845, and 886. As an indication of the expansion of the observation-well program, it may be stated that the size of those water-supply papers increased from 268 pages for Water-Supply Paper 777 to 933 pages for Water-Supply Paper 886. This increase in number of pages was, however, not due entirely to increase in number of wells or frequency of measurements, but resulted in large part from the fact that several years were required to bring the records of essentially all of wells into the published reports and further, that the back records were published for all of the wells.

Well-drillers' associations

The close contacts with the various State well-drillers' associations that were begun in 1922 [641] were continued during the present period. The

[641] p. 181, 1919-1928.

Survey was receiving an increasing number of requests for information and advice on well construction, and its chief source of information was

Water-Supply Paper 257 which, as Fiedler phrases it,[42] "though funda-

[42] Letter to author.

mentally sound has long been out of date." Therefore, closer contact with the well drillers' associations was highly desirable. To insure this, A. G. Fiedler, who had specialized in well-drilling methods, was given the assignment of meeting with well drillers and assisting them in improving the character of well construction. Minneapolis was the center of well-drilling activities and there in August 1928, he opened an office. During the next three years he devoted his time to continuing those contacts. Largely as a result the number of State associations of well drillers was increased from 3 to 16.[43] Soon after opening the

[43] Letter from A. G. Fiedler to author.

Minneapolis office Fiedler requested the district engineers to obtain the names and addresses of representative well drillers in each State in order that he might broaden his contacts. The various associations held annual conventions which Fiedler attended, and usually gave an instructive paper on a pertinent subject. In that connection, the Washington office stated:[44]

[44] Water-Resources Bull., Mar. 11, 1929.

> Problems of the drillers in different States are many and varied, and there is much opportunity for State agencies and the Federal Survey to help them.

Early in 1930, a national association, known as the American Association of Water Well Drillers, was organized. On its advisory council, O. E. Meinzer represented the National Research Council (Division of Geology and Geography), and A. G. Fiedler represented the Survey. At its first convention Meinzer gave a paper on "The future of the water-well drilling industry," and Fiedler one on "The sanitary aspects of ground-water supplies." He also presented a moving picture which he had created on the subject, "The story of water-well drilling."

Other government agencies were asking for advice on well-drilling, and to answer those inquiries more effectively, the Minneapolis office was closed in June 1931 and Fiedler transferred to Washington. He or other members of the division continued to attend well-drillers' meetings, which were less frequent during the later years of the period as the associations became less active.

Quality of water

During this period, there was the same close cooperation with the Quality of Water Division as had prevailed previously. In the areal investigations, samples of water were usually collected from a limited number of wells and springs, and these were sent to the laboratory of the Quality of Water Division in Washington for chemical analysis. Some samples were also analyzed in certain State laboratories, and on some projects, field tests for certain chemical constituents were made by the

ground-water geologists and engineers. Use was also made of analyses obtained from other sources after they had been examined and approved by the Quality of Water Division. Most of the reports contain sections relating to the quality of the water, usually prepared by the ground-water men but reviewed and often revised by quality of water critics.

Special reports

Early in the present period, O. E. Meinzer, as an aid, and possibly a spur, to quantitative investigations, brought together in an outline of methods for estimating ground-water supplies,[45] brief descriptions of

[45] Water-Supply Paper 638-C.

the various methods which had been developed not only by the Survey but by hydrologists in other agencies, or working independently. He pointed out the pioneer work of C. H. Lee in the Owens Valley,[46] and sketched the

[46] Follansbee, Robert: History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 432.

development of subsequent methods. In summing up this discussion, Meinzer stated:[47]

[47] Water-Supply Paper 638-C, pp. 142-3.

> There are many ways in which the problem of available supplies of ground water can be attacked, but it also shows that the subject is complicated, and that there are difficulties in applying any of method that have been outlined. *** No one method is applicable to all conditions. In some areas, several more or less independent methods can be used which serve to give checks on the accuracy of the work. In other areas only a single method may be applicable, or it may be almost impossible to make effective use of any of the known methods.

So important was this paper that the British journal Water and Water Engineering published the text with only minor abbreviations.[48]

[48] Water Resources Bull., Jan. 10, 1933, p. 66.

During the activities of the predecessor surveys,[49] Gilbert for the

[49] Follansbee, Robert: History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 6-20.

Wheeler Survey, and Peale for the Hayden Survey, had compiled lists of thermal springs and had discussed their geologic relations, but no subsequent compilations and geologic discussions had been made until 1925-27, when Norah D. Stearns started a compilation of data on thermal springs which had been collected by Survey geologists, and others. Subsequently, H. T. Stearns and G. A. Waring added to the list, and prepared the geologic text. Of the more than 1,000 thermal-spring locations listed,

more than half are in the States of Idaho, California, and Nevada. From the measured or estimated discharge of more than 700 thermal springs, the total flow of all the springs listed was found to be not more than 500,000 gallons a minute, or 1,114 second-feet. The largest is that of Warm Springs Creek in Fergus County, Montana, with a discharge of 80,000 gallons a minute, or 178 second-feet. Water-Supply Paper 679-B "Thermal Springs in the United States" was published in 1937.

In a number of investigations it has been necessary to explore wells for underground leaks which might contaminate the fresh water supplies with highly mineralized water in other formations penetrated by the wells, and various methods for determining such leaks have been developed. Four methods in general use were described by Penn Livingston and Walter Lynch in Water-Supply Paper 796-A, published in 1937. Briefly, these methods were: (1) the pumping method in which samples were taken at measured time intervals during pumping; the progressive changes in saline content indicating that salt water was being drawn into the wells; (2) the velocity method, suitable only in artesian wells, by which a current meter lowered into the well indicated the location of salt water leaks by determining the levels at which changes in the rate of upward movement of the water occurred; (3) the sampler method, in which a special sampling device lowered into the well brought up water samples from various depths for analysis; and (4) the electric-conductivity method, in which special electric equipment measured the conductivity of the water at various depths.

Interest in ground-water investigations had become so widespread that during the latter part of the period Meinzer prepared a summary of ground water in the United States. He divided the country into four regions which respect to ground water, (1) the East-Central old-rock region, (2) the Atlantic and Gulf Coastal Plain, (3) the Great Plains region, and (4) the Western Mountain region. He also summarized the utilization of ground water, the methods and results of ground-water investigations, and the work of the Survey and cooperating agencies. This summary was published in 1939 as Water-Supply Paper 836-D.

State cooperative investigations

Massachusetts.- Cooperative investigations with the Massachusetts Department of Public Works were started in the summer of 1938, with the expectation that the standard well inventory type of investigation would be on a county basis, and M. L. Brashears, Jr. was detailed to the project. The first areas selected were those of Lowell and Aberjona River Valley in Middlesex County where ground water is pumped. By the end of the period, an inventory of the wells in the Lowell area had been made, and periodic measurements of 10 observation wells were made in May 1939. The investigation had hardly started by June 1939.

Expenditures from cooperative funds were:

State	$1,979	Survey	$2,006

New York.- As a result of the drought of 1930, 65 communities in New York State reported acute shortages in their water supplies, and there were undoubtedly other communities similarly situated for which reports were not received. Also, there was a serious ground-water problem on Long Island, one of the fastest growing sections of the State. To investigate these conditions and take action to remedy them, the Legislature in 1931 appointed a Joint Legislative Committee and provided it with an appropriation to obtain expert assistance. As the Long Island investigation was the only one in which the Survey cooperated, only that phase of the State program enters the picture.

Long Island: Nassau and Suffolk Counties with a combined population of nearly half a million were wholly dependent upon the ground water, and it was recognized that too great a draft on the ground-water supply would allow salt water to replace the fresh water withdrawn. After a year's investigation the Joint Legislative Committee found that the question of safe yield could only be determined by an extensive investigation. D. G. Thompson, while in New York early in November 1931, conferred with representatives of the Joint Legislative Committee and other interested agencies, and as a result cooperation with the Survey was arranged. A preliminary agreement signed Dec. 21, 1931, and extending to June 30, 1932, provided for contributions of $3,500 each by the Committee and the Survey. However, the Committee's funds were reduced by legislative action so that only $1,500 of the original $3,500 was available, and to carry out the investigation, Nassau County contributed $2,000 and Suffolk County $1,000. In subsequent years, the Legislature made small appropriations to the Water Power and Control Commission for the purpose of meeting the State's share of the expenses. Shortly after the agreement was signed, the situation was further complicated by an application to the Water Power and Control Commission by the City of New York to increase greatly its already large diversion from the ground water on Long Island, until such time as the new supply from the Delaware River should be available. In connection with the use of ground water by the city of New York, it will be recalled 650/ that in the early days of the Century, the Survey cooperated

650/ Follansbee, Robert: History of Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, p. 172.

with the Commission on additional Water Supply for New York City in making the first successful quantitative ground-water study. Thus Long Island was not an unknown region to the Survey.

D. G. Thompson was placed in charge of the investigation which was started late in December 1931, but as he was completing other work at that time, A. G. Fiedler started the work with Kyle Forrest from headquarters in Mineola, and continued in charge until May 1932, when Thompson assumed active charge. Later, F. G. Wells, borrowed from the Geologic Branch, was in the field from July to November 1932 studying the geology. The field work included the collection of well logs, and other information about geologic conditions, collection of records of consumption from public water supplies on Long Island, and collection of water samples for analysis. Periodic readings on the numerous observation wells were made, and on five wells recorders were installed. Pumping tests at several localities were observed for the purpose of determining the

effect of pumping from wells.[651] To study the relation between

[651] Memo. to press, Mar. 20, 1933.

precipitation, ground-water levels, and stream flow, the Albany district maintained six gaging stations, the records for which had the highest possible degree of accuracy.[652] A preliminary report dealing chiefly

[652] p. 185.

with the ground water pumped for public supplies was published in 1936 by the Water Power and Control Commission.[653] During the remainder of

[653] Bull. GW-1.

the period the investigations were concerned chiefly with studies of the changes in ground-water levels and the number of observation wells were gradually increased to about 100 at the end of the period. Weekly measurements were made chiefly in those areas where conditions were actually or potentially critical. As a matter of passing interest it may be noted that during the storm of September 17-21, 1938, the water table rose 7.2 inches.[654] The increasing emphasis placed on water-level

[654] Water-Supply Paper 867, p. 1.

observations required an increase in the personnel, which at the end of the period consisted of R. M. Leggette, M. L. Brashears, Jr., C. E. Jacob, J G. Ferris, and E. J. Schaefer. The first two were geologists and the other three engineers. D. G. Thompson was in charge of investigation from May 1932 to October 1934; W. H. Monroe, transferred from the Geologic Branch, from November 1934 to June 1935, when R. M. Leggette was placed in charge. The headquarters were moved from Mineola to Jamaica in June 1933. As a result of the first year's investigation the 1933 session of the Legislature enacted a law requiring approval by the State Water Power and Control Commission for all new wells on Long Island having a capacity in excess of 100,000 gallons per day.[655]

[655] Trans. Am. Geophysical Union, pt. II, p. 316.

Croton Valley: The old bedrock valley of the Croton River below new Croton Dam lies about 100 feet below the present river bed and is filled with unconsolidated gravel, sand, and clay. Just below the dam the village of Croton obtains its supply from the valley ground water, and in 1933 the village of Ossining (of Sing Sing fame) desired an investigation to determine whether the safe yield of the ground water from an area a short distance downstream from that utilized by the village of Croton would warrant consideration as a municipal supply, and as the ground-water level in the valley was influenced by the stage of Croton River, the Albany district established three gaging stations to determine such stages.

Cooperation for a limited investigation was arranged in July 1933, which included selection and periodic measurements of nine observation

wells, one of which was equipped with a recorder, and the others were read weekly by the city engineer. This program did not give the desired results, and in December 1935, D. G. Thompson and A. W. Harrington recommended that in order to establish more definitely the geologic and hydrologic conditions, and extensive program of test drilling and pumping be carried out. This recommendation was received favorably and as a result of an additional agreement, the test-well program was started in August 1936. During the drilling operations unwashed samples were selected for field determination of permeability as checks on these results. The Slichter method of measuring ground-water velocity and the Thiem method for determining permeability were used.[656] During the enlarged investigation, weekly readings were made

[656] Trans. Am. Geoph. Union, 1938, pt. I, pp. 421-28.

on 47 observation wells and continuous records obtained from 5 wells equipped with recorders. This investigation was completed June 30, 1938. The total cost to the city was about $10,000. The exact amount of Survey funds expended is unknown at this time, but presumably was about $10,000.

Monroe County: This was a cooperative project with the County Planning Board, for the purpose of making a detailed inventory of the wells in the county and employing chiefly relief workers. The project, which was on a 50-50 repay basis so far as the Survey's expenditures were concerned, was under R. M. Leggette's supervision, and in addition to that supervision the Quality of Water Division made some water analyses.

Expenditures from State, County, municipal, and Survey funds for ground-water investigations in New York state were:

Year	State, county and municipal	Survey	Year	State, county and municipal	Survey
1932	$2,498	$3,502	1936	$7,802	$ 6,350
1933	5,502	4,438	1937	13,844	13,025
1934	7,923	3,415	1938	11,685	8,998
1935	10,805	6,334	1939	11,681	9,212

Connecticut.- The value of a ground-water investigation had been recognized by the State for some years, but funds were not available for that purpose. When relief projects came into the picture in the fall of 1933, the State Planning Board sponsored a project to gather preliminary data on a State-wide ground-water investigation. The Survey, through B. L. Bigwood, district engineer in Connecticut, planned and supervised the project. That is the official statement,[657]

[657] 5th Bien. Rept. 1932-34, State Water Com., p. 9.

but Mr. Bigwood has written the author that the Survey's part was actually directed by the Ground Water Division. To meet the expense of Survey supervision, the State Water Commission increased its stream-

gaging cooperation. The investigation was continued as a WPA project through 1938, with a personnel varying from 30 to 50 in number. By that time, WPA funds were no longer available and the state-wide investigation was stopped. The results of the state-wide investigation were issued in mimeograph reports, Ground-Water Survey Bulletins GW 1 to GW 6, by the Works Progress Administration for Connecticut. So important was the investigation in the New Haven area on the Coast where salt water was intruding on the ground-water supplies, with increased withdrawals, that the investigation was continued in that area through cooperation with the State Water Commission under the direction of R. M. Leggette. This investigation consisted chiefly in periodic measurements of the observation wells, and analyses by the Quality of Water Division,[658] of samples

[658] p. 363.

of the lower Connecticut River water in connection with the study of salt intrusion into the tidal reaches of the river.[659] In its account of the

[659] Letter from B. L. Bigwood to author.

investigation the State Water Commission[660] divided the observation wells

[660] Eighth Bien. Rept. 1938-40, p.

into four groups by use of the water supplies. These uses were air-conditioning for commercial buildings, refrigeration in storing meats and dairy products, manufacturing, and lastly, a small non-pumping group in the residential district.

Expenditures from available funds were:

Year	State	Survey
1935	$500	$387
1938	700	611
1939	550	552

New Jersey.- From July 1927 , when it became necessary for the Survey to assign D. G. Thompson to other work through June 1931, the State Department of Conservation and Development, later the State Water Policy Commission, carried on its own ground-water investigations. However, cooperation did not cease entirely. H. C. Barksdale was converted to a WAE status and placed on the State payroll to carry on the work. Mr. Thompson continued to supervise the program by correspondence and occasional personal contact. The Survey was interested in the study of the possibility of salt-water contamination of ground-water supplies in the Atlantic City area, and furnished four recorders for use on wells in that investigation. During those years the State became more impressed with the importance of ground-water investigations and in 1931 decided to expand its program. Fortunately the Survey could offer 50-50 cooperation, and formal cooperation again became effective July 1, 1931. Mr. Thompson was given general supervision and Mr. Barksdale was placed in charge of the investigations. He was assisted by R. W. Sundstrom.

The intensive quantitative character of the investigations needed to solve New Jersey's ground-water problems required continuing observation of the variable factors of precipitation and pumpage. As it was impossible to cover the entire State with this type of investigation, the studies were confined chiefly to certain areas where either ground-water supplies were critical, or where the conditions were representative of larger areas. During the previous period, investigations had been begun in the Atlantic City, Asbury Park, Camden, Canoe Brook, Runyon, and East Paterson areas. During the present years, investigations were continued and expanded in these areas.

Heavy withdrawals in the Runyon area, particularly since 1925, had so depleted the ground water that the artesian head in some localities had been lowered as much as 110 feet since the first well was installed in 1897, and had reached an elevation 70 feet below sea level. In connection with the Runyon investigation, three gaging stations were installed by the Surface Water Division at Ground Water expense in three adjacent small drainage basins to compare the runoff and thus determine the possibility of inter-basin percolation.[661] About 1932 the Army Engineers made a study of the proposed New Jersey Ship Canal, the original location of which would cut across the Runyon well field of the Perth-Amboy Water Dept. The Survey studies showed that the probable effect of a canal in that location would be the infiltration of salt water from the canal into the fresh ground water. A progress report on a part of the Runyon area for which the geologic features were studied by M. E. Johnson, assistant State geologist, was published by the State.[662] To study the possible advance of salt water, a series of test wells were drilled about 1938 between the industrial well fields in Parlin and the source of salt water intrusion, and samples of the water obtained periodically. This sampling indicated the advance of salt water through the sand.[663]

661/ Water Resources Bull., Sept. 10, 1932.

662/ State Water Policy Com. Special Rept. 7: 1937.

663/ Barksdale, H. C., The contamination of ground-water by salt water near Parlin, N. J.: Am. Geoph. Un. Trans. 1940, pt. II, pp 471-3.

In the Atlantic City area, the City Water Dept. drilled five large capacity wells to the so-called 100-foot sand in spite of warnings issued by Thompson in his report on this area. Pumpage from these wells so lowered the water table that salt water intrusion made it necessary to abandon the use of most of them, and a study of remedial measures was made. The salt-water intrusion was studied by means of driven-well points many of which were driven to a depths of about 100 feet. Water samples collected from each sand penetrated made it possible to study the vertical distribution of salt water in each well. The 200-foot sand, another source of supply, had also been heavily developed and there was a latent danger of similar contamination. Three test wells were installed between the well field and possible source of salt water intrusion for the purpose of determining by frequent samples the

approach of salt water to the well field.[664]

664/ State Water Policy Com.: Special Rept. 6, 1936.

In March 1938, R. C. Baker was employed to assist with the ground-water work in New Jersey.

Annual expenditures from cooperative funds were:

Year	State	Survey	Year	State	Survey	Year	State	Survey
1931	$ 551	241	1934	$7,432	$4,197	1937	$7,153	$7,404
1932	7,245	7,067	1935	7,386	7,543	1938	8,205	7,372
1933	7,440	7,307	1936	7,227	7,694	1939	7,271	8,558

Pennsylvania.- Cooperation with the Pennsylvania Topographic and Geologic Survey, which started in 1925, continued during the period. In these investigations, which covered both the geologic and hydrologic features, information on the latter was obtained chiefly through interviews with well drillers, owners of wells, officials of public water works, and engineers of oil and gas companies. In 1928, R. M. Leggette began a survey of the northwestern part of the State and continued it until completion the following year. During that investigation he selected the first observation well in Pennsylvania and had it read monthly by a local observer.[665] In 1930, S. W. Lohman was detailed to the Pennsylvania investigations and that year investigated counties in the northeastern part of the State. He selected one observation well and employed a local observer.

665/ Water-Supply Paper 777, p. 161.

By 1931 the disastrous drought of the previous year had increased interest in ground water and the regular areal ground-water survey was temporarily suspended while a State-wide program of observation wells was started. The State geologist became interested in this program largely through the efforts of C. F. Merriam, of the Pennsylvania Water and Power Co., who saw the value of such a program in connection with the flow of the Susquehanna River. About 35 wells in various parts of the State were selected for the purpose of making a systematic study of the water-table fluctuations in additional cooperation with the Surface Water Division. The wells selected were generally near gaging stations in order that the gage observers could read them weekly in connection with their regular duties.

The continuing ground-water program was resumed in 1933. During 1933 and 1934, 14 counties in the south-central part of the State were investigated, and in 1935, the 8 counties in the north-central part were investigated, the office studies being completed in 1936. This completed the areal ground-water survey of the State. The reports covering the areas studied during the period were published by the State in four bulletins.[666]

666/ Penn. Geol. Survey, 4th Series Bull., W3, W4, W5, W6.

The cooperative work during the remainder of the period was limited to the supervision by R. W. Sundstrom, from the neighboring office in Trenton, N. J., of the weekly readings on the observation wells which were gradually reduced to 30 in 1939, one being equipped with a water-stage recorder.

Expenditures from available funds were:

Year	State	Survey	Year	State	Survey
1929	$2,500	$1,500	1935	$1,826	$1,122
1930	1,567	1,531	1936	1,884	1,723
1931	2,424	2,260	1937	1,616	1,559
1932	2,088	2,034	1938	750	706
1933	323	617	1939	250	245
1934	1,494	575			

Virginia.- The 1930 drought, which was particularly severe in Virginia[667], increased interest in the ground-water resources, and in July 1931 cooperation was arranged with the State Geological Survey for a systematic investigation in Virginia. The first unit comprised the northern tier of counties of Arlington, Fairfax, Prince Williams, Louden, Clarke, and Frederick. It was selected not only because of its proximity to Washington, but also because it served as a type-area, including segments of several geologic and ground-water provinces or sub-provinces.[668]

667/ p. 142.

668/ Letter from O. E. Meinzer to author.

R. C. Cady was assigned to the Virginia investigations and from July to October he collected records of 1,300 wells, chiefly from well drillers and well owners. These included estimated yields, which were chiefly small quantities as many of the wells had not been developed to full capacity. Samples from 40 wells were obtained for analysis in Washington. A summary of this information, together with a description of the geologic conditions favorable to occurrence of ground water, were published as a preliminary report by the State.[669] This preliminary report was desired in order to make available as soon as possible the information for use of residents in increasing their individual ground-water supplies which were still feeling the effect of the drought.

669/ Cady, R. C., Prelim. Rept. Ground-Water Resources of Northern Virginia; Va. Geol. Survey, Bull. 41, 1933.

The next unit selected was the Shenandoah Valley, where Cady spent September and October 1932 and a short time in September 1933, collecting data similar to that in the previous investigation. From the experience gained, records of wells were collected chiefly from a few reliable well drillers. These records numbered 450 instead of the much larger number in the first investigation. Water samples from 40 wells were collected for analysis. These results, together with a description of the geologic formations producing ground water were published by the State.[670]

66/ Cady, R. C., Ground-Water Resources of Shenandoah Valley, Va.: Va. Geol. Survey, Bull. 46, 1936.

During the fiscal years 1936 and 1937, cooperation was suspended owing to a lack of State funds, and the only ground-water work was the establishment of 14 observation wells in the State, of which four were in northern Virginia. Cooperation was resumed July 1, 1937, and continued during the remainder of the period. The complete report on northern Virginia, which contained much more detailed information than the preliminary report, including pumpage records from municipal wells at Falls Church, published by the State in 1938.67/

67/ Cady, R. C., Ground-water Resources of Northern Va.: Va. Geol. Survey, Bull. 50, 1938.

In August 1937, D. J. Cederstrom was assigned to Virginia and started investigations in southeastern Virginia, chiefly in tidewater Virginia south of the James River. There was considerable industry in that area and as a considerable number of inquiries regarding ground-water possibilities had been received, that area was selected as the third unit in the state-wide investigation. It lasted well into the next period where it will be described.

Annual expenditures from cooperative funds were:

Year	State	Survey	Year	State	Survey
1932	$2,650	$2,635	1936	$ 0	$ 2
1933	1,604	1,619	1937	0	0
1934	995	795	1938	2,000	1,687
1935	156	155	1939	560	584

North Carolina.- Before the Ground Water Division began its more or less nation-wide observation-well program in 1934, the North Carolina Department of Conservation and Development in August 1931, through its chief engineer, Thorndike Saville, started a program in cooperation with the Surface Water Division, which was already cooperating in the State's stream-gaging program. The object of the program was to forecast stream flow. This program was reviewed in the field by Dr. Meinzer. Records were started on 12 wells throughout the State, and the program with a fluctuating number of wells continued during the period.

An investigation of the Elizabeth City area was made by the Ground Water Division in 1932 and 1933. Elizabeth City, which obtained its water supply from Pasquotank River, wished to obtain a ground-water supply, either from shallow or deep wells, and the North Carolina Department of Conservation and Development called upon the Survey for assistance. D. G. Thompson made a preliminary examination in September 1932, and reported that available information was insufficient to solve the problem and that a more extended investigation should be made. As a result of this report cooperation was effected with the Department of Conservation and Development, and S. W. Lohman was assigned to the project. He started work in November 1932, and spent about 2 months in

the field, during which time test drilling and test pumping were conducted. Although the investigation covered both shallow and deep wells, particular attention was paid to the former. Samples of the water-bearing material and of water from the various wells, many of which were shallow, were analyzed in Washington. The field work was completed in June 1933, and the results published in Water-Supply Paper 773-A. On the basis of these results, the city developed a new water supply from shallow wells. In accordance with recommendations made by the Survey, the City constructed a number of observation wells, and also experimented with wells of various sizes and screens with different kinds of intake openings. The experimental work was supervised by A. G. Fiedler, who, with the assistance of employees of the Elizabeth City Water Department, installed and tested several types of wells. The additional cooperation was completed early in the fiscal year 1939.

Expenditures from cooperative funds were:

Year	City	Survey
1933	$1,437	$1,305
1934	200	233
1938	166	171
1939	169	94

Georgia.- The industrial growth of Georgia during the thirties, particularly in the coastal region, caused such an increase in the withdrawal of ground water by pumpage in Savannah, and to a lesser extent in Brunswick, that a serious decline in water level occurred. In order to study the occurrence and quantity of artesian water perennially available, not only in the coastal region but also in Dougherty County, in the southwestern part of the state, where the problem of obtaining an adequate water supply for Albany was urgent, cooperation with the Division of Mines, Mining and Geology, of the Georgia Department of National Resources, was arranged in 1938. As practically no additional State funds were available, it was necessary to reduce the allotment of such funds to the Surface Water Division and for quality-of-water analyses to provide a modest beginning for the ground-water investigation.[672] The investigation in

672/ Letter from F. M. Bell to author.

the coastal region was made by M. A. Warren and that in Dougherty County by Mr. Warren assisted by a State employee. The latter investigation was not completed. V. T. Stringfield was in charge of both investigations.

In the coastal region near Savannah, an intensive study of the artesian pressure and the effect of heavy pumping, started in November 1938, was made and continued into the next period, where it is described.

Expenditures from cooperative funds during 1939 were:

State $4,080 Survey $3,390

Florida.- Although Florida has a high yearly precipitation, the seasonal distribution is such that irrigation for truck farming and citrus growing is required, and the main source of such irrigation supplies

is ground water. Near the coast, there was the danger that unregulated use of artesian water would seriously reduce the artesian head, thereby causing the possibility of infiltration of salt water and thus contamination of the ground-water reservoirs. The 1929 Legislature enacted a law, applicable to gulf-bordering Sarasota, Manatee, and Charlotte Counties, regulating the drilling and operation of wells and the conservation of the artesian water. The Stage geologist, Dr. Herman Gunter, was the administrative official.

To administer the new law successfully it was necessary to have more information relative to the safe yield of ground-water aquifers of that region as well as in other sections of the State where other ground-water problems existed. The State geologist arranged cooperation in 1930, and selected Sarasota County as one of the first areas to be investigated. D. G. Thompson was given supervision of the Florida work, which was performed by V. T. Stringfield. One of the most important phases of the investigation was the exploration of artesian wells for the purpose of determining the location of leaks, location of water-bearing zones yielding salt water, and zones yielding water of the highest quality.673/ In

673/ Water-Resources Bulletin, Nov. 10, 1932.

this phase of the investigation which was supervised by A. G. Fiedler, from September 15 to October 10, 1932, both the deep-well current meter and the electric-resistivity methods were used.674/ The Sarasota investi-

674/ Am. Geophysical Union Trans., June 1933, pp. 481-487.

gation was completed in 1932, and the results were published in the 23-24th annual report of the State Geological Survey.675/

675/ Stringfield, V. T., Ground-water resources of Sarasota County, Fla., and Exploration of artesian wells in Sarasota County, Fla.

While the intensive investigation of Sarasota County was under way, observation-well records and records of water use were started in Manatee, Orange, Duval, Pinellas, Seminole, Hillsborough, and Charlotte Counties. By so doing, records from those wells were available when the detailed investigations in those counties were undertaken later. Preliminary investigations in Manatee, Orange, Pinellas, Hillsborough, Seminole, and Duval Counties were made to determine the chief users of ground water, the number of wells, the artesian head, and other pertinent data. A preliminary report was issued by the State.676/

676/ Stringfield, V. T., Ground-water investigations in Florida: Florida State Geol. Survey, Bull. 11, 1933.

In April 1933, an investigation was made by Stringfield in the Lake Okeechobee area to obtain data relative to available ground water suitable for domestic and public supplies, and to collect well-drillers' records. To determine the depth at which highly mineralized water enters the well the electric resistance of the water in several wells was measured. Field tests of the chloride content of all wells visited were made and samples of water from representative wells were analyzed in Washington by the Quality of Water Division. The results of this informa-

tion were published by the State.[677] This brief investigation led to an

677/ Stringfield, V. T., Ground water in the Lake Okeechobee Area Fla.: Florida State Geol. Survey Report of Investigations No. 2, 1933.

intensive investigation of the Miami area started in the fall of 1939.[678]

678/ Letter from V. T. Stringfield to author.

Following the Lake Okeechobee investigation, a similar investigation of Seminole County was made in May 1933, and the results were published by the State.[679] In 1934 and 1935, State funds were not available for

679/ Op. cit. Report of Investigation No. 1, 1934.

regular cooperation, but with PWA funds and informal cooperation, Stringfield made a study of artesian conditions in the peninsular part of Florida.[680] The results were published as Water-Supply Paper 773-C, in

680/ p. 348.

which was printed the first map of the artesian pressure surface of the principal artesian aquifer.

When State cooperation was resumed in July 1935, it was decided to extend to the western part of Florida, the general survey of artesian water as an aid in studying local ground-water problems. This survey was completed by Stringfield in 1937, and an investigation of the ground-water supply of the Pensacola area in the extreme western edge of the State was undertaken, together with one of the areas west of the Suwannee River. By that time, the rate of pumping water for industrial uses in the Jacksonville area had increased so fast that concern was felt regarding the safe yield. In 1938, H. H. Cooper, Jr. started an investigation in the Jacksonville area, where observations on artesian pressure had been in progress since 1930. A typewritten report and brief mimeographed report on the Pensacole area was released to the public. Before the close of this period, plans were being made for the extensive water-resources investigation of southeastern Florida that began in the fall of 1939 in cooperation with Dade County and the cities of Miami, Miami Beach, and Coral Gables.

Annual expenditures from cooperative funds were:

Year	State	Survey	Year	State	Survey
1931	$4,000	$3,873	1936	$5,368	$4,795
1932	1,477	2,129	1937	2,804	1,679
1933	3,523	2,095	1938	1,742	2,649
1934	0	863	1939	2,919	2,324
1935	0	42			

Alabama.- In July 1928, cooperation with the State Geological Survey was arranged for the purpose of making a systematic survey of the ground-water resources of the State. The depression years, however, terminated the cooperation in 1930. During the cooperation, W. D.

Johnston, Jr. investigated the area of the Paleozoic rocks, covering 25 counties. He prepared a report which was published by the State in 1933.[681] W.P.

681/ Johnston Jr., Ground-water in the Paleozoic rocks of Northern Alabama, Ala. Geological Survey, Special Rept. 16, 1933.

Expenditures from cooperative funds were:

Year	State	Survey
1929	$2,600	$2,600
1930	2,725	1,752
1931	140	110

Mississippi.- Because of serious water-supply problems in the so-called Delta section and the southern section of the State, interested citizens obtained a budget appropriation of $10,000 for the State Geological Survey to enable it to cooperate with the Survey in a ground-water investigation.[682]

682/ Miss. Geol. Survey: 17th Bien. Rept. July 1, 1938-June 30, 1940.

Cooperation was started in June 1938, under direction of V. T. Stringfield, and G. F. Brown was assigned to the investigation, which was concentrated chiefly in 2 important artesian areas, the Mississippi alluvial plain and the southern part of the State. Although both projects were started in the fiscal year 1939, they will be described in the next period. In addition, a state-wide observation-well program was started. Twenty-four observation wells were selected and on six, recorders were placed.

Expenditures from cooperative funds were:

State	Survey
$5,050	$4,841

Louisiana.- Expanding industries and increasing population increased so greatly the use of ground water that there arose an urgent need for ground-water data with special reference to safe yields. This resulted in an arrangement of cooperation with the Louisiana Department of Conservation in May 1938. The two most critical areas were selected first, where heavy withdrawals had caused serious decline in water levels. One area was in Rapides Parish where the city of Alexandria obtained its water supply from ground water, and where the water level had declined from a few feet above ground surface to more than 100 feet below the surface. That investigation was started immediately by J. C. Maher under the supervision of V. T. Stringfield. Data were obtained from drillers' logs for 46 wells extended back to 1934, and information on 375 wells, 67 being selected for periodic observation from which piezometric surfaces were determined. Samples from 61 wells were analyzed in Washington. The results of the investigation, which was completed in 1939, were published by Louisiana Geological Survey as Bulletin 17.

The second critical area comprised most of the rice-growing lands in Jefferson Davis and Acadia Parishes in which water was pumped from more than 500 large wells to irrigate the rice fields. This heavy withdrawal had made it necessary to lower the pumps in the wells about 45 feet in the past 30 years. A preliminary investigation was started in June 1938 by J. C. Maher, but the real investigation was made during the first year of the next period. Another investigation started in the period was that of Grand and La Salle Parishes in the central part of the State. It was started in the fall of 1938 and continued into the next period, where it is described.

In 1939, the network of observation wells was expanded to include five additional parishes, and by the end of the period, periodic observations were being made on 116 wells in 10 parishes.

Expenditures from available funds were:

Year	State	Survey
1938	$ 737	$ 847
1939	4,254	4,941

Arkansas.- The only investigation during the period was that of Grand Prairie region, in which water equal in amount to the minimum flow of the Arkansas River was pumped from wells for the irrigation of rice fields. The growth of the rice-growing industry had been due largely to the fact that an abundant supply of water, chiefly from about a thousand wells, was available at moderate cost. The annual withdrawal of such large quantities of water had the inevitable result of lowering the head in the wells with a corresponding increase in pumping costs, and this reduction in head was becoming more serious. In April 1927 this situation was called to the Survey's attention by Senator Caraway, and arrangements were made with the State Geological Survey for a cooperative investigation when funds were available. That year O. E. Meinzer visited the area and made readings on 14 wells. The investigation was started in 1928, and to finance the State's share of its cost, the funds of the State Geological Survey were augmented by private subscriptions through the Stuttgart Chamber of Commerce, by funds contributed by the State Agricultural Experiment Station, and finally to complete the amount required, the Governor issued a deficiency proclamation for additional money to be paid from State funds.

D. G. Thompson was given charge of the investigation which required not only a geologic and hydrologic study in the Grand Prairie region, but a less detailed study in a larger area adjacent. Work was started in July 1928, with the collection of detailed data on some 500 wells, of which 150 were selected as observation wells. To determine the elevations of some of these, several hundred miles of levels were run. An estimate of the annual consumption of ground water was based on the amount pumped from a few representative wells and the area irrigated from to determine the duty per acre, which in turn was applied to the entire irrigated acreage in the area. The field investigation was completed in 1929, and thereafter periodic readings of the observation wells were made by, or under the direction of, Kyle Engler, of the State Agricultural Experiment Stations, under Survey supervision. In 1936, the number of these

these wells was increased to 238, but decreased slightly later. A preliminary report on the Grand Prairie region was in the form of a memorandum to the press released January 26, 1931.

Aquifer performance tests were made in 1938 by L. K. Wenzel, R. G. Kazmann, and Kyle Engler, to determine the rate of percolation into the area. Additional tests were made during the next period.

The annual expenditures from the available funds were as follows:

Year	State	Survey	Year	State	Survey
1929	$5,400	$2,400	1935	$ 0	$ 0
1930	4,074	1,855	1936	0	0
1931	1,400	1,417	1937	1,186	299
1932	300	281	1938	1,284	1,677
1933	401	247	1939	1,782	1,924
1934	0	154			

The resumption of cooperation in 1937 made it possible to visit the area at intervals and supervise more closely the collection of the well records and to make the aquifer performance tests.

Tennessee.- Cooperation with the Division of Geology of the State Department of Education, which was started in 1927, was continued during the early years of the present period. The investigation of the counties in the western part of the State started June 1, 1928 by F. G. Wells, was completed in the fall of 1929, and the results were published as Water-Supply Paper 656. Within the area investigated ground-water conditions in Memphis constituted a very important part of the investigation, and at least two months were devoted to accumulating data in that city. A sad commentary on the probity of at least one Memphis citizen is contained in the statement that a water-stage recorder locked in a large shed only a few feet from a main street in the residential section had been stolen.[683] A report covering the Memphis area was published as

683/ Water-Resources Bull., July 10, 1929.

Water-Supply Paper 638-A.

In the fiscal year 1931 C. V. Theis, under the direction of D. G. Thompson, started an investigation of 12 counties in south-central Tennessee and completed it the following year. The results were published as Water-Supply Paper 677. The depression years so reduced available cooperative funds that no additional investigations were made.

Expenditures from cooperative funds were as follows:

Year	State	Survey
1929	$3,000	$1,000
1930	1,884	2,890
1931	3,500	3,131
1932	0	92
1933	294	611

Ohio.- The only investigation made during the period was one in the southwestern part of the State in cooperation with Butler and Hamilton Counties. Although the municipal supply for Cincinnati is obtained from the Ohio River, large amounts of ground water are pumped for industries and for suburban supplies in the Mill Creek Valley outside the city limits, and in Hamilton and Middletown, in Miami River Valley in Butler County. The dry years of the middle thirties had accelerated the decline in water level to an alarming extent. In the fall of 1936, the Survey, at the request of the county commissioners, detailed D. G. Thompson to make a preliminary investigation which was completed that year, and report was released. In 1938, cooperation with the two counties was arranged for the purpose of determining the safe yield of the water-bearing beds and methods of increasing the ground-water supply. This investigation was started by Mr. Thompson and F. H. Klaer, Jr., in the summer of 1938, and continued into the next period where it is described.

Expenditures from cooperative funds were:

Year	County	Survey
1938	$ 250	$ 223
1939	4,354	4,048

Indiana.- The importance of ground water in Indiana is indicated by the fact that 241 of the 291 municipal water supplies in the State came from ground water, as shown by data compiled by the Indiana Public Health Division.[68]/ In view of the need for ground-water information in

68]/ U. S. Geological Survey Water-Supply Paper 840, p. 69, 1937.

Indiana, and at the request of J. P. Kerr, Assistant State Geologist, a ground-water program was started on a small scale in 1935, in cooperation with the Department of Conservation, Division of Geology. In the summer of 1935, R. C. Cady made a reconnaissance of the northern part of the State and selected 87 observation wells and arranged for their periodic measurement by a number of Federal, State, and municipal agencies. These measurements were begun October 15, 1935. During the fall of 1936 and the winter of 1937, V. T. Stringfield reviewed the program and extended it to the southern part of the State. Some of the results of the work are given in Water-Supply Papers 777, 817, and 840. Information obtained on the Indianapolis area, where most of the industrial supplies and a part of the public supply were derived from ground water, showed a serious lowering of the water levels in wells, chiefly as a result of increased use. Therefore, C. L. McGuinness was assigned in September 1938, to an intensive investigation of the area. The investigation continued into the next period, and is there described.

Expenditures from cooperative funds were:

Year	State	Survey
1936	$ 738	$ 569
1937	1,268	808
1938	921	739
1939	751	902

Michigan.- As the objects of the Michigan investigations and methods of operation were unique, they are described at some length. The drought of 1930 had increased the hazard of forest fires, and the Michigan Forest Fire Experiment Station had developed power equipment for fighting forest fires. To be effective, adequate water supplies from wells were required, and the State Geological Survey decided upon a ground-water investigation to determine where water in sufficient quantities could be found at depths of 20 feet or less in the regions subject to forest fires. One of the most valuable uses of ground water in fighting fire is to prevent an outbreak or flaring up of the flames along a fire line after the first advance has been checked.[685]

685/ Water-Resources Bull., Apr. 10, 1934, p. 45.

Cooperation was effected with the Survey in the summer of 1932, by which the latter was to furnish technical advice and study the ground-water possibilities, and the State was to furnish the employees and equipment and do the detailed work necessary, chiefly the construction of wells. As the State was carrying on a program of tree planting and had several nurseries in Roscommon County, located in the northern part of the southern peninsula, that county was selected for the investigation. S. W. Lohman was assigned to the project and during 1932, with the assistance of a geologist in the State Survey, carried on investigations in four townships.

The power equipment tested experimentally by G. I. Stewart of the Michigan Forest Fire Experiment Station at Roscommon consisted of a truck-mounted 215 gallon water tank which was filled and emptied as needed, by means of a small portable reciprocating pump driven by a gasoline engine. The shallow wells were put down by jetting with water from the tank, and under favorable conditions, only 5 minutes was required to sink into the sand a 20-foot well, consisting of $1\frac{1}{4}$ inch boiler tubing as casing. These were the exploratory wells to determine the depth to water. For fire fighting, a 4-inch casing was jetted down, a $3\frac{1}{2}$ inch well screen inserted, the casing jacked up to bare the screen, a 1-inch fire hose attached and filled to a pressure of 125 pounds per square inch. This operation also under favorable circumstances required only 5 minutes.

In 1933, when the Civilian Conservation Corps was organized for the principal purpose of conserving and developing the forests, O. E. Meinzer suggested the utilization of that agency to expedite the investigation, and eight parties, each consisting of six or seven CCC men, headed by a geologist of the Survey were organized. The power pump used the previous year was relatively expensive, and as funds were not available to furnish such equipment to each party, A. G. Fiedler proposed the substitution of double acting hand-operated pumps. This also was tested by G. I. Stewart and found satisfactory. The equipment for each party consisted of a truck on which was mounted a 215-gallon water tank, and a double-acting hand pump, together with lengths of pipe, fire hose, etc., for sinking the well casings by jetting. Two-inch casing was used instead of the $1\frac{1}{4}$ inch casing used the previous year. The hand pump enabled the casing to be jetted down as quickly as the power pump. After the wells were completed, the same equipment was used to pump water from them in a test of capacity. Water was also pumped from the wells in fighting 14

fires in 1933. 686/

686/ Water-Resources Bull., Apr. 10, 1934.

The test-well program continued through 1937, but afterward was reduced with the reduction in CCC forces. Only those used as observation wells were continued. These test wells merely determined the conditions, and when a fire occurred, new wells were put down.

During 1934, V. T. Stringfield, who had been detailed to Michigan in 1933, cooperated with geologists of the State survey in starting a systematic program of selecting observation wells in the State. Two hundred and forty observation wells at which monthly measurements were made were selected. Most of the work of measuring the wells was performed by geologists of the State Survey, assigned to the CCC work, and as the CCC activities were greatly reduced in 1938, the number of observation wells was reduced to 87.

Expenditures from available funds were:

Year	State	Survey
1933	$2,706	$1,322
1934	2,328	904
1935	1,432	1,140
1936	1,398	198
1937	1,336	1,139

Although there was no formal agreement during the remainder of the period, observation well records were continued.

Iowa.- 687/ Ground water is the chief source of Iowa water supplies,

687/ Abstracted from Water-Supply Paper 886, pp. 13-15.

and large quantities of water are pumped from many water-bearing formations of different character and geologic age. In 1938, cooperation was effected with the Iowa Geological Survey for the purpose of obtaining past and present data on pumpage from ground water, and to correlate that information to fluctuations in water levels and with the geologic source of water supplies. Work was started September 1, with T. W. Robinson studying the hydraulic engineering features, and a State geologist, H. G. Hershey, the geologic features. In addition to investigating areas effected by heavy pumping, periodic measurements were made of observation wells in areas not affected by pumping. Monthly measurements of water levels were made by 32 observation wells by the wetted tape method, and many readings made on wells equipped with air lines and pressure gages. Six aquifer performance tests were made to determine the capacity of wells and the hydrologic coefficients of the water-bearing formations.

One phase of Robinson's investigation worthy of mention was the study of the water-level fluctuations registered by a recorder in a non-flowing artesian well in Iowa City. These fluctuations are semi-diurnal in period, and the study correlated them with the transit of the moon, and were concluded to be "earth tides" produced by the attraction of the moon

and sun. This study was a confirmation of the fluctuations observed in two wells during the Pecos River investigation the previous year.[688]

688/ Am. Geophys. Union. Trans., pt. 4, pp. 656-666, 1939.

The Iowa investigation was continued beyond the end of the period.

Expenditures from cooperative funds during 1939 were:

State, $5,016; Survey, $4,338

In connection with Survey activities in Iowa, reference should be made to previous assistance rendered the State Geological Survey in 1934. As a result of the drought, many ground-water supplies became seriously depleted. The deeper supplies, however, were not seriously affected, and the State started a program of rehabilitating some of the deep wells. One phase of this program was the exploration of the wells to detect underground leaks, or to determine the feasibility of casing out highly mineralized water and utilize only such supplies as might be of satisfactory quality. To A. G. Fiedler was assigned the task of exploring wells that offered rehabilitation possibilities and training a State employee in the use of the Survey's deep-well equipment, which was loaned the State. This assignment lasted about six weeks.[689]

689/ Letter from O. E. Meinzer to author.

North Dakota.- During the previous period, the State Geological Survey had made an inventory of wells in North Dakota and had made follow-up readings on some wells at long intervals. In the summer of 1937, the State Survey sponsored a WPA project to select and maintain weekly readings in connection with its state-wide well observation program. The State Survey also desired a study of the artesian basin in the Ellendale-Jamestown area to determine whether the conservation work in that area had resulted in a rise in pressure or at least in checking the decline. The supervisor of the WPA project was to have charge of the State-wide observation well project and a State employee of the conservation project. Cooperation was arranged with the Survey, and L. K. Wenzel was placed in charge of both projects.[690] The first year (1937), 50 wells, chiefly in the eastern

690/ Memo for Press, Feb. 7, 1939.

eastern part of the state, were selected and observations started. In 1938, 30 additional wells, chiefly in the western part, were added. Of the 80 wells that were being measured in 1939, two were equipped with recorders. The observation-well project was continued beyond 1939. A report on the artesian basin was published as Water-Supply Paper 889a.

Expenditures from cooperative funds were:

Year	State	Survey
1938	$3,039	$1,949
1939	1,462	2,227

South Dakota.- The severe drought of 1933 and 1934 so depleted the surface water supplies in South Dakota that acute water shortages occurred. As a result the 1935 session of the Legislature appropriated $1,500 for

> making a survey of the need for drilling artesian wells and the construction of reservoirs to store and conserve water flows from such wells and *** making a survey and report of the various Artesian Well basins throughout the state and in gathering facts and statistics to enable the State Geologist and the Governor to determine whether or not such wells should be drilled.691/

691/ Sen. Bill 23.

Cooperation with the State Geological Survey was arranged soon afterward for an investigation of the artesian basin and shallow supplies in the western part of the State. T. W. Robinson, who as assigned to the investigation, spent the period June 21, 1935, to September 4, 1935, in the field, collecting data to determine (1) the static level of the artesian water, or height above sea level to which the water would rise in tightly-cased wells, (2) the rate and amount of decline of static water level in the past, (3) the possibility of developing deeper artesian aquifers as a source of water supply, and (4) the temperature and quality of water.692/ He also investigated available shallow supplies.

692/ Letter from T. W. Robinson to author.

The geologic studies were made by, E. P. Rothrock the State Geologist.

The results of the investigation included all available data on 75 wells, chiefly in the Dakota sandstone in West Central South Dakota. A map showing the piezometric surface of the water was prepared. The report was published by the State Geological Survey as Report of investigations No. 26.

Expenditures from cooperative funds were:

Year	State	Survey
1935	$ 200	$ 128
1936	1,179	1,442

Nebraska.- In 1929, the Nebraska Geological Survey began a State-wide ground-water investigation. The first unit was the Platte Valley and the northern part of the upland plain to the south, where the wide use of ground water for all purposes, including the necessary development of ground-water supplies for irrigation, made it imperative that a better understanding of the geology and hydrology of the valley and adjacent areas should be obtained.693/ Beginning July 1, 1930, cooperation was effected with the U. S. Geological Survey, which continued during the remainder of the period. A. L. Lugn was the State representative in the investigation, and L. K. Wenzel, the Survey's representative. Lugn studied the geology and general hydrology of the region, and Wenzel, the hydrologic problems of the valley. By means of a small hydraulic rotary rig, lines of test holes were drilled across the valley in 1931, 1932, and 1933. Observation wells between Chapman and Gothenburg were selected for periodic measurements, an inventory of irrigation wells was made, the permeability and specific yield of the water-bearing materials were determined by laboratory study of samples and by aquifer performance tests. The Slichter method of determining the velocity of ground water was first used to a limited extent. In the pumping tests the Thiem method of determining permeability of the water-bearing material was investigated and effectively used, not only to determine permeability but also specific yield, or effective storage capacity. The investigation was completed in 1934, and the results were published in Water-Supply Paper 779.

693/ Water-Supply Paper 779, p. 2.

As a result of the dry years culminating in the drought of 1934, concern was felt for ground-water supplies throughout Nebraska, and in 1934, a State-wide program of water level measurements in well was started. L. K. Wenzel and H. A. Waite, the latter at that time a State employee, spent three months in the field locating about 350 observation wells, of which 60 had been used during the Platte Valley investigations. Most of the wells selected were wells in which the water levels were unaffected or only moderately affected by pumping. The water levels in the wells ranged from 2 feet to 275 feet below the land surface. This program was continued during the remainder of the period and was gradually enlarge until it included about 400 wells. In 1937, periodic measurement of the temperature of water in the wells was begun, and samples of water from 100 wells were analyzed by the Quality of Water Division.

The second investigation in the State-wide program was in Keith County, and was made during the summer of 1935. The construction of the Platte Valley Irrigation District and of the Central Nebraska Public Power and Irrigation District, with construction of large reservoirs, made increasingly important a study of the ground water in that area. In this investigation 350 observation wells were selected and their elevations determined by readings on two altimeters, one located at a fixed point and read at 5-minute intervals to correct for changes in atmospheric pressure and temperature. From periodic readings in these wells, a few of which were bored for the purpose, a map was prepared showing the depth to the water table throughtout the county.

Water from 29 wells was analyzed by the Quality of Water Division. The investigation was made by L. K. Wenzel and H. A. Waite, and the results were published as Water-Supply Paper 848.

During the first investigation the existence of a depression of the water table at Grand Island had been noted. The water levels in the city wells had been declining for many years, and as the consumption of ground water was increasing, much concern regarding the adequacy of the ground-water supply was felt. In 1935, the city water department, through informal cooperation with the Survey, constructed 55 observation wells and began periodic observations. Pumpage records were also compiled. The results of this investigation were published as Water-Supply Paper 836-E.

The next investigation was made by L. K. Wenzel, R.C. Cady and H. A. Waite in Scottsbluff County in the western part of the State, where ground water was being used for irrigation and municipal supplies. Field work was started in July and continued until December 1937, with weekly readings of 45 observation wells and recorder records on 3 wells continued until August 1938. The investigation included a program of test-hole drilling by means of the State-owned rig. Samples of material were analyzed in the hydrologic laboratory in Washington, and one pumping test was made to determine permeability. Samples of water were analyzed by the Quality of Water Division. The results were published as Water-Supply Paper 943.

The last investigation during thepresent period was that of Box Butte County, in the northwestern part of the State, on the upland divide between the North Platte and Niobrara Rivers. As a result of the dry years, a few apparently successful attempts to irrigate from ground water had been made, and interest in the ground-water supply had increased. The investigation was to determine where ground water of good quality could be obtained, how much is available, and what would be the pumping lift. The field work was done chiefly between June and October 1938. R. C. Cady made the geologic studies and O. J. Scherer collected most of the hydrologic data, both under the supervision of L. K. Wenzel. Ten test holes were drilled; records of more than 200 wells were collected; the water levels in 17 observation wells were measured at 10-day intervals; and measurements of the discharge of some of the irrigation wells were made. The results were published as Water-Supply Paper 969.

Expenditures from cooperative funds were:

Year	State	Survey	Year	State	Survey
1931	$5,223	$4,083	1936	$7,153	$4,394
1932	7,347	7,176	1937	2,879	3,943
1933	3,322	3,751	1938	6,840	6,486
1934	2,794	2,592	1939	3,290	5,894
1935	4,634	3,279			

Kansas.- In the spring of 1937, largely as a result of the recent drought years, the State Geologist, who had been gathering ground-water data, proposed continuing cooperation as a means of enlarging the State ground-water program and utilizing the Survey's specialists in ground water investigations.694/ In his letter proposing cooperation,

694/ Letter from Dr. R. C. Moore to Director.

Dr. Moore stated that the Kansas Geological Survey had made arrangements with the State Board of Health to allot $5,000 to the ground-water studies, provided that cooperation with the U. S. Geological Survey could be arranged; the first project to be investigated was the so-called "equus-beds" area just north of Wichita. In recent years, improper handling by oil companies of the brines in evaporation ponds had allowed the brines to seep into the shallow, fresh ground water, which was the source of rural and potential urban water supplies.695/ In response to that letter,

695/ Op. Cit.

W. N. White conferred with the State officials in Lawrence, and a program was arranged for the first year's operations, which included not only the equus-beds area but also an investigation in the so-called Dust Bowl area in Morton and Stevens Counties. As it later developed, the investigations in Morton and Stevens Counties, and other counties in the western part of the State was not begun until after June 30, 1939.

Cooperation became effective July 1, 1937, and D. G. Thompson spent July and August obtaining preliminary information relative to the problems in the vicinity of Wichita and McPherson. Early in August he was jointed by S. W. Lohman, who was placed in charge of the Kansas investigations, temporarily under Thompson's supervision. By September definite plans were formulated and Thompson turned the work over to Lohman, who spent three months collecting records of public ground-water supplies, making an inventory of existing wells and starting an observation-well program.

Some time previously, the City of Wichita had cooperated with the State Geological Survey in making a reconnaissance for a new ground-water supply in a general area north of Wichita. In the spring of 1938, the city was seeking a new ground-water supply and had made an application for PWa funds. To substantiate its claims, definite plans had to be submitted within a few months. As the Survey was already investigating the ground water in a part of the area under consideration by the city, the latter, beginning in July 1938, contributed a total of $9,000 in order that the scope of the investigation might be enlarged to meet the city's needs. Nineteen test wells were drilled with cable-tool rigs under Lohman's supervision. These ranged in depth from 150 to 276 feet. The city also, through its consulting engineers, put down about 40 rotary test holes ranging in depth from 161 to 269 feet. The enlarged program was begun in July, when J. C. Frye was appointed as Lohman's assistant, but did not get under way until August, and by the end of September, the city wanted the solution of its problem.

making a study of irrigation possibilities in that general area, this agency requested the Survey to concentrate attention first on that portion of Ford County lying in the Arkansas Valley. The field work consisted chiefly in making an inventory of existing wells, including pumpage records, and the selection of about 37 observation wells in all parts of the country for periodic measurements. The investigation was completed during the summer of 1939, and the results were published by the State Survey.

Expenditures from cooperative funds were:

Fiscal Year	State and Municipal	Survey
1938	$3,237	$6,931
1939	18,306	15,290

Oklahoma.- The Oklahoma Panhandle after 4 years of low rainfall was a part of that great area called the "Dust Bowl", and some successful experimental irrigation from wells had aroused interest in irrigation from ground-water sources. To determine the suitability of the ground water for irrigation and the safe yield, the Oklahoma Geological Survey in June 1936 requested the U. S. Geological Survey to consider cooperation. W. N. White was detailed to make a reconnaissance, and the following year cooperation was arranged. He supervised the ensuing field work in the Panhandle. In August 1937, S. L. Schoff started the investigation in Texas County, which is one of the three counties comprising the Panhandle. This included a study of the outcrops of the water-bearing formations, an inventory of 540 wells, and periodic measurements of 45 observation wells. The investigation was completed in 1938, and the results were published by the Oklahoma Geological Survey.696/ Upon the

696/ Bull. 59.

completion of the Texas County study, the program was extended to Cimarron County, where field work was started July 1938 and completed at the end of the period. More than 400 wells were measured, the withdrawals from many wells being measured or estimated, and available drillers' logs obtained. Samples from 42 wells were analyzed in Washington, and the water-bearing sands studied both by the Survey and by the State agency. Recent geologic studies by J. W. Stovall of the University of Oklahoma were utilized. The results were published by the Oklahoma Geological Survey.697/

697/ Bull. 64.

Expenditures from cooperative funds were:

Year	State	Survey
1937	$ 96	$ 92
1938	1,802	1,386
1939	2,768	2,822

Referring to this phase of the investigation, Lohman writes:[698]

698/ Letter to author.

> This investigation presented many difficulties owing largely to the fact that the city *** wanted the final answer to the whole question by September *** or barely after the investigation was begun ***. Thus, it was necessary to work fast and hold many conferences *** reporting progress. The decision on the part of the city had to be made before we were far enough along to be absolutely certain that the quantity of water desired was available.

It may be added that the new supply based on incomplete data has proved successful.

To obtain the answer to the original question about the oil brines, about 60 driven wells were put down, chiefly on the downstream sides of the disposal ponds, and water samples were taken at vertical intervals of 5 feet. The samples were titrated for chloride in the field by means of a small laboratory mounted on a truck. Partly as a result of these studies, the State Board of Health encouraged the oil companies to construct brine-disposal wells leading to the porous rock, far below the surface, where the injected brine could not contaminate the fresh water supplies. An account of the "equus-beds" investigation was published by the Society of Economic Geologists[699] and will later be published in

699/ Lohman, Stanley W., and Frye, John C., Geology and ground-water resources of the "equus-beds" area in south-central Kansas: Econ. Geol., vol. XXXV, No. 7, pp. 832-866, Nov. 1940.

more detail as a bulletin of the Kansas Geological Survey. The investigation was continued beyond June 1939, and certain phases of it are still in progress, including the observation-well program and an investigation of the safe yield of the well-field area. During this investigation samples of water from the wells were tested in the field for chloride content in a truck-mounted laboratory equipped for that purpose. Material obtained from the wells at different depths was tested for permeability in a field laboratory by means of a motor-driven rotary shaker equipped with standard screens.

The only other investigation during the period was in Ford County, located in the High Plains in southwestern Kansas, where as a result of the drought years, some experimenting with deep-well irrigation had been done. Dr. Moore was asked to investigate the situation, and at his request Lohman interrupted his Wichita area investigation to make a reconnaissance during November 1937 with W. N. White and S. L. Schoff. This reconnaissance indicated that the problem was not only one of available water supply but also one of determining whether such irrigation would be economically feasible.[700] In October 1938, H. A. Waite was given a

700/ State Geol. Survey, Mineral Resources Circular 9.

Federal appointment and was assigned to make the investigation under Lohman's supervision. As the Bureau of Agricultural Economics was

Texas.- The systematic survey which was started in 1929, continued during the period. The reason for the survey and its purposes are best described by the State Board of Water Engineers, the cooperating agency:701/

701/ Ninth Report, 1930, p. 10.

> It is the almost invariable experience in the development of artesian areas that there is a progressive lowering of the head of water in wells. This is caused by the annual withdrawal of more water than the rainfall can replace. In many cases this excessive withdrawal has virtually destroyed the usefulness of large artesian basins that would, otherwise, under proper use, have proven a highly profitable asset. Such cases have happened, and other cases are now in progress in Texas. * * *
>
> There is a fairly definite limit to the amount of water that can be withdrawn from any given artesian basin without endangering the supply. And that limit is ascertainable to a reasonable degree of accuracy by employing the skill of the geologist and the engineer.

The situation in Texas was called to the attention of the 41st Legislature, with the result that in July 1929, an appropriation of $20,000 per year for two years was made for an investigation under the direction of the Board of Water Engineers;702/ subsequent legislatures

702/ 2nd Called Sess. Chap. 37.

continued the appropriation in varying amounts. As an indication of the urgency of the situation the Board of Water Engineers (in its own language) immediately entered into cooperation with the Survey for a systematic investigation, by counties, of all feasible ground-water basins in the State. Quoting again from the Ninth Report:

> The underground waters of the state are more than ten times the volume of the surface waters, and the orderly development of the state requires a knowledge of the location and extent of the various underground basins and requires that some State control be exercised over the use of these waters in order to prevent wasteful development.

Cooperation also was arranged with the Engineering Experiment Station A & M College, and Division of Sanitary Engineering, State Health Department, the former to complete field work in Frio and Atascosa Counties which had been started in 1929 by the Station in cooperation with the Missouri Pacific Railroad. That investigation was made a part of the Survey's cooperative investigations early in 1930. The State Health Department was to make bacterial analyses of the water in the areas studied, but very few such analyses were made and the Health Department soon dropped out of the picture.

W. N. White was placed in charge of the investigations with several assistants, as available funds made it possible to investigate more than one area at a time. In the beginning, it was determined that the results

should be released to the public as promptly as possible, and that was done by releasing reports in manuscript form, and later published as Water-Supply Papers.

The first investigation started by the Survey was that in Uvalde and Medina Counties, and in the Winter Garden district in Dimmit and Zavala Counties, where additional ground-water supplies especially for irrigation were needed. The field work in Uvalde and Medina Counties was started by A. N. Sayre, September 12, 1929, and continued until May 25, 1930, with occasional observations of water-well levels since that time. The geology was mapped, and for 250 water wells, data regarding diameter and depth, rock formation supplying water, quality and use made of water, and depth to water in the well were collected. Forty-five samples of water were analyzed in the Washington laboratory. The Edwards limestone, which is crossed by streams in the area, is an important source of the ground water, and a piezometric profile was prepared. The Surface Water Division had maintained gaging stations on a number of streams above and below the Edwards limestone outcrop, and from those records, together with those from a series of seepage measurements, made it possible to estimate roughly the amount of water entering the limestone. The results of the investigation were published as Water-Supply Paper 678.

The investigation in Dimmit and Zavala Counties were started by S. F. Turner and T. H. Robinson in the latter part of September 1929, following a preliminary study by O. E. Meinzer, W. N. White and S. S. Nye. Detailed studies were continued by Robinson until the summer of 1930, when Penn Livingston succeeded him to do the salt water work. The investigation included studies of the geology with special reference to the Carrizo sand which furnishes nearly all of the usable ground water of the area; but it was devoted mainly to the computation of well data, including pumpage records, water level fluctuation in observation wells, depth and thickness of the Carrizo sand, as shown by well records, mutual interference between wells shown by pumping tests, and the position of leaks in wells that had become contaminated by salty water. The investigation of the leaky well was made by Livingston, assistant by Walter Lynch and was completed in the fall of 1931. The methods used are described in Water-Supply Paper 796-A. The inventory of wells and pumpage was repeated in 1938-39 by G. H. Cromack, engineer with the Texas Board of Water Engineers. Mimeographed reports giving a discussion of the geology and principal results of the hydrological studies were published by the Survey in mimeographed form in 1931 and 1933. The well records, well water analyses, water level records, and results of the salt water exploratory program were first released in manuscript form in 1934,and a revised well report including the 1938-39 inventories was published by the Board of Water Engineers in 1940, in a mimeographed report containing 140 pages and maps. Periodic measurements of water levels in observation wells have been made ever since the investigation was started in 1929.

In November 1929, A. G. Fiedler started an investigation in Somervell County where the artesian head at many wells, as a result of the large number of wells, had declined to a serious extent. A preliminary study of the artesian problems in the area had been made in September 1926, and a press notice released by the Survey Feb. 16, 1930. The field work

was performed during November and December 1929, and in June 1930.

The general investigation comprised a study of the use and waste of artesian water, and the safe yield of the artesian reservoir including the underground leakage and methods of constructing wells. To determine the seasonal fluctuation, a Bristol pressure gage was attached to a deep well recently completed. Interference of one well upon another was also studied. The investigation of underground leakage was made by means of the deep-well current meter, and by the packer method. A program for conservation of the artesian water was recommended. The results of the investigation were published as Water-Supply Paper 660.

Early in 1930 the cooperative survey started by the Engineering Experiment station was made a part of the general cooperative investigations, and was continued by J. T. Lonsdale who had started it in June 1929 for the purpose of determining the ground-water supply available for irrigation. The field work was performed from June to August in the years 1929 and 1930, and December 1931 and June 1932. This was an areal survey, which did not determine the actual quantity available, but by means of geologic studies and yield of existing wells and depths to water surface estimated the present use and the fact that such use was not seriously depleting the ground-water reservoir. Samples of water from 45 wells were analyzed in the Washington laboratory. The results were published as Water-Supply Paper 676.

Perhaps the most important investigation carried on during the period was that of the Houston area. Houston, the chief city in Texas, receives its water supply from ground water and the increased draft had lowered the water levels to such an extent that concern was felt regarding that supply. Accordingly, an investigation was started in December 1930 by W. N. White, Penn Livingston and S. F. Turner. As the water supply is an underground reservoir, it was felt that the most reliable approach to the safe yield was by a study of the relation of the water levels in various wells to the amount of water pumped.

Monthly readings of the depth to water levels in about 82 selected wells were made, and 8 water-stage recorders were operated on 8 additional wells. Available data on pumpage were collected; details of 900 water wells and logs of 500 water wells or oil-test wells were tabulated. The outcrops of the principal water-bearing formations were mapped, and the penetration of rainfall on the outcrop studied. Twenty samples of loose sand and fine gravel from well cuttings, and 46 samples of sand and silt from drill cores from deep wells were analyzed in the hydrologic laboratory in Washington to determine the permeability. The first phase of the investigation was completed in 1933, and at that time, the ground-water supply was found to be adequate for the demands upon it. The Survey suggested, however, that any new wells drilled by the City should be located at a considerable distance from any of the existing centers of pumpage.[703] Records of water levels and pumpage were

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703/ Water Supply Paper 889-C, p. 143.

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continued. Additional pumpage in 1937 reduced the water levels to such an extent that the City contributed $5,000 in 1938 and a more intensive investigation was started. As it continued through the following period, the description will be deferred to that period.

During the spring of 1931 and the summer of 1932, an investigation of Duval County was made by A. N. Sayre for the purpose of determining the availability and quality of ground water supplies in the county and their relation of the artesian waters in Brooks, Kleberg, and Willacy Counties. Records from more than 300 wells, and samples from 32 representative wells, were collected and the samples analyzed in Washington. Some samples of water were analyzed in the field for chlorides, sulphates, and hardness, by S. F. Turner and J. C. Cumley. Numerous measurements to determine fluctuations due to rainfall, were made at selected wells. The results were published as Water-Supply Paper 776.

A study of the Balmorhea area was made for the purpose of determining whether ground water withdrawal for irrigation would reduce the flow of springs which are the chief source of the surface water being used for irrigation. The field work was done chiefly during the years 1931-33 by W. N. White and S. S. Nye, with H. S. Gale making the geologic studies. Weirs and water-stage recorders were maintained for some two years on 5 springs and gages on several streams. Several series of meter measurements were made by V. M. Rupp of the Surface Water Division, to determine the losses by seepage from the main irrigation canal, and gains by ground-water inflow in several relatively short stretches. Depth to water levels in 13 shallow wells were measured monthly or oftener for nearly two years, and a water-stage recorder was operated in one well for $1\frac{1}{2}$ years. Analyses of the spring waters were made in Washington. The results were published as Water-Supply Paper 849.

A survey of Webb County was made by J. T. Lonsdale of the Engineering Experiment station from June to August in 1931 and 1932. It was designed to be a practical guide to the ground-water resources with special reference to irrigation. For 189 wells, data on depths and diameters, character of water-bearing material, and yield were collected. Samples from 24 wells were analyzed in Washington. The results were published as Water-Supply Paper 778. This was the last cooperative investigation made by the Engineering Experiment Station. The Missouri Pacific Railroad has put up the funds used by the Engineering Experiment Station on the cooperative work, but the depression years dried up that source.

In the fall of 1932, W. N. White and A. N. Sayre started an investigation in the San Antonio area which was continued and carried to a conclusion by Penn Livingston and Sayre in 1933-34 to determine the capacity of the reservoir in the Edwards limestone, and the approximate amount that can be withdrawn annually without serious depletion. This reservoir is the source of the artesian wells and springs in that area. Existing gaging stations are located on practically all streams crossing the limestone outdrop, and on some stations are located above and below the outcrop. The records from those stations, together with series of meter measurements between stations, made by the Surface Water Division, made it possible to determine the gains or losses. Records from many of the 400 wells visited were computed or measured, and from this information and that relating to the length of time the wells are allowed to flow or are pumped during the year, an estimate of the total discharge from the wells in the Edwards limestone in 1934 was made. During that year levels were run to connect many wells and the depth to the water surface was measured, from which piezometric profiles were constructed. A continuous record of the fluctuations in artesian head was available for a record kept by the

city water department. In 1932, a water-stage recorder was placed on an unused well near Fort Sam Houston. Periodic measurements were also made to determine the fluctuations in artesian pressure in about 40 selected wells. The results were published as Water-Supply Paper 773C.

As a matter of interest, it may be added that in 1941, the San Antonio Public Service Company drilled in the San Antonio area a well 1,032 feet deep that was reputed to be the largest flowing well in the United States. In June 1942, the Surface Water Division measured its flow. The well had been capped, but the valve was opened and the full flow discharged into the San Antonio River. Two sets of measurements of the river a few hundred feet above and below the point where the well water entered the river showed the flow of the well to be 37 second-feet.

Penn Livingston started an investigation of Kleberg County in December 1932 to determine the amount of water used from deep artesian wells in the county and estimate the available supplies of fresh ground water which lies between layers of salt water. A plan was to be developed for conserving fresh water and prevent its being contaminated by the salt water. Four hundred and thirty-four wells were located and mapped; tests of 10 wells were made by electrical conductivity apparatus to determine the locations of salt-water leaks. Some of the wells were connected by levels to determine the piezometric profile. From that profile and the average permeability determined for areas in neighboring counties, the annual replenishment from the outcrop to the wells was estimated. Samples from most of the wells were field-tested for chlorides and hardness and samples from 13 wells analyzed in Washington. The results were published as Water-Supply Paper 773d.

During the depression years of 1934 and 1935, the cooperative funds were so curtailed that the district personnel was almost wiped out by transfers and no new investigations on the systematic survey were started. However, some work was done by means of PWA and WPA funds.

In 1934, PWA funds were allotted for a study of the High Plains and Gulf Coastal Plains areas. Studies of various parts of the High Plains had been made by the Survey and a large amount of preliminary data, including well records and measurements of water levels in wells, obtained. In addition, during 1936, geologists and engineers of the Resettlement Administration and made a study of wells in several High Plains localities. A description of the High Plains investigation, including those in this period, are given in the history of the following period. The Gulf Coastal Plains investigation was strictly a water-well inventory in Jackson, Nueces, and Wharton Counties. So important was the study of the High Plains that beginning in 1937, that area became a part of regular cooperative program which included geologic studies, compilation of data on new irrigation wells, amount of water pumped and change in water levels.

In 1936, under the sponsorship of the State, a WPA grant was made and the work was placed in charge of S. F. Turner and W. O. George for the Survey, and Dr. E. P. Schoch of the Bureau of Industrial Chemistry, University of Texas. The latter furnished office space and some assistance and gave some guidance on the many analyses of water samples. This was a State-wide inventory of water wells and water-table and seepage studies, including the analyzing of thousands of water samples. From 50 to 150

test holes and wells were drilled and logged in each county, and a record kept of depth to water in them, if the water-table was reached. From 200 to 400 existing wells and springs in each county were visited and mapped, and all available information obtained. Samples of water were analyzed. The data were assembled by counties and distributed to the public in mimeograph form, as an immediate guide to well-drilling. They would also serve as a basis for more intensive investigations later. The results to 1940 were also published as Water-Supply Paper 889-F.

With funds increased for the fiscal year 1936, the systematic survey was resumed and an investigation, international in character in the El Paso area in which El Paso and Juarez both obtain their municipal supplies from wells penetrating a series of sand and clays, was started in January 1936. At the request of the El Paso Water Board, W. N. White went to El Paso and spent a week studying various engineering reports made for the city and mapped a program which was accepted. A. N. Sayre and Penn Livingston started the field work in the summer of 1936. The water from some of the beds is potable, but from many beds it is highly mineralized. The lowering of the fresh-water level in the wells by pumping led to the danger of contamination of the fresh-water supply by the mineralized supplies, and that danger led to the cooperative investigation in which both El Paso and Juarez cooperated through the State Board of Water Engineers. Some 35 observation wells, 4 equipped with recorders, on both sides of the International Boundary were measured. A particular feature of this investigation was the use by the Geophysical Section of the Survey of resistivity methods to locate salt-water bodies in the El Paso area,[704] a new procedure in ground-water investigations. The field work was continued during 1936.

704/ Trans. Am. Geophysical Union, 1937, pt. II, p. 393.

An investigation of the Lufkin area, participated in by the city of Lufkin, was started by A. N. Sayre in January 1937. Its purpose was to determine the possibility of obtaining large quantities from wells for municipal and industrial purposes in Angelina County. J. F. Hauser, a cooperative State employee, under Sayre's supervision, collected most of the data and the hydrologic parts of the report were written by Messrs. White and Sayre. One hundred and eighty-eight wells and six springs were located, cuttings and drill cores from wells and samples of those as well as sand outcrop were tested for permeability and mechanical composition, by V. C. Fishel in the Washington laboratory. The results were published as Water-Supply Paper 849A.

In April 1937, an investigation of the Big Spring area, particularly in the city of Big Spring, was started by Penn Livingston and R. R. Bennett. The purpose of the investigation was to obtain basic geologic and hydrologic data regarding the occurrence, quantity, and quality of ground water and the best method of utilization. The city was particularly interested as an additional municipal supply was needed. In addition to the logs of 16 wells, records of all 246 wells in the area were collected, and lines of levels were run to connect them, and the depth to water surface in each measured, from which piezometric profiles were constructed and 12 samples of Trinity sand were tested in the Washington laboratory for permeability. The field investigation was finished in

1938 and the results were published as Water-Supply Paper 913. Five wells were being pumped, and the records of pumpage were compiled.

At the request of the city of Bryan, which desired an additional water supply, S. F. Turner made a brief investigation of the existing ground-water conditions in that area, and submitted a report to the City in January 1938, recommending additional well drilling. A test well was drilled by the City in May and June 1938, and more wells were drilled later. An oil company drilled a fifth well.

In 1937, the program of periodic measurements of selected observation wells as a part of the cooperative program was expanded to include large areas in the Texas Panhandle and in central and eastern Texas. By 1939, periodic measurements were being made on about 1,300 wells in the State.

When the cooperative investigations had been in progress 6 years, the Board of Water Engineers summed up the outstanding conclusions, as follows:705/

705/ Twelfth Report, 1936, pp 41-42.

> The areas in Texas that are underlain by water-bearing formations capable of yielding sufficient water for irrigation or large municipal or industrial supplies are relatively small when compared with the total area of the State, but in the aggregate, amount to thousands of square miles. In general, the capacity of the large underground reservoirs is very great, but the average annual contribution to the supply is limited. In every area irrigated from wells, that has been investigated, the amount of good land that is susceptible of irrigation is several times the amount that can be safely supplied from the underground reservoirs. *** Everywhere there is a limit to the safe withdrawal. *** If this limit is persistently exceeded disaster will follow. ***
>
> Large quantities of artesian water are wasted in Texas, especially on the Coastal Plain. Waste in substantial quantities has been found in every one of the areas of flowing wells that has been investigated. *** It should be fully understood that practically everywhere in the State that underground water has been extensively developed whole communities are drawing from one common reservoir and any depletion of the reservoir is suffered by all.

Expenditures from available funds were:

Year	State	Survey	Year	State	Survey
1930	$12,642	$ 3,748	1935	$ 4,354	$ 6,732
1931	15,556	19,987	1936	15,108	12,741
1932	15,811	20,099	1937	17,626	19,469
1933	23,190	15,085	1938	33,871	30,566
1934	9,816	7,705	1939	30,353	35,556

The depression years reduced the cooperative funds drastically. To recover ground lost, the Legislature in 1937, made a special appropriation to be spent by August 31, 1937, the end of the State's fiscal year, and increased substantially, the appropriations for the remainder of the period.

New Mexico.- Cooperation with the State Engineer, which began in 1925, was continued through the present period, during which time several new projects were investigated, and reports thereon were published in the Biennial Reports of the State Engineer. Supplemental reports were also made on the Roswell artesian basin, which had been investigated from 1925 to 1928. [706] In all investigations, periodic measurements of the observa-

706/ pp. 171-173 (1919-1928)

tion wells were continued after the main work was completed, and supplemental reports covering the interpretation of these records, together with available stream-flow records and meteorological date, and records of water pumped were made to the State engineer and published in his biennial reports, as well as in the Survey's annual water-level reports. By so doing, the investigations were continued. About 1935, C. V. Theis was placed in charge of all projects.

Mr. Theis writes:[707]

707/ Letter to author.

> I do not know exactly when I was placed in charge of all New Mexico investigations officially because as I remember it, the work, like Topsy, just grew. The date should probably be 1935, as in that year Walter White turned over the Mimbres work to me and since that time there has been no other work by others than those from this office.

Headquarters were established by Mr. Theis in Albuquerque in March 1936 with the beginning of the Rio Grande Joint Investigation.[708]

708/ p. 349.

Mimbres Valley: About 6,000 acres in the Mimbres Valley were being successfully irrigated by pumping from ground water, and the landowners and business interests of Deming, the principal city in the valley, believed that the ground-water resources should be developed to the safe limit of the available supply. Realizing the danger of overdevelopment, the Deming Chamber of Commerce requested the State engineer to make plans for a quantitative investigation. This request was referred to the Survey, and A. G. Fiedler, in charge of the Roswell project, made a preliminary study of the problem in August 1927, and selected 25 observation wells on 5 of which water-stage recorders were installed.[709] Under the

709/ Eighth Biennial Report, State Engineer, 1926-28, pp. 159-171.

State engineer's direction the wells were read at frequent intervals. Cooperation was arranged with the Survey, and in July 1928 W. N. White

began the investigation of the quantity of ground water available, the practical problem being to determine how much water could be pumped without serious depletion of the ground-water reservoir and lowering the water table below the limits of economic pumping.[710] The number of observation

710/ Water-Supply Paper 637-B, p. 71.

wells was increased to 150, of which 6, located at critical points, were equipped with water-stage recorders. To determine the percolation of water from the Mimbres River to the ground water annually, current-meter measurements at various points below the Faywood gaging station at periodic intervals were required. As the State engineer was carrying on an independent stream-gaging program at the time, the State hydrographers made measurements. Tests of materials underlying the surface were made to determine permeability, and measurements of the rate of ground-water movement made. All available pumping records were assembled as a basis for estimating the amount pumped annually. The investigation was completed in 1930 and the results published as Water-Supply Paper 637-B, but a program of obtaining systematic records of pumpage and water levels was continued throughout the period.

Lea County: Without adequate surface supplies, dry farming had been carried on with the natural hazard of deficient rainfall. A few farmers installed pumps on shallow wells and in some cases irrigated successfully. Prior to the beginning of the cooperative investigation, the State engineer's office had selected observation wells and connected them with sea-level datum. S. S. Nye started the cooperative investigation in September 1929 by making a reconnaissance of the shallow-well area. He continued his work during the summer of 1930, and assembled most of the base data pertaining to the occurrence of ground water, its direction of movement, and its quality. Beginning in November, periodic readings of 30 selected wells were made by the State engineer's office. Mr. Theis resume the investigation in Lea County in 1932, when nearly 3 years' records of water-level fluctuations were available. He was in the field from August to November, spending much of his time in studying the water-bearing material at the outcrop. Samples of the water-bearing material were sent to the hydrologic laboratory in Washington for analysis.

Roosevelt and Curry Counties (Portales Valley): Most of the area of these adjacent counties is either cattle range or is farmed without irrigation except in the Portales Valley, an abandoned stream channel, where water is pumped from wells. A considerable increase in this pumping made it essential to determine the amount of available ground water, and an investigation was started in 1931 when Mr. Theis was detailed to the project. He was in the field from July 15 to November 28, covering the entire area of the two counties but giving special attention to Portales Valley. Monthly measurements on 35 observation wells, 6 equipped with recorders, in Portales Valley were started in November. Additional field work was performed during December 1932 and a part of the time from September 1933 to May 1934. In March 1934, a standard Weather Bureau Class A evaporation pan was established. After the close of the investigation, 54 wells were measured bi-monthly and 200 annually, and records of pumpage were obtained for each year.

Pecos Valley, near Carlsbad: In September 1932, the U. S. Potash Co. began operations in the Pecos Valley and used as a depository for the waste brine containing 10 percent sodium chloride, Laguna Grande de la Sal, which has no visible outlet. Some years later irrigators from the Pecos River reported that the river water was becoming so saline as to injure their crops. To determine whether the waste brine was percolating to the Pecos River through underground channels, a cooperative investigation was arranged, and T. W. Robinson began work in April 1937 and completed his field investigations in June 1938, at which time a report was made. Further investigations were made by A. M. Morgan, assisted by W. E. Hale, and continued beyond the end of the period. As this was an unusual investigation some detailed description is warranted. It was necessary to determine whether water was escaping to the river underground. Shallow wells were drilled in the lake and along the margins which indicated no discharge of brine from the lake. Analyses of the river water at various points showed a marked increase at one point, indicating another source of the brine, and seven test wells were drilled to determine the salt content and artesian head of the water-bearing formations encountered. One formation proved to be the source of the brine.711/

711/ Letter from T. W. Robinson to author.

Roswell area (shallow wells).- Irrigation from shallow wells in the Roswell area had increased in recent years and by 1937, about 40,000 acres were being irrigated wholly or in part from shallow ground water and permits for 11,000 acres additional had been issued.712/ It therefore

712/ 12th - 13th Bien. Rept. State engineer, p. 159.

became necessary to determine the amount of available shallow ground water and A. M. Morgan made that investigation, spending the period April to October 1937, and January 1938 in the field. About 50 wells in shallow ground water were selected for periodic observation, but during the investigation, more than 400 wells were measured.

The investigation in the Middle Rio Grande Valley was made from April 1936 to June 1938.713/ It was a part of the Rio Grande Joint

713/ pp. 349-350.

Investigation, described on pp. 78-79.

In March 1939, an investigation of Hot Spring, N. Mex. was started and continued into the following period, where it is described.

Annual expenditures from cooperative funds during the period were:

Year	State	Survey	Year	State	Survey
1929	$4,500	$3,000	1935	$1,999	$1,366
1930	4,445	5,014	1936	2,719	1,874
1931	1,046	1,496	1937	2,108	5,312
1932	2,902	2,996	1938	13,247	9,610
1933	2,058	3,157	1939	12,814	13,010
1934	945	1,074			

Idaho.- Cooperative ground-water investigations were conducted in different parts of Idaho for several years prior to this period and several reports on the results of this work were published. In 1928, cooperation was arranged with the Idaho Bureau of Mines and Geology, and the Idaho Department of Reclamation for a comphrehensive investigation of the entire Snake River Plains and tributary valleys. Several private companies contributed funds to the latter agency to further the work. The investigation was started May 1, 1928, with H. T. Stearns in charge. Lynn Crandall, who for many years had been investigating the duty of water, canal losses, and ground-water conditions of the Snake River Valley, collaborated in compiling and interpreting the data pertaining to the surface-water losses and ground-water gains. To determine the direction in which the ground water was moving in different parts of the region, it was necessary to measure the depth to the water table in all available wells, and to connect them by a network of levels. W. G. Steward, an old-time member of the Survey, who later spent many years studying water problems in Idaho for the Bureau of Reclamation, was placed in charge of the collection of the available records of about 4,000 wells. Eleven test wells were drilled in Big and Little Lost River Valleys in connection with this investigation. Considerable time was also spent on a study of the hot and cold springs in the region.[714] The field

714/ Letter from Lynn Crandall to author.

work was completed in 1930, and the report a year later. It was published as Water-Supply Paper 774, with the well records in Water-Supply Paper 775.

In 1931 cooperation with the Idaho Department of Reclamation was arranged for the purpose of studying the ground-water resources of Malad and Curlew Valleys in Oneida County. This investigation was to determine the possibility of obtaining additional supplies from ground water for irrigation, and of storing surplus surface water in small reservoirs. This project, which was in charge of D. G. Thompson, was started in the summer of 1931 and was completed in the spring of 1932. In connection with the surface-water investigation, several small reservoir sites were surveyed in detail and a gaging station established near each site by the Boise district office.[715]

715/ Memo. to press, May 7, 1932.

Expenditures from cooperative funds were:

Year	State	Survey
1929	$6,700	$2,000
1930	5,712	544
1931	0	0
1932	2,702	2,707

Utah.- Ground-water investigations in Utah were stated in 1931 in cooperation with Salt Lake City, and in 1932 with the City of Ogden, and from 1935 to the end of the period the investigations became State-wide in scope through cooperation with the State engineer. Prior to the State-wide investigations, R. M. Leggette had charge of the Utah investigations, assisted by G. H. Taylor from 1931 to 1935 and L. K. Wenzel during the 1932 field season. Mr. Taylor was placed in charge of the State-wide investigations in 1935, and was assisted by H. E. Thomas.

Salt Lake City: During the late twenties Salt Lake City was seriously in need of an additional water supply, and the possibility of a ground-water supply from the artesian area nearby was considered. The mayor solicited Senator Reed Smoot's aid in interesting the Survey in an investigation, with the result that O. E. Meinzer went to Salt Lake City in February 1930 to confer with the city authorities. Soon afterward a proposal for an intensive investigation for the purpose of determining the safe yield from the artesian area and the best method of recovery and utilization, was made to the City. It was not until April 1931, more than a year later, that the City notified the Survey of its ability to finance its share of the cost, and a two-year agreement was signed July 18, 1931. Work was started immediately by R. M. Leggette and G. H. Taylor. One hundred sixty observation wells were selected at which monthly measurements were made, and beginning in February 1932, weekly measurements of 10 wells were made. In addition, recorders were placed on 5 wells, 3 having the water level below the ground surface and 2 on flowing wells to measure the pressure head. A preliminary report was submitted in the form of a press notice, dated July 23, 1932, [716] and based

716/ Ground-water supplies in the vicinity of Salt Lake City, Utah, by R. M. Leggette and G. H. Taylor.

upon this report some 14 successful wells delivering up to 10 second-feet, with a total of 46 second-feet, each were drilled during the summer of 1934; these wells prevented a serious shortage of municipal water supply when all other city sources essentially failed for several weeks during that summer. The field investigation was completed in June 1935, and thereafter, the periodic well measurements were continued by the City. During the investigation, fluctuations in the ground-water level caused by an earthquake were recorded by two water-stage recorders on observation wells. This was one of the first occurrences when such fluctuations were actually recorded; [717] numerous similar recordings were observed sub-

717/ Water-Resources Bulletin, Apr. 10, 1933.

sequently. Report not yet completed.

City of Ogden: The City of Ogden obtains its water supply from artesian wells in the Ogden Valley, and to determine the recharge of the artesian reservoir and its relation to the surface streams, cooperation with the Survey was effected June 15, 1932. Field work was carried on during the summer and fall by R. M. Leggette and L. K. Wenzel, during the summer and fall of 1933 by L. M. Leggette, and during 1933 and 1934 by G. H. Taylor. As no wells existed in which the necessary records of water-level changes could be measured, it was necessary to drill six observation wells, which were equipped with water-stage recorders. Seepage measurements along the South Fork of Ogden River were made to determine the loss from the stream bed to the ground-water reservoir. At the close of the field work the observation-well records were continued by the City engineer's office. The results of the Ogden Valley investigations were published as Water-Supply Paper 796-D.

State-wide program: The dry years culminating in the drought of 1934, by reducing the ground-water levels, emphasized the importance of ground water to the State of Utah, and the disputes between owners of nearby wells increased the demand for State-wide regulation of ground water. The 1935 Legislature enacted a ground-water law administered by the State engineer, and made an appropriation contingent on equal cooperation with a Federal or State agency, to start an investigation of the ground waters of the State. This investigation was needed for the administration of the ground-water law and to form the basis for the conservation of existing supplies and the development of new ones. Cooperation with the Survey became effective July 1, 1935. The program was to be a continuing one covering all ground-water areas in the state. It had three main objectives: (1) Collection of data concerning the position and fluctuations of ground-water levels in each area; (2) detailed and intensive investigations of areas in which ground-water conditions have become critical; and (3) similar detailed investigations to determine the possibilities of development in areas where little or no ground water was being used.[718]

718/ Twentieth Bien. Rept. State Engr., 1935-6, p.91.

As the first objective, the fluctuation of the water table was the basis for all the ensuing investigations, on which the remaining objectives would be based, that phase was taken up first, and during the first year 230 observation wells, 18 equipped with recorders, were selected in some 25 ground-water areas. This work was steadily expanded until in 1939 there were 935 observation wells, of which 830 were measured periodically and the remainder once or twice a year. The number of wells equipped with recorders was increased to 30.[719] Investigations in areas where the

719/ Water-Supply Paper 886, p. 762.

ground-water conditions had become critical, the second objective in the State-wide program, were started in the Cedar City Valley, Parowan Valley, and Escalante Valley. These investigations, started in 1938, were continued into the next period where they are described.

Referring to the results obtained during the first three years, the State engineer wrote: 720/

720/ Twenty-first Bien. Rept. 1937-1938, p.

> The recording of fluctuations of ground-water levels has resulted in the accumulation of data which will be invaluable to the State authorities in their regulation and conservation of the ground-water resources.
>
> Records already secured have indicated those areas most in danger of overdraft, and comprehensive studies must be made to determine the amount of water that can be withdrawn annually without endangering the water supply of the entire area. Erroneous well-drilling practices have been recognized because of these studies, and methods for remedying these conditions have been suggested. Damage resulting from improper well-development methods in certain areas have been corrected.

In the next biennial report he stated: 721/

721/ Twenty-second Bien. Rept. 1939-40, p. 44.

> Investigations on the present basis should be continued whereby detailed geologic and hydrologic work in one or more critical underground-water areas can be accomplished, and the yearly inventory of the underground-water levels continued.

Annual expenditures from available funds were as follows:

Year	State	Survey	Year	State	Survey
1932	$5,132	$7,527	1936	$5,339	$4,442
1933	7,797	4,595	1937	4,985	5,028
1934	3,876	2,223	1938	5,356	5,124
1935	2,945	955	1939	8,160	9,717

Note: Expenditures 1932-1935 were from funds furnished by Salt Lake City and Ogden.

Nevada.- In 1938 the State engineer of Nevada requested the Survey to make a brief investigation of the underground leakage from artesian wells in the vicinity of Las Vegas. Some of the residents thought that the gradual decrease in artesian head was due to large leaks in the wells. Penn Livingston was detailed to the investigation and spent August 11 to September 13, 1938, in the field. Forty-two wells, selected as representative of the much larger number in the area, were explored with the deep-well current meter. The discharge from flowing wells was also measured, and their artesian pressures determined. The results were published as Water-Supply Paper 849-D.

The expenditures were: State, $500; Survey, $481. Much of the State fund was furnished by the City of Las Vegas and Clark County.

Washington.- The first investigation during the period was that of the interstate project in the Walla Walla Basin in 1933-34. The Washington Department of Conservation and Development was the cooperating agency in Washington. See under Oregon.

The City of Tacoma was in need of an additional water supply. Although the greater part of its supply was obtained from the Green River, a considerable quantity at times was drawn from wells. The city was confronted with the problem either of spending a large sum to obtain an additional surface-water supply, or of making greater use of ground water which would be less expensive. That raised the question of the safe yield of the latter source as well as its chemical quality. To finance an investigation, the Tacoma Department of Public Utilities entered into an agreement with the Survey. The investigation was started in August 1937 by A. M. Piper and G. A. La Rocque, Jr. The City had kept records of the amount of water pumped since 1907 and also of the water levels in the wells. In addition to assembling these data, additional records were obtained including pumping tests on two wells, the geology mapped in the region of Tacoma covering an area of some 400 square miles to determine fundamental ground-water conditions, and the available supply in part of the area estimated. Two typewritten progress reports were released in 1939, one covering the compilations of data in the immediate vicinity of Tacoma,[722] and the other a report on an adjacent area the ground-water

722/ Ground water in the Tacoma area, Wash.: Prog. rept. No. 1.

conditions of which determine the practicability of sustained large withdrawals from wells and springs near the city.[723] The investigation was

723/ Ground water in the Tacoma area, Wash.: Prog. rept. No. 2.

continued beyond the period.

Interest in ground-water supplies was increasing and it was realized that eventually legislative action controlling the use of such supplies would be required and that a knowledge of the use being made of ground-water supplies was essential and as a first step. Accordingly the State Department of Conservation and Development arranged for a continuing cooperation with the Survey in a State-wide ground-water investigation, which was begun July 1, 1937, under the direction of A. M. Piper. A canvass of public water supplies from wells and springs was first made by correspondence and was later amplified by a general reconnaissance of ground-water basins.[724] During that investigation a modest beginning was made in or-

724/ Letter from A. M. Piper to author.

ganizing a state-wide observation-well program which comprised 22 wells at the end of the period.

An investigation of the upper Spokane Valley which extends from Pend Oreille and Coer d' Alene lakes in Idaho southwestward across Rathdrum Prairie and westward along the Spokane River Valley to a point about 10 miles west of Spokane, was undertaken in cooperation with the State. The underflow in the Spokane Valley is very large, and during the summer, it augments the flow of the Spokane River by as much as 1,000 second-feet,

thus greatly increasing the amount of firm hydro power. The ground-water is also extensively used by the city of Spokane and outlying communities, and also by irrigation interests. The source of this underflow and its safe yield was therefore of concern not only to the City and the Washington Power Co., but also to the irrigation farmers. As a basis for the investigation, base data which had been collected by the City, the Great Northern Railroad, and the Washington Power Co. since 1907 were turned over to the Survey for compilation and interpretation. Records were obtained on about 20 observation wells, three of which were equipped with recorders. The investigation which was chiefly hydrologic was made by A. M. Piper and G. A. LaRocque, Jr., and was continued beyond the present period. A progress report through the year 1938 was released in October 1939 and the water-table fluctuations were published as Water-Supply Paper 889-B.

During the years of relief projects, the State had sponsored a project to compile the drillers' records of some 500 water-supply wells which was carried on intermittently until 1937 when it was discontinued. Later, as phrased by the Supervisor of Hydraulics,[725]

725/ Ninth Bien. Rept.: Dept. Cons. & Devel. Oct. 1, 1936 to Sept. 30, 1938, p. 66.

> To salvage the useful data from this project, the records of about 500 wells have been assembled and released by the Geological Survey.

The release consisted in depositing with the cooperating agencies typewritten copies of the records.

When State cooperation was started, the Supervisor of Hydraulics stated in his biennial report:[726]

726/ Op. cit. p. 65.

> Beginning in 1937, a very modest start had been made on an inventory of ground-water resources in the State in cooperation with the United States Geological Survey. An inventory of this sort is fundamental to planning for present use of the underground water where (1) no other source is available for public supplies or other uses, (2) the safe yield of the ground-water basins is influenced by the manner of utilizing the streams, and (3) the use of ground water has some particular advantage in relation to industrial uses, such as lower temperatures, uniformity in chemical composition, or absence of suspended matter.

Annual expenditures from cooperative funds were:

Year	State	Survey
1934	$ 300	$ 159
1938	4,996	4,756
1939	4,689	4,123

Oregon.- The Willamette Valley, lying between the Coast and Cascade Ranges in northwestern Oregon, has insufficient rainfall during the greater part of the growing season to mature certain crops. The Department of Soils of the Oregon Agricultural Experiment Station had demonstrated the possibility of greater and better crops of berries and other fruits, if irrigation water were available late in the summer. As much of the area was at a considerable distance from the Willamette River, and on much higher ground, the most feasible source of such supply was ground water.[727] The Department of Soils therefore proposed a cooperative inves-

727/ Letter from T. W. Robinson to author.

tigation. O. E. Meinzer and H. T. Stearns made a reconnaissance of the area in the summer of 1927, and completed arrangements for a survey of the ground-water supplies. A. M. Piper started the investigation in July 1928 and continued it through 1929, obtaining all available well records, studying the geology, and starting periodic readings on about 45 observation wells. Samples from 35 wells were analyzed by the Quality of Water Division. T. W. Robinson spent some 6 weeks on the investigation in 1929. In 1930, the field work and records were suspended, at the request of the State agency, as there was urgent need for an investigation in other areas in the State. The only additional field work performed in the area was from September 1935 to June 1937, when the Army engineers, as a part of their flood-control investigation of the Willamette River, maintained, under Piper's supervision, periodic readings on 125 observation wells, some being those observed previously. As cooperation had ceased in 1934, due to lack of State funds, and was not resumed until 1936, it was not until later that the study of the Willamette Valley was completed and the results published in Water-Supply Paper 890.

In the vicinity of The Dalles, several hundred acres of orchards were cultivated chiefly by dry-farming methods, but the precipitation was not sufficient for the best results. Hence the Department of Soils desired an investigation of the possibility of irrigating with ground water. A. M. Piper started field work in May 1930 and completed it the following September. The results were published as Water-Supply Paper 659-B.

It is evident that when cooperation was started in 1928 the Harney Basin was in the picture as in October 1928, during the course of the Willamette investigation, Piper made a reconnaissance in that area. Harney Basin is a closed basin in the south-central part of Oregon, the lowest section being occupied by Harney, Malheur, and Mud Lakes. Field work under Piper's supervision was started in August 1930 and completed in September 1932. T. W. Robinson studied the hydrologic features, and C. F. Park, Jr., the geology. In this area, particular attention was paid to the Silvies subarea, in which the recharge of the valley fill was determined by the water table, seepage, absorptive, and discharge methods. More than 100 observation wells in the Harney Basin were read periodically. Some of these wells were arranged in pairs, one in each reaching the shallow, unconfined ground water and the other, the confined water in the deep beds of the valley fill. Readings from these pairs of wells showed the difference between the shape of the water table and the piezometric surface from the confined water. To determine the chemical character of the ground water, samples were taken from 100 wells, 7 perennial springs, and surface streams. These were analyzed by the Quality of Water Division. The inves-

tigation was completed in September 1932, and the results were published as Water-Supply Paper 841.

In the spring of 1933, an investigation of the Walla Walla Basin was started. The Walla Walla River (known to the Indians as the Tum-A-Lum) is an interstate stream, of whose flow a considerable part seeps into the ground on the alluvial plain at the base of the foothills. Some of this flow reappears as springs below Milton-Freewater, Oregon and across the State line in Washington, which are utilized for irrigation. Not only are gravity diversions from the river made in Oregon, but also a very considerable amount of ground water has been pumped in recent years. Believing that the Washington irrigators were not receiving their fair share of the water from the Walla Walla Basin, both surface and ground, the State of Washington brought suit against the State of Oregon to determine the rights of each State. Both States agreed that an investigation of the ground water should be made by a disinterested party, and the Survey was requested to make that investigation. The Washington Department of Conservation and Development and the Oregon Water Resources Department contributed to the cost. As the citizens of Umatilla County in Oregon were vitally interested in the proceedings the Umatilla County Court also contributed. Because both of the need for quick results and the small amount of funds available, the investigation was limited to two objectives: (1) the relation between the Walla Walla River and the body of ground water which supplies the irrigation wells and certain perennial springs on the valley plain, and (2) to ascertain the general ground-water conditions of the area so far as they might influence that relation.

Mr. Piper made a reconnaissance of the area in August 1932 and selected 13 key observation wells. Later, 23 additional wells were selected by cooperating agencies and a few observations made on the 36 wells. The investigation was started on May 1, 1933, with T. W. Robinson in charge of the hydrologic phase, and later H. E. Thomas was assigned to the geologic phase. The field work was completed in August 1933, and the report covering it was used as evidence in the hearings held by a Master in Chancery appointed by the U. S. Supreme Court. Routine observations on wells and springs were continued by the cooperating agencies. Although the report was not published, it was released in typewritten form.728/

728/ Ground water in the Walla Walla Basin, Oregon-Washington, Oct. 30, 1933.

For a year following the close of the Walla Walla investigation, cooperative funds were not available. In the summer of 1935, cooperation was arranged with the State Water Resources Department for the purpose of making a small-scale beginning on an observation-well program in the Willamette Valley and in the semi-arid region east of the Cascade Mountains. Connected with that was a WPA project which constructed nine observation wells in Baker and Grande Ronde Valleys. Except for some 20 wells in the Walla Walla Basin, the observation-well program was suspended early in 1937 for lack of funds, but it was started again late in 1938, when cooperation was resumed both with the Water Resources Department and the Agricultural Experiment station. At that time 65 observation wells were being measured periodically.

Expenditures from available funds were:

Year	State	Survey	Year	State	Survey
1929	$2,500	$2,500	1935	$ 0	$ 0
1930	2,667	2,959	1936	938	913
1931	3,807	3,700	1937	353	403
1932	5,000	4,664	1938	1,241	1,018
1933	2,468	3,231	1939	1,809	1,667
1934	1,474	808			

California.- The investigation of the ground-water recharge from Mokelumne River, started in 1926 [729] in cooperation with the East Bay Municipal Utilities District, was continued until 1935. As the investigation proceeded it was felt that the results being obtained were not sufficient to determine accurately the effect upon the ground-water reservoir of diversions from Mokelumne River. Therefore, a conference with the cooperating officials was held in July 1931 at which time it was decided to obtain additional geologic information, and make more frequent discharge measurements at the river gaging stations. For the additional geologic work, H. S. Gale was reinstated in the Survey, and H. E. Thomas transferred from the Geologic Branch. By 1933 the ground-water investigations except those pertaining to the rainfall penetration, were completed and the latter were continued until 1935, at which time the field work was completed and the Lodi headquarters closed. The stream gaging under H. D. McGlashan was continued. H. T. Stearns, who had been in charge of the work from its inception, was assigned to other work in 1930, and G. H. Taylor was placed in charge of the investigation, with T. W. Robinson as assistant. With the enlarged scope in 1931, A. M. Piper was given charge of the project and continued until its close. At various times C. A. McClelland, B. R. Colby, G. M. Sherwood, and L. K. Wenzel were assigned to the project. A final report was published as Water-Supply Paper 780.

729/ p. 170 (1919-1928).

The following expenditures were made from the available funds:

Year	State	Survey
1929	$7,500	$ 500
1930	9,976	600
1931	11,002	5,426
1932	15,082	7,317
1933	13,753	7,258
1934	6,836	2,801
1935	5,001	2,399
1936	1,000	829

Hawaii.- Until the present period, in addition to the investigations of H. S. Palmer for the City of Honolulu, the principal cooperative investigation in Hawaii had been that of the Kau District.[739] The Terri-

730/ p. 175 - (1919-1928).

torial Division of Hydrography, which was practically the Survey's Honolulu district in surface-water investigations, had been making periodic measurements of selected wells in artesian areas on Oahu, but had not attempted to interpret the readings in terms of safe yield of ground-water supply. In 1924, when M. H. Carson became Territorial chief hydrographer and also the Survey's district engineer, he saw the need for such action and suggested it to the Washington office. In 1927, C. H. Merriam, of C. Brewer and Co., sugar factors - the sugar interests being among the largest users of ground water - made the same suggestion to Governor W. R. Farrington. The latter, in 1928, requested that Oahu be surveyed in the same manner as the Kau district, and that all available data on artesian wells be assembled and interpreted. And to make his request effective, he obtained from the next session of the Territorial Legislature an appropriation for ground-water investigations. H. T. Stearns, who had completed the Kau district report some years previously, was selected to make the Hawaiian investigations. However, as he was then engaged with the Idaho investigations, and as it would be a year before he would become available, K. N. Vaksvik, artesian engineer of the Territorial Division of Hydrography, on July 1, 1929, began the collection of Oahu well records, and the preparation of a bibliography for the report.731/ Having completed his Idaho assignment,

731/ Letter from H. T. Stearns to author.

Mr. Stearns arrived in Honolulu in July 1930 to assume charge of the Oahu investigations, with special reference to the geologic features. In the fall of that year, Mr. Meinzer spent three weeks with Mr. Stearns and while in the Islands, had the experience of circling the Island of Molokai by motor boat. That business was combined with pleasure is shown by Mr. Meinzer's statement that he caught the largest fish which weighed 56 pounds.

The original plan did not contemplate much new field work but Mr. Stearns soon found that many new geologic conditions so affected the occurrence of ground water that it was necessary to spend a whole year, instead of three months, in field work. In describing the purpose of the work, he writes:732/

732/ Geology and ground-water resources of the Island of Oahu, Hawaii: Div. of Hydrography, Bull. 1, p. 9, 1935.

> The purpose *** is to make available and interpret the great mass of data collected in the past relating to the artesian wells of Oahu, to point out methods of developing basal ground water, to determine methods of recharging the artesian basins and for conserving artesian water, and to describe the geologic conditions that determine the occurrence of high-level ground water.

As ground-water recharge was an important phase of the investigation, a study of the disposal of the rainfall involved a study of transpiration and evaporation, and hence two stations equipped with rain gages and transpiration and evaporation pans were established. Six recorders were also installed on observation wells. Records from existing gaging stations were used to determine losses from stream beds to ground water.

All available well data were compiled. These included not only results of periodic measurements of some 20 observation wells, but also available records of all wells drilled on the island, and many pumpage records maintained by the various plantations, in some instances since the early days of the century. Salinity records were also included, as in times of excessive pumping contamination from sea water may occur. The Oahu investigation was for the most part completed in 1933, and the results were published by the Division of Hydrography.733/

733/ Bulletins 1 - 5.

In 1933, Mr. Stearns, with H. A. Powers, started a similar investigation on Maui, with headquarters at Spreckelsville. A thorough study was made of the geology and ground-water conditions of this island. Records of wells and pumpage maintained by several plantations were compiled. Stearns became interested in the possible use of geophysics in the study of ground-water problems, and in March 1936, J. H. Swartz, then of the Geophysical Section of the Bureau of Mines, made preliminary studies consisting of magnetometer and electric resistivity measurements. The Maui investigation was completed after the close of this period, and the results were given in a comprehensive report by Stearns and Macdonald, which was published by the Division of Hydrography as Bulletin 7, in 1942.

An investigation of the Island of Molokai was started in 1935. While the Molokai investigation was being made, a brief investigation of Lanai was made during the summer of 1936. During that investigation, Mr. Swartz transferred his geophysical equipment from Maui to Lanai where he made measurements at 23 resistivity stations extending in a transverse across the island. In March 1939 an investigation on Kahoolawe was started but was not completed until after the close of the period. The results of the Lanai and Kahoolawe investigations were published by the Division of Hydrography.734/

734/ Bulletin 6.

During 1932, the Island of Maui experienced a water shortage, which affected particularly the sugar plantations and many farms and ranches, and a study of additional ground-water supplies was urgently needed. As a result, Maui was selected for the next investigation which was started by Mr. Stearns that year with headquarters at Spreckelsville, and was carried on intermittently into the next period, as other duties permitted. Mr. Stearns lived on the island from 1932 to 1938. H. A. Powers studied the so-called ditch country of East Maui from October 1932 to December 1934. A thorough study of the geology and ground-water conditions of the island was made and to help in the development of additional supplies, the information obtained was made available, and recommendations made to the water users. Of the developments made which met most of the island's needs, some were the results of those recommendations. Mr. Stearns became interested in geophysical methods for studying ground-water problems then being developed and J. H. Sinitz, then of the Geophysical Section of the Bureau of Mines, made preliminary studies consisting of magnetometer and electrical resistivity measurements in 1936 and a final survey between March 1938 and November 1939, when he was assisted by G. R. MacCarthy and A. C. Byers. Mr. MacCarthy made a resistively survey of the Isthmus in 1939.

Records of the principal springs with their average discharge for several years, were obtained from the East Maui Irrigation Co., together with the average discharge of the water-development tunnels. Summaries of spring-fed or perennial streams were compiled, chiefly from Survey records.

The Bureau of Reclamation was planning an investigation on the island of Molokai and in anticipation of that study, Mr. Stearns in 1935 started an investigation in the Windward valleys to obtain the basic geologic and hydrologic data for the Bureau's investigations. The Windward valleys are accessible with much difficulty and in the establishment of the camps in that area, CCC aid was enlisted. The field work lasted from June 1 to September 13, 1935, during which time D. J. Cederstrom studied the leeward valleys of East Molokai to collect rock specimens for microscopic study. In 1938 and 1939, Mr. Stearns investigated water supplies for Kaunakakai and adjacent areas at the request of the County officials. He selected the site for a well shaft which was started in 1939 by the WPA but stopped later for lack of equipment. A test hole was then drilled by the County, which showed potable water. Another test hole was drilled for the Survey at the Hoolehua Airfield in 1938. During 1938, arrangements were made to obtain periodic readings on three observation wells. By 1939, the Geophysical Section had been transferred from the Bureau of Mines to the Geologic Branch of the Survey, and G. R. McCarthy made a resistivity survey of the isthmus area that year. The investigation of Molokai was in progress at the end of the period.

To meet the constantly increasing demand of Lanai City for water, a brief investigation of the Island of Lanai was made by Mr. Stearns from June 13 to August 4, 1936, and Mr. Swartz, assisted by J. Y. Nitta, did geophysical prospecting for water. Numerous pumping tests in the principal shaft showing drawdown and the chloride content of the water pumped were made by the Hawaiian Pineapple Co. As pumping tests indicated that the shaft would not yield more than 100,000 gallons per day without the salt content increasing seriously, it was recommended that a tunnel be driven from the sump located at the bottom of the shaft.

The last investigation made during the period was that of Kahoolawe, the smallest of the 8 islands, and an extinct volcano. It is semi-arid and well water is needed for stock, which is supplied entirely from storage of rain and flood waters, as all wells so far dug yielded water that was too brackish. During droughts, it was necessary to haul water by boat from Maui 7 miles distant. Mr. Stearns spent March 5 to 13, 1939 studying the geology and ground-water possibilities. Mr. MacCarthy made an electrical resistivity survey somewhat later and Mr. Macdonald made a petrographic survey.

The results of both the Lanai and Kahoolawe investigations were published by the Division of Hydrography.735/

735/ Geology and ground-water resources of Lanai and Kahoolawe, Hawaii: Bull. 6.

Toward the end of the period, electric resistivity investigations were made by J. H. Swartz, assisted by G. R. McCarthey and A. C. Byers, who were then in the Geologic Survey. Tests were made on Oahu and Moloki to determine the depths to salty ground water, and in a small area on Maui, an intensive investigation was made of the possibilities of determining the rock

structure in a volcanic terrain.

Records of water levels, artesian pressure, pumpage and chloride contents for the Territory, including the islands of Hawaii and Kauai, and were published in the annual reports of the Survey on water levels and artesian pressure.

In addition to supervising the investigations described, Mr. Stearns carried on special investigations relating to ground water, condemnation of land, location of rock bodies in quarries, sites for tunnels of all sorts, and diverse other investigations for the armed forces in Hawaii.

In May 1939, G. A. Macdonald was given a Survey appointment and assigned to Hawaii for ground-water work under the direction of Mr. Stearns. Mr. Macdonald was an experienced petrologist and was given this assignment especially to study the petrology of the rocks with reference to their geologic and hydrologic characteristics.

Annual expenditures from cooperative funds were:

Year	Territory	Survey
1931	$7,994	$3,707
1932	7,739	9,111
1933	5,833	6,059
1934	5,067	2,926
1935	4,021	4,746
1936	3,498	6,591
1937	6,011	5,626
1938	9,719	14,257
1939	25,091	18,905

The large increases during the last two years were for the purpose of making the intensive geophysical investigations and test borings.

Federal cooperative investigations

The Federal cooperative investigations, which were more than brief examinations and reports, are here described.

Public Works Administration.- On September 3, 1933, the Public Works Administration made an allocation of $100,000 (subsequently increased to $106,300) for work by the Ground Water Division, on five major projects. These projects covered areas in which there were ground-water problems for which no cooperative funds were available, and for which the Federal interest was sufficient to justify the use of Federal funds.736/ The men

736/ Letter from O. E. Meinzer to author.

assigned to these projects were chiefly PWA appointees and members of the Geologic Branch, which was short of funds because of the cut in appropriations.

High Plains: A reconnaissance of an area of some 70,000 square miles, extending from the Smoky Hill River in Kansas southward about 500 miles through parts of Kansas, Colorado, Oklahoma, Texas, and New Mexico, was

started in the late summer of 1933 by C. V. Theis assisted by H. P. Burleigh and H. A. Waite. Practically all water in the region, except along the Arkansas River, is pumped from wells, and a knowledge of its availability and quantity was of great importance. This reconnaissance was completed by the end of 1934. The results were not published but were later used in several quantitative investigations in different parts of the region.737/ A resume was published in a memorandum to the press

737/ Letter from C. V. Theis to author.

dated October 30, 1935.

High Plateau: The work in the High Plateau was done in several large areas in Utah, Colorado, New Mexico, and Arizona where water-supply problems existed and where not much ground-water investigation had been made. The first in point of time was a reconnaissance of an area in southeastern Utah and southwestern Colorado which was started in October 1933 by G. A. Waring and M. M. Knechtel. Its purpose was to determine the available supplies from wells and springs, and the prospects of developing additional supplies from deep-seated artesian basins. The reconnaissance was completed by the latter part of November. A report containing information on wells and springs and some chemical analyses was released for public inspection.

The work in New Mexico was an investigation of some 17,000 square miles in the northwestern part of the State. G. A. Waring and D. A. Andrews spent several months in the latter part of 1933 in a reconnaissance of the water supplies from wells and springs and of the prospect of developing artesian water supplies. The results of the investigation were not published but typewritten copies were opened to public inspection.

In Arizona, three widely scattered areas were investigated. The first was a large area, which was called the Holbrook area in the eastern part of the State, where cattle and sheep grazing are the chief industries. The investigation was started November 1, 1933, by M. A. Harrell, and E. B. Eckel. Information on nearly all springs and wells was collected, and samples from 118 wells and springs were analyzed by the Quality of Water Division. The field work was completed Mar. 1, 1934, and the results published as Water-Supply Paper 836-B.

An area in the valleys of the Gila River and San Simon Creek, in the southeastern part of Arizona, was investigated by M. M. Knechtel during the winter of 1933-34. The records were published as Water-Supply Paper 796-F.

D. A. Andrews spent January and February 1934, investigating the Avra-Altar Valley, in the southern part of the State, chiefly in the interest of water for domestic and stock use. The results were published as Water-Supply Paper 796-E.

The Survey was making an investigation of the ground-water resources of Long Island738/, N. Y., and to obtain additional information which was

738/ pp. 300-301.

needed at that time, H. R. Blank was employed from July 1934 to June 1935 to make geologic studies and examination of well cuttings.739/ In addition,

739/ Letter from M. L. Brashears, Jr. to author.

other personnel were employed during the fiscal year 1934.

Cooperative investigations in Michigan 740/ and North Carolina740/ during

740/ pp. 315-316; 307-308.

1932 and 1933 had shown the possibility of obtaining water supplies from shallow wells, and it was decided to investigate the feasibility of such water supplies in various sections of the Coastal Plain. This investigation consisted in putting down test wells by the jetting method and in making pumping tests of them. A small gasoline-driven jetting machine mounted on a 1½-ton truck was purchased. Wells from 2 to 4 inches in diameter could be put down to depths of more than 100 feet. Under A. G. Fiedler's supervision, M. A. Pentz commended operations early in 1934 and drilled many small wells in New Jersey, Virginia, and North Carolina. Referring to the Coastal Plain work, Meinzer writes:741/

741/ Letter to author.

> The reports prepared as a result of this work have not been published, but have proved valuable in our later work and especially in the war emergency when so many water supplies are being developed on the Coastal Plain for the Navy and other war purposes.

A group of warm springs in the western central part of Georgia are used by the Georgia Warm Springs Foundation, a philanthropic agency, in the treatment of infantile paralysis. At the request of the Foundation an investigation, more intensive in character than the other PWA projects, was made from October 1, 1933, to June 30, 1935. On account of the widespread interest in the work of the Foundation, several agencies, both Federal and State, cooperated in rendering assistance. D. F. Hewett, was placed in charge. The geology of the Warm Springs quadrangle was mapped by G. W. Crickmay and D. F. Hewett. The hydrologic study included observations of rainfall, water levels in wells, spring and stream discharge from an area of 32 square miles, and chemical character and temperature of the water. The equipment for measuring the rainfall and stream flow was installed by the Survey's Montgomery district. A summary report was published as Water-Supply Paper 819.

The cooperative funds for investigations in Florida had been spent on intensive studies in local area to meet pressing needs, and as a result it had not been possible to make a regional investigation of artesian conditions of the Florida penninsula, although it was recognized that such an investigation would be of great value in studying the local problems. In November of 1933, a start on the much-needed investigation was made by V. T. Stringfield, assisted by F. C. Westendick. Mr. Stringfield spen about 8 months and Mr. Westendick about a year, on the field work, during which time available information on hydrologic conditions was obtained, but the

principal objective was to determine at as many points as possible, the height above sea level to which the artesian water would rise in order to determine the area of recharge and discharge, and direction of the movement of the artesian water. Water-Supply Paper 773-C in which the results were published, contains a map of the Florida peninsula showing the piezometric surface of artesian water.

National Resources Committee.- The Rio Grande Joint Investigation, 7th 7th pp. 75-79.-

which was sponsored by the National Resources Committee and financed in part by that agency through an allocation of PWA funds, required a ground-water investigation during one field season in two critical areas, one in the San Luis Valley in Colorado, and the other in the Middle Rio Grande Valley in New Mexico. Several years previously the State engineers of Colorado and New Mexico had made separate investigations of the ground-water levels in the San Luis Valley, but neither State was disposed to accept the results of the other in considering a division of the waters of the Rio Grande, which involved among other factors the amount of ground water which could be recovered by means of a proposed sump drain from the "closed basin" in the San Luis Valley. The Middle Rio Grande Valley was practically covered by the Middle Rio Grande Conservancy District, in which drainage was a serious problem because of the high water table.

The two ground-water investigations were under the direction of C. V. Theis. Work in the San Luis Valley, which was in immediate charge of T. W. Robinson, with headquarters at Alamosa, was started in March 1936 and the field work was essentially completed in January 1937. As ground water in much of the area, particularly in the closed basin, was within a few feet of the surface, observation wells were bored by means of post-hole augers. About 150 observation wells were bored and an equal number of wells bored during the earlier investigations were also used, giving a total of 300 observation wells that were read periodically. Three of the wells were equipped with recorders. To determine the permeability of the water-bearing material, a pumping test on one well near Monte Vista was made, and frequent readings were taken on four observation wells sunk nearby. The Theis method was used to determine the permeability of the water-bearing material. Underlying the shallow ground water in the valley floor and separated from it by a confining bed is a large body of artesian water which has been developed by more than 6,000 flowing wells in an area of 1,430 square miles. An inventory of these wells, including the measurement of the discharge of each, was an important part of the investigation. As the discharges were small they were measured volumetrically means of a bucket and stop watch. Tests by means of the Theis method for determining the transmissibility of artesian aquifers were made in flowing wells at five representative points. In these tests the static head was measured after the well had been closed for several days. The well was then opened and allowed to flow for several days during which time the discharge was measured at intervals to determine the uniformity of flow. The well was again closed and the static head measured periodically by means of the soil plug and mercury manometer, until it approached its original static head.

The investigation in the Middle Rio Grande Valley was directly in charge of C. V. Theis, and was started in April 1936. Although scheduled to be completed within a year, the State engineer of New Mexico desired the continuance of the investigation and furnished cooperative funds which carried the work through December 1937. To continue it through May 1938, the Middle Rio Grande Conservancy District contributed cooperative funds. The investigation consisted largely in establishing 900 observation wells, most of which were bored with post-hole augers, as the ground water was generally within 8 feet of the surface. The number of wells was gradually increased to 1,100, all within that portion of the valley between the Angostura diversion dam, near Algadones, and the south line of the Bosque del Apache Grant, 17 miles south of Socorro. The stages of many drains, canals, and laterals were also measured.

The definite time limit on the Rio Grande Joint Investigation set by the National Resources Committee was too short to allow an orderly investigation or to obtain records of water levels, etc., during a sufficiently long period. It may be stated, however, that the later investigations in the Middle Rio Grande Valley confirmed in the main the conclusions reached during the first year[743] The results were published by the National Re-

743/ Twelfth and Thirteenth Bien. Repts. State Engr., N. Mex., p. 263, 1934-38.

sources Committee:[744]

744/ Regional Planning, Part VI, Upper Rio Grande, Feb. 1938.

Expenditures from National Resources Committee funds were:

1936 $16,000 1937 $14,700

Referring to its report on deficiencies in existing hydrologic data[745]

745/ p. 79.

the National Resources Committee recommended that information concerning the amount, position, and fluctuation of ground-water levels should be expanded by the installation of 4,000 wells at base stations, and 6,000 cooperative secondary wells, and by carrying on corollary geologic and hydrologic investigations. The estimated first year's cost for this work was $406,250 from Federal funds and $131,250 from cooperative funds. The lack of funds prevented this program from being put into effect during the present period.

Soil Conservation Projects.- Soon after cooperation with the Soil Conservation Service was started on the eight projects,[746] arrangements

746/ p. 81.

were made to obtain records of water levels from observation wells on the projects, and R. M. Leggette set up a program of 213 observation wells, 24 of which were equipped with recorders. Weekly observations were made

on the non-recording wells. The observation wells were divided among the projects, as follow:

Project	Number of wells	Recorders	Range in depth (feet)	Started
Tarkio, Ia-Mo.	17	1	5-45	April 1934
Deep River, N. C.	28	0	11-54	Summer 1934
Stillwater, Okla	17	1	21-47	May 1934
Limestone Creek, Kans.	52	10	19-88	March 1934
Elm Creek, Tex.	28	6	6-20	April 1934
Tiger River, S. C.	28	4	15-56	July 1934
Coon Creek, Wisc.	15	0	13-182	June 1934
Palouse River, Wash.	28	2	12-19	Nov. 1934
Total	213	24		

The measurement were made by the Survey or by Soil Conservation employees on the projects. The results were interpreted by the Ground Water Division, and were published with brief interpretive texts, in the annual water-level reports. The program, with some change in the number of wells, was continued during the remainder of the period.

Expenditures from Soil Conservation Service funds were:

1936	$ 842	1938	$ 838
1937	2,305	1939	1,200'

Army Engineers.- Just as the Bureau of Reclamation in the previous period had called upon the Survey for advice the geology of the proposed dam sites, so did the Army Engineers during the present period. In connection with the "308" investigations, G. M. Hall investigated dam sites in the Tennessee River Basin during July 1928. As he was employed directly by the Army Engineers, this was not strictly a cooperative investigation.

In connection with the "308" investigation, R. M. Leggette, in October 1930, examined dam sites in the Upper Missouri River Valley, and in November 1930, S. W. Lohman examined sites in the Rappahannock River Basin, Virginia.

In the spring of 1935, following the drought of 1934, the Army Engineers began an investigation to determine the extent of the water supply shortage in the valleys of the James and Sheyenne Rivers in North and South Dakota, and in that connection A. N. Sayre made a study of ground water conditions. He visited 16 cities and towns and obtained information regarding water supplies with special reference to depletion of ground-water.[747]

747/ Am. Geoph. Union: Trans. 1936, pt. II, p. 360.

Following the disastrous floods of July 1935 in central New York, the

Army Engineers made extensive studies of flood control measures and R. M. Leggette was called upon to study dam sites, and in August 1936, C. V. Theis studied problems connected with the Conchas Dam, N. Mex.

During the flood-control investigations, A. M. Piper devoted considerable time between the years 1936 and 1939 in studying proposed dam sites in Oregon, Colorado, Arizona, and New Mexico.

Expenditures from Army Engineers funds were:

1931	$1,225	1937	$2,171
1934	46	1938	53
1935	1,560	1939	1,060
1936	2,236		

Navy Department.-- During the fiscal years 1930 and 1931, H. T. Stearns made a study of an available ground-water supply for a proposed Naval Administration Depot at Lauluale, Oahu. In 1932, G. T. Pardee made an investigation for the development of a ground-water supply at the Puget Sound Navy Yard, and in 1934, A. M. Piper made a reconnaissance for a water supply for the Sunnyvale Air Station. Stearns made an investigation of the ground-water resources of the island of Guam in the fiscal years 1937 and 1938, and prepared a report, "Geology and water resources of the Island of Guam, Marranas Islands, " which, during the ensuing war years was given considerable study by the Navy. In 1939, an intensive investigation at the Naval Powder Factory at Indian Head, Md., including a series of carefully controlled pumping tests was made by A. G. Fiedler, assisted by D. J. Cederstrom and C. E. Jacob. It was in connection with this investigation that Theis developed the graphic method.

Expenditures from Navy Department funds were:

1930	$436	1932	$263	1935	$198	1938	$864
1931	937	1934	389	1937	655	1939	3,078

The details of the 1935 investigations are not available at this time.

Bureau of Reclamation.- The investigation of dam and reservoir sites, which had been made for the Bureau of Reclamation since 1923, was continued in 1929. Owing to the presence of gypsum underlying a portion of the Avalon Reservoir, on the Pecos River at Carlsbad, N. M., there had been some uncertainty regarding the feasibility of enlarging the reservoir, and when funds for that purpose were granted by Congress, the following restriction was added:748/

748/ 45 Stat. L pt. II, p. 1343.

> Provided that no part of this appropriation *** shall be available until the Director of the U. S. Geological Survey shall have reported favorably on the foundation of the Avalon dam and on the depth to which water may be stored in the proposed enlarged project.

The Director convened a board of geologists and engineers in Washington in March 1929. After reviewing the conflicting reports made previously it

was decided that Kirk Bryan's report could not be disregarded and that additional drilling at critical points was needed. Kirk Bryan was selected to supervise the drilling which was performed by the Bureau of Reclamation, and he was also to make other investigations. Active work was started July 7, 1929. This work was completed by the first of September and Bryan's report was reviewed by a board of geologist appointed by the Director and consisting of O. E. Meinzer, H. D. Miser, and A. C. Spencer. Expenditures from Bureau of Reclamation funds were $1,573.

Subsistence Homesteads and Resettlement Administration.- The Subsistence Homestead organization was created during the depression to provide homes with small tracts of land on which families could subsist while regular employment could not be obtained. This agency was later merged with the Resettlement Administration. The subsistence homesteads and also the resettling of families that were removed from the so-called submarginal areas during the drought years encountered many problems of ground-water supplies, and the Survey was called upon for assistance. The Ground Water Division made investigations for several subsistence-homestead projects on which workers from nearby industrial centers would be able to obtain at least a part of their subsistence from the soil.

A brief investigation and report were made by O. E. Meinzer for the first Subsistence Homestead project, which was the highly advertized project at Reedsville, W. Va., in which Mrs. Roosevelt took great personal interest.

In May 1934, J. W. Mangan, the Survey's district engineer, was authorized to investigate the availability of water supplies of the Coalport, McGarvey Ridge and Ramsey tracts in southern Clearfield County, Pa., being considered by the Division of Subsistence Homesteads. He reported that for the first two projects, water should be obtained from wells rather than nearby streams. S. W. Lohman was accordingly detailed to the investigation, and spent several days visitings the tracts and obtaining data including samples on wells and springs. A report covering the ground-water possibilities was made to the Division of Subsistence Homesteads on July 21, 1934.

G. M. Hall made an investigation of the ground water conditions at the Birmingham, Alabama homesteads and made a report September 14, 1934.

In December 1935 and January 1936 R. C. Cady made a ground water investigation for a project near Dayton, Ohio. In this project the Resettlement Administration requested the Survey to investigate the ground-water supplies available from both deep and shallow wells for homesteads ranging in number from 120 to 140. Upon the completion of the investigation a report was transmitted to the Resettlement Administration.[749]

749/ Cady, R. C., Subsistence homestead project near Dayton, Ohio., Jan. 1936, (unpublished).

Beginning in May 1936 and continuing until March 1937, Cady spent the greater part of his time investigating ground-water supplies for resettlement projects. The first investigation was that for a number of possible resettlement sites west of San Antonio, Tex. This was made in the early spring of 1936. The next investigation was chiefly an office study by Cade made in response to a request for

> A brief generalized statement regarding ground-water resources of the drought areas in 10 western States with special reference to the development of irrigation supplies from wells.

The study was based chiefly on Meinzer's definition of ground-water provinces,[750] supplemented by State and Survey reports. It was completed in July 1936.[751]

750/ Water-Supply Paper 489.

751/ Ground water in the drought-stricken areas in North and South Dakota, Mont., Wyo., Nebr., Kans., Colo., Okla., N. Mex., and Tex., July 31, 1936, (unpublished).

The third investigation dealt with ground-water supplies in "selected areas for new or closer settlement on the Texas Coastal Plain," and was based largely on published Survey reports and well records compiled by the Survey and the Texas Board of Water Engineers, supplemented by some general information obtained in the field by Cady.[752] The final investigation was in Wise County, Texas, where an area planning project had been set up. In that area a spectacular widespread gulley type of erosion had reached the stage where serious agricultural, economic, and social consequences had become evident. A study of various phases of those consequences required a general knowledge of the occurrence of ground-water supplies, and the Survey was called upon to supply that information. Cady spent the greater part of February 1937 in the field collecting well data chiefly, and completed his report May 27, 1937.[753]

752/ Cady, R. C., Summary of ground-water supplies in selected areas for new or closer settlement on the Texas Coastal Plain, Feb. 24, 1937 (unpublished).

753/ Cady, R. C., Ground water in Wise County, Tex., May 27, 1937 (unpublished).

Expenditures from available funds were:

1934	$355	1936	$1,033	1937	$3,983

Indian Service.- During the period a number of ground-water investigations for the Indian Service were made, the principal ones being examination of Zuni dam in July 1928, by Kirk Bryan; Tesuque Pueblo, N. Mex. in August 1928, by Kirk Bryan; Haskell Indian Institute, in November 1928, by W. N. White; Rosebud Indian Reservation, S. Dak., in August 1929, by A. G. Fiedler; Fort Belknap Indian Agency, near Harlem, Mont., during April

1934, by A. N. Sayre; San Carlos irrigation project, in New Mexico, during November 1934, by W. N. White; upper Gila River Valley, N. Mex., in July 1938, by C. V. Theis; and Jicarilla Indian Reservation, N. Mex., in November 1938, by G. C. Taylor, Jr.

Expenditures from Indian Service funds were:

1934	$412	1938	$ 54
1935	934	1939	1,060

Bureau of Prisons.- About a dozen investigations, mostly requiring only a few days each, and concerned with ground-water supplies for as many Federal prisons, were made during the period by various members of the division.

Annual expenditures from Bureau of Prison funds were:

1930	$ 20	1933	$ 93	1937	$340
1931	749	1934	100	1938	44
1932	291	1936	173	1939	108

Division of Territorial and Island Possessions.- The Island of St. Croix, one of the Virgin group purchased from Denmark in 1917, was in need of additional water supplies, especially to provide for drought periods. In the fall of 1938, the Division of Territorial and Island Possessions required technical advice in selecting sites for test drilling to be undertaken on lands of the Virgin Islands Co., a quasi-public corporation, particularly in connection with the Bethleham sugar mill. D. J. Cederstrom was given the assignment and left Washington November 30, 1938. He spent about four months in the field and returned to Washington April 28, 1939. Making use of previous geologic investigations, Mr. Cederstrom selected sites for two test wells, one of which was drilled by the contractor to a depth of 1,508 feet and the other to a depth of 470 feet. One or two other sites, which were drilled later, were selected. As time permitted, a study of the geology and ground-water resources were made.754/ The results were published as

754/ Cederstrom, D. J., Geology and ground-water resources of St. Croix, Virgin Islands U.S.A.; June 1941 (unpublished).

Water Supply Paper 1067. The cost of that investigation was $1,689.

Federal Power Commission.- The Rocky Mountain Power Company proposed to construct a dam 2 miles below the outlet of Flathead Lake, Montana, which would raise the lake level from 4 to 6 feet, and this was protested on the ground that it would flood or water log lands bordering the lake. On May 29, 1928, the Federal Power Commission, which was considering the power company's application for license, authorized the Survey to make an investigation. As both surface and ground water were involved, most of the actual field work was performed by the Helena district, with the ground-water phase under O. E. Meinzer's supervision. The project was started May 31, 1928, when a conference was held at Polson, at which time it was decided to establish observation wells to determine the effect of lake and river elevations upon the ground-water levels in the alluvial area at the head of Flathead Lake. The work was started within a few days by A. H. Tuttle assisted by G. C. Sanders, and later by C. S. Heidl.

A total of 47 observation wells were established, 37 being sunk for that purpose. The tops of the casings were connected with a bench mark of the Rocky Mountain Power Company to establish a common datum to which all water levels could be referred. Readings to water surface were made by means of a sounding weight attached to a steel tape. Two wells were equipped with water-stage recorders. Of the 47 observation wells, 5 were open wells used for domestic water supply on ranches, and these were read to determine any possible depletion of the ground water due to domestic use. The readings on these wells were later discontinued as the ranchers, being unfriendly to the power company, did not wish to have their wells read for its benefit.[755]

755/ Letter from A. H. Tuttle to author.

Observations were made at monthly intervals and oftener during times of rapidly changing surface-water levels. These observations were continued during the period, and the records were published in the annual water-level reports. In 1937, the Federal Power Commission requested a report based on the accumulated records of water levels and R. C. Cady spent a few days in the field inspecting the area and later in studying the records, after which he prepared a report that was published as Water-Supply Paper 849-B.

The chief expense involved was sinking the wells and making the periodic measurements. To meet the cost, the Rocky Mountain Power Company, through the Federal Power Commission, paid $1,334.[756] Addi-

756/ Letter from O. E. Meinzer to author.

tional expenditures connected with the investigation are given on p. 719.

Personnel

The complete civil service technical personnel during the period was as follows:

O. E. Meinzer	July 1, 1928 to June 30, 1939
H. C. Barksdale	July 1, 1928 to June 30, 1939
Kirk Bryan	July 1, 1928 to June 30, 1939
A. G. Fiedler	July 1, 1928 to June 30, 1939
G. M. Hall	July 1, 1928 to June 30, 1939
R. M. Leggette	July 1, 1928 to June 30, 1939
S. S. Nye	July 1, 1928 to Feb. 17, 1936
A. M. Piper	July 1, 1928 to June 30, 1939
T. W. Robinson	July 1, 1928 to June 30, 1939
H. T. Stearns	July 1, 1928 to June 30, 1939
G. H. Taylor	July 1, 1928 to June 30, 1939
F. G. Wells	(July 1, 1928 to July 1, 1930 (July 12, 1932 to July 7, 1934
W. N. White	July 1, 1928 to June 30, 1939
W. D. Johnston, Jr.	July 5, 1928 to June 30, 1930
J. L. Saunders	Aug. 16, 1928 to Apr. 17, 1929
A. N. Sayre	Sept. 12, 1929 to June 30, 1939
S. F. Turner	Sept. 26, 1929 to June 30, 1939

C. A. McClelland	Oct. 1, 1929 to July 4, 1933
V. C. Fishel	Dec. 5, 1929 to June 30, 1939
L. K. Wenzel	Dec. 5, 1929 to June 30, 1939
Burt Burlingame	Jan. 4, 1930 to Aug. 31, 1930
G. M. Sherwood	June 5, 1930 to June 30, 1933
B. R. Colby	June 16, 1930 to June 30, 1933
R. C. Cady	June 23, 1930 to June 30, 1939
P. P. Livingston	July 1, 1930 to June 30, 1939
S. W. Lohman	July 1, 1930 to June 30, 1939
C. V. Theis	July 7, 1930 to June 30, 1939
V. T. Stringfield	July 10, 1930 to June 30, 1939
R. W. Sundstrom	Aug. 17, 1931 to June 30, 1939
H. S. Gale	Oct. 21, 1931 to June 30, 1933
H. E. Thomas	Dec. 12, 1931 to June 30, 1939
Kyle Forrest	Jan. 5, 1932 to June 30, 1934
C. F. Park, Jr.	May 1, 1932 to Apr. 1, 1933
H. A. Powers	July 1, 1932 to Sept. 30, 1934
C. P. Ross	July 18, 1932 to Oct. 17, 1932
G. A. Waring	Sept. 26, 1933 to May 31, 1935
D. A. Andrews	Oct. 1, 1933 to May 16, 1934
M. M. Knechtel	Oct. 1, 1933 to July 29, 1934
W. H. Monroe	(Oct. 1, 1933 to Aug. 15, 1934
	(Nov. 1, 1934 to June 30, 1935
E. B. Eckel	Oct. 29, 1933 to Apr. 1, 1934
W. G. Pierce	Nov. 16, 1933 to Mar. 15, 1934
M. A. Pentz	Feb. 1, 1934 to June 30, 1935
C. E. Jacob	July 20, 1936 to June 30, 1939
M. L. Brashears, Jr.	July 23, 1936 to June 30, 1939
A. M. Morgan	Apr. 21, 1937 to June 30, 1939
F. H. Klaer, Jr.	June 21, 1937 to June 30, 1939
R. R. Bennett	June 28, 1937 to June 30, 1939
D. J. Cederstrom	July 6, 1937 to June 30, 1939
G. C. Taylor, Jr.	Aug. 9, 1937 to June 30, 1939
S. L. Schoff	Aug. 9, 1937 to June 30, 1939
G. A. La Rocque, Jr.	Nov. 1, 1937 to June 30, 1939
A. C. Byers	Jan. 1, 1938 to June 30, 1939
G. R. McCarthey	Jan. 1, 1938 to June 30, 1939
R. C. Baker	Mar. 3, 1938 to June 30, 1939
J. C. Maher	May 16, 1938 to June 30, 1939
E. J. Schaefer	June 30, 1938 to June 30, 1939
J. G. Ferris	July 25, 1938 to June 30, 1939
J. C. Frye	July 28, 1938 to June 30, 1939
C. L. McGuinness	Aug. 8, 1938 to June 30, 1939
G. F. Brown	Aug. 30, 1938 to June 30, 1939
H. A. Waite	Sept. 21, 1938 to June 30, 1939
M. A. Warren	Oct. 26, 1938 to June 30, 1939
H. H. Cooper, Jr.	Nov. 1, 1938 to June 30, 1939
W. E. Hale	Nov. 1, 1938 to June 30, 1939
W. K. Back	Nov. 16, 1938 to June 30, 1939
N. A. Rose	Jan. 23, 1939 to June 30, 1939
C. S. Conover	Feb. 1, 1939 to June 30, 1939
E. W. Reed	Mar. 10, 1939 to June 30, 1939
G. A. Macdonald	May 17, 1939 to June 30, 1939.

QUALITY OF WATER DIVISION

Like the other divisions of the Branch, the Quality of Water Division increased its activities several fold during the period. Perhaps the principal reason for this was the growing appreciation of the intimate relation of chemical quality of water to its utility for many purposes.[757] State cooperation in Virginia and Georgia, and the increas-

757/ Letter from W. D. Collins to author.

ing number of inquiries regarding the quality of water supplies for industrial uses were important factors, as was the development of the sediment studies on the Colorado River which had been started on a modest scale in 1925.[758] A measure of the increase in activities is the annual

758/ p. 185 (1919-1928).

amount of funds available from all sources during the period, as follows:

1929	$15,000	1933	$28,011	1937	$54,898
1930	30,019	1934	26,670	1938	66,876
1931	39,553	1935	38,899	1939	64,175
1932	30,563	1936	32,540		

As much of the work of the Division is based on analyses of water, another measure of the increase in activities is afforded by the comparison between the number of analyses made during the present and preceding periods. From 1919 to 1928 a total of 4,300 analyses were made as compared with 20,900 analyses from 1928 to 1939. In addition, many thousand analyses were made by cooperating agencies under the Survey's general supervision.

Referring to the use of the records, Mr. Collins writes:[759]

759/ Letter to author.

> Always the records of the Survey have been consulted by some of the more alert planners and designers of industrial plants, but with the increasing attention to water quality necessitated by more closely controlled manufacturing operations, and more heavily loaded power plants, a large number of requests are received from persons interested in the location of industrial plants. Among the users of the Survey data on water quality are the industrial agents of the railroads. Their own chemists know the character of the water supplies used by the locomotives, but they turn to the Survey for facts about the supplies from other sources that will be available to industrial plants that may be induced to locate in the territory served by any one railroad.

The analytical work of the Division was concerned both with ground water and surface water, and with reference to that relation Mr. Collins writes:[760]

760/ Letter to author.

> Practically every investigation of ground water involves

more or less consideration of quality. No study of the quality of surface waters can be made without the use of data on discharge. Study of low-water discharge of surface streams involves consideration of ground-water supplies.

For the benefit of those who sometimes seemed to feel that the chemical character of a water was the only feature worth considering, and also for those who thought "water is water" and quantity was the only characteristic worth any attention, some one wrote, "You cannot successfully irrigate much land with a thimbleful of the best water in the world, but you cannot do any better with unlimited quantities of water from Great Salt Lake."

Until the work of measuring the sediment and dissolved matter in the Colorado River was started in 1925, the work of the Division did not have a continuing program except the general program of analyzing both ground and surface water throughout the country, as the need for such analyses arose. But during the present period not only was the work on dissolved and suspended matter in the Colorado River continued, but continuing programs of water analysis over definite areas were started in Georgia and New Mexico through direct cooperation with State agencies. These programs continued beyond this period of the history.

Organization

W. D. Collins continued as chief of the Division during the period, with C. S. Howard as his principal assistant. The personnel was increased from 4 chemists, 1 sub-professional, and 1 clerk in 1928, to 14 chemists, 5 clerks, and 5 sub-professional employees in 1939.

Analyses for Ground Water Division.- With the increase in the activities of the Ground Water Division came an increase in the number of analyses of water samples for that Division. So essential was a determination of the quality of ground water that it became an established procedure of the Ground Water Division to allot to the Quality of Water Division a small proportion of the cooperative or non-cooperative funds provided for specific studies of ground water. Annual allotments from such funds were:

1931	$2,860	1934	$ 300	1937	$1,500
1932	3,250	1935	900	1938	6,400
1933	2,700	1936	1,000	1939	4,400

State cooperation

In previous years the States had not cooperated with the Division except in Florida, where informal cooperation with the State Board of Health occurred in 1924.[76] However, during the present period coopera-

76/ p. 188 (1919-1928).

tion was arranged with four States, and this cooperation resulted in expenditures from State funds, as follows:

Cooperative State funds.

Year	Virginia	Georgia	New Mexico	Connecticut	Total
1930	$5,089				$5,089
1931	4,967				4,967
1937		$ 889	$1,139		2,028
1938		5,711	12,000	$700	18,411
1939		3,376	10,000	550	13,926

In addition, $1,500 of surface-water cooperative funds was made available in California in 1932 in connection with the supplemental analyses of certain river waters,[762] and $5,883 of Colorado funds and $1,784 of New Mexico funds during the Rio Grande Joint Investigation in 1936 and 1937. As these funds did not represent direct cooperation with the States, they are not included in the foregoing table.

762/ pp. 376-377.

Virginia: Not satisfied with making an investigation of the quantity of water in the streams, the progressive State Commission on Conservation and Development in 1929 cooperated with the Survey in a study of the quality of that water, a study which continued for two years. J. J. Durzulaitis, who was not only the Survey's district engineer, but also the chief engineer of the State's Division of Water Resources and Power, assisted in selecting the 16 gaging stations at which daily samples were collected. To obtain more representative results, as well as to reduce the labor required, the daily samples at 10-day intervals were united to make composite samples and these were analyzed. During the second year daily samples were collected at 17 gaging stations and single samples were collected at high and low stages of streams at 53 gaging stations. During the life of the project 1,340 complete analyses were made, and the resulting report[763] was, as Collins states,[764] "the most comprehensive and adequate report so far published on the industrial quality of surface waters in a State." The analytical work was started by S. K. Love, and analyses were made at various times by Thomas Judson, K. T. Williams, E. W. Lohr, H. S. Haller, and O. C. Kenworthy.

763/ State Commission on Conservation and Development: Bull. 3.

764/ Letter to author.

Expenditures from Virginia funds were:

Year	State	Survey
1930	$5,089	$1,839
1931	4,967	4,500

Georgia: Cooperation with the State Division of Mines, Mining, and Geology, which became effective March 1, 1937, was unique in State cooperation as the lump sum appropriated was for both stream gaging and the

analysis of water, and the division of funds between the two activities was made by the State and Survey cooperating officials. At that time W. L. Lamar went to Atlanta to arrange for a laboratory in which the analyses could be made. But after investigating the situation it was decided in the interest of economy to make the analyses in the Survey's Washington laboratory. When the work was started, daily samples were obtained at gaging stations and analyses made of composite samples. As the work progressed, a demand arose for analyses of public water supplies used by industry and at the end of the first year the number of gaging station samples was greatly reduced. Lamar visited the cities and larger towns and arranged to have water samples sent to the Survey for analysis from 66 towns. About that time the ground water supplies of Savannah became seriously depleted owing to the greatly increased industrial demand, and the City was considering obtaining additional water from the Savannah River. As the Savannah River is tidal in its lower reaches, it was necessary to know how far upstream the salt water penetrated in order that the proposed intake should be above possible salt water contamination. The Survey was urged to make that investigation, but as it would be a relatively expensive study no immediate action was taken. But the demand for the study became so strong that the salinity study was financed by reducing the analyses of the surface waters. A laboratory was established in a large storeroom in the Savannah post office. The salinity study was such a departure from the regular procedures that a somewhat detailed description may be warranted. In general, the sampling was planned to cover the time of greatest salinity during daylight hours each day at each sampling point. Three samples were collected at half-hour intervals within a period that was selected on the basis of the tide tables. The sampling time was corrected weekly in accordance with the results obtained. During some tidal cycles samples were collected every half hour or hour for a period of some 28 hours. At such times pilots on ocean-going vessels were warned to watch out for the boats doing sampling in the channel. Fortunately, such warnings were taken seriously. Daily samples were collected at the selected sampling points from December 1, 1937, to November 30, 1938, and again from July 21 to September 30, 1939. Cooperative funds were not adequate to complete the computation of the records and a WPA project under Survey supervision was set up to advance the computation, but the report was not completed. A brief summary of the work was published in an article by Mr. Lamar in the Transactions of the American Geophysical Union for 1940, pages 463-470.

Expenditures from Georgia funds were:

Year	State	Survey
1937	$ 889	$2,197
1938	5,711	4,357
1939	3,376	3,617

New Mexico: The analyses of the Rio Grande waters made during the Rio Grande Joint Investigation were scheduled to be discontinued with the end of that work in January 1937. However, the State of New Mexico desired the continuance of the analyses on a reduced scale, and the State Engineer entered into cooperation with the Survey for that purpose. C. S. Howard continued in charge of the work which included daily sampling at three points on the main river, weekly samples at two other main-river stations, and occasional samples at seven points on

tributaries. The electrical conductivity[765] of the daily samples was

765/ p. 369.

determined, and the samples composited at 10-day intervals for analysis.[766]

766/ State Engineer: Twelfth and Thirteenth Bien. Repts. p. 58.

This investigation was completed in 1937.

The investigation of the source of salinity in the Pecos River, in which the ground water phases were studied by the Ground Water Division[767]

767/ p. 333.

was started in April 1937, and to enable the Quality of Water Division to make the many analyses of both surface and ground water, the State Engineer made a separate agreement. Mr. Howard took charge of organizing the work and devoted much time to it later. Headquarters were established first at Carlsbad, but these were soon moved to Roswell, where laboratory space was provided at the New Mexico Military Institute. W. F. White, Jr., was placed in immediate charge of the laboratory, and was assisted by W. E. Duncan. Other assistants obtained locally were employed from time to time. In describing this work, which was actually started in July 1937 and was later merged with the Pecos River Joint investigation, at the close of the present period, Mr. Collins writes:[768]

768/ Letter to author.

> In general the observers who collected samples were reliable and conscientious but the usual difficulties were experienced with some of the observers on the Pecos project. The daily conductance measurements would indicate identical samples for two days a week at some stations. Usually Saturday and Sunday or Sunday and Monday came up with identical samples in the midst of fairly rapidly changing concentration from day to day during the rest of the week. At some places a little kindly reminder sufficed to correct the situation; at others it was necessary and possible to engage another observer; but at some stations it was necessary to make the best of it or abandon the station because it was not practicable to engage another observer.
>
> On the Pecos project the Division experienced its only serious accident to a regular employee. White was not successful in avoiding a drunken-driven car as he was returning to Roswell with some samples. White's car, about a year old, was reduced to a $25 trade-in value and he was confined to the hospital for a while. In time he recovered fully, but for some time after he returned to duty he had to refrain from doing the heavier tasks involved in field work.

Expenditures from New Mexico funds were:

Year	State	Survey
1937	$1,139	$2,288
1938	12,000	10,593
1939	10,000	10,076

Connecticut: The study of the intrusion of sea water in the ground-water supplies from the tidal reaches of the Connecticut River that was being made by the Ground Water Division,[769] required a study of salinity

769/ pp. 302-303.

and a cooperative agreement with the State Water Commission was made in July 1937 and continued during the remainder of the period. The salinity study in Connecticut had its beginning soon after the start of the ground-water study in 1933. At that time a few determinations of chloride in wells near salt water were made, and when the study of intrusion of salt water in the tidal reaches of the Connecticut River was started in 1934, a comprehensive salinity study was planned with sampling schedules prepared to cover all conditions of tide and stream flow. The study was under Mr. Howard's supervision. From the beginning of the salinity study in 1934 to its ending in 1939, some 150,000 samples were collected, and during the greater part of that period an almost unlimited supply of WPA help for sampling and analyzing was available. The results obtained during the first 3 years were published in mimeograph form by the State Commission.[770] Mr. Collins writes:[771]

770/ The salinity of the Connecticut River, Oct. 1, 1934 to Sept. 30, 1937, Bull. S-1.

771/ Letter to author.

> As the local representative of the Survey, Bigwood assisted greatly in making arrangements with the State and WPA officials, and in carrying out the work throughout its course.

Expenditures from Connecticut funds were:

Year	State	Survey
1938	$700	$609
1939	550	552

Federal cooperation

With the general expansion of federal activities beginning in 1933, the Division was called upon for cooperative work by a number of Federal agencies, which paid the cost of the investigations required. The amounts so expended were as follows:

Expenditures from cooperative federal funds

Agency	1933	1934	1935	1936	1937	1938	1939
PWA		$11,267	$25,700	$ 1,260			
Indian Service					$ 2,000		
Soil Conservation Service						$6,951	$ 4,600
Flood Control Com.							5,400
National Resources Com.					833		
Public Health Service	$400						1,823
Misc. Federal Cooperation	300		1,000	10,700	10,867		
Total	$700	$11,267	$26,700	$11,960	$13,700	$6,951	$11,823

The details of the miscellaneous cooperation are not available.

In addition to the cooperation listed above, many requests for advice were received and some of those requests have been described following the description of the cooperative projects listed.

Public Works Administration.- In addition to the PWA funds for supervision of the sediment determination for streams on the eight Soil Conservation Service projects,[772] the Division participated with the other Divisions in studying conditions in the vicinity of Warm Springs, Ga. Lamar spent parts of December 1933, March and April 1934, and June 1935 in the field. He made measurements of the temperatures of the waters, and installed two continuous recording thermometers, one on the warm springs and one on a cold spring. He also collected samples for analyses both in the field and in Washington.

[772] p. 350.

Another inquiry had to do with the connection between the fluoride and the dental defect known as mottled enamel. In 1935, the PWA had under consideration a project to supply a small western town with water from a well, and accompanying the application was an analysis of a sample from a well in the neighborhood. This was referred to the Survey,

and although the sample had not been analyzed for fluoride the water was of a type most likely to contain large quantities of fluoride. A sample from the well under consideration was obtained from the field and when analyzed by the special method developed by the Survey,[773] it was found

773/ pp. 369.-

to have so much fluoride that if used it appeared probable that about 90 per cent of the children drinking the water would have mottled enamel. As there was no practical method then known for treating the water of a public supply to remove the fluoride, the project was rejected in favor of one providing a surface supply.

Indian Service.- During the course of the Rio Grande Joint Investigation, a number of agencies contributed funds, and from those of the Indian Service, expenditures of $2,000 during 1937 were made by the Quality of Water Division.

Soil Conservation Service.- One of the most important phases of the cooperative program on the eight soil erosion projects[774] was the

774/ pp. 80-83.

determination of the amount of sediment in the streams, and the Quality of Water Division furnished the equipment for that purpose and supervised the analyses. These latter were made in laboratories on each project. From the beginning of the work in 1934 until 1937, the expenditures were made chiefly from PWA funds, but thereafter Soil Conservation funds were used.

The results of the measurements were delivered to the Soil Conservation Service as soon as available and were discussed with various officials from time to time. W. G. Hoyt and Walter Langbein prepared discussions of some of the records.[775]

775/ Op. cit.

In describing this work, Mr. Collins states:[776]

776/ Letter to author.

> It was admitted that a large-scale experiment could not be carried on with the precision of measurement possible on the small experimental plots. Collins insisted that the measurement of weight of transported material would be good enough to show any differences as great as 25 per cent due to changed land-use features, but that changes of 2 or probably 5 per cent in the measured loads might easily be due to experimental uncertainties. No one could be sure that rainfall, and source of run-off, and erosion would be the same on both areas of each pair under observation. One might be sure that it would not.

Flood Control Coordinating Committee.- Cooperation with the Flood Control Coordinating Committee was limited to two projects. The first, and larger, was that on the Boise River, Idaho, which was started in November 1938.[777] The sediment samples at the 13 gaging stations in the

777/ p. 93.

project were analyzed in a laboratory at Boise, by H. A. Swenson, under S. K. Love's supervision. The laboratory occupied a rented store and much of the space in it was occupied by the numerous cases of milk bottles containing the water samples. To the casual passer-by it appeared to be a milk station, and at first and until disillusioned, there were prospective customers for milk. The project continued beyond June 1939.

The other project was a temporary one on the St. Francis River in Missouri, started in February 1939.[778] Mr. Love supervised the analyses

778/ p. 91.

of the few sediment samples in a local laboratory at Rolla, Mo.

National Resources Committee.- During the course of the Rio Grande Joint Investigation which was sponsored by the National Resources Committee and for which it contributed PWA funds, the Quality of Water Division made expenditures from such funds in 1936 amounting to $833.

Indicative of the importance which the National Resources Committee attached to the analysis of surface waters, the Committee in 1936 recommended that, for the analysis of mineral content, oxygen content, and sediment load, 200 base stations should be established and maintained continuously for at least 10 years at the sites of existing gaging stations. In addition to those base stations, at least 400 secondary stations should be operated each year for a 1-year period, the locations being changed annually.[779] As the Committee's recommendation for the

779/ Deficiencies in basic hydrologic data: Nat'l. Res. Com. Sept. 1936, p. 37.

necessary funds did not meet with Congressional approval, the proposed program was not put into effect.

Public Health Service.- During 1933 the Public Health Service was making an examination of pollution of the Potomac River below Washington and borrowed the services of K. T. Williams for analytical work in that connection.

In Giles County, Tennessee, and Coffee County, Alabama, where the general economic level and character of the population were similar, the death rate from tuberculosis was from 4 to 9 times higher in the former than in the latter. In 1938, the Public Health Service made an investigation to determine whether natural conditions were a factor in the death rates in the two counties. The Geologic Branch was called upon for a geologist to study the geologic conditions, and the Quality of Water Division for a chemist to determine the chemical character of the water supplies. Miss Margaret Foster was detailed to the project, and spent some time in the field inspecting water supplies, and analyzed in the laboratory more than 400 samples of water representing all types of supplies. No relation between quality of water and incidence of tuberculosis was found.

National Park Service.- In 1933, when the Shenandoah National Park was being made ready for visitors, the Survey was called upon to analyze some of the waters proposed for use at camp or cabin sites. These analyses showed that some of the waters were so corrosive that it was necessary to treat them if the waters were to flow through copper pipe as planned.

In September 1934, W. L. Lamar spent four days in Hot Springs, Ark., measuring the temperatures of hot and cold springs, and the temperatures in different parts of the reservoirs in which the hot water is stored and cooled for the baths. He also collected samples which were analyzed in Washington. The results of the investigation were furnished the Park Service.

Security and Exchange Commission.- In response to an inquiry in June 1939 from the Security and Exchange Commission, charged with supervision over the issuance of securities by domestic corporations, the Survey made for the first time in its experience what Mr. Collins termed[780] "An analysis of water for watered stock of the kind offered

780/ Letter to author.

for sale to gullible investors." A prospective distilling company had made application to the Commission to list its securities, and included in its list of assets an item of $72,000 due to the alleged fact that a creek on the property was particularly adapted to the manufacture of whisky. The accompanying analysis showed that the creek water was very similar to that of a nearby river of which Collins and Calvert had made a series of analyses during 1906-7. Mr. Collins adds[781] that "The

781/ Letter to author.

testimony of experts in the manufacture of whisky did not give any special credit to the river or creek water."

Federal Housing Authority.- The Federal Housing Authority consulted the records and publications of the Survey in connection with specifications for plumbing supplies for housing projects or other structures. Also for help in planning for the treatment of water supplies that proved to have more corrosive ability than was taken into account in the plans for the projects. Some projects had red water from action on iron or steel boilers, tanks, and pipes; some had water that left blue or greenish stains as a result of its action on copper pipe. On some projects to be supplied with notably noncorrosive water considerable savings were made when the Survey advised that with such water there was no need for any more expensive pipe than standard galvanized iron or steel pipe.

Reconstruction Finance Corporation.- During the hectic days of setting up PWA projects, there were many applications for grants or loans for water-works projects. These applications were usually accompanied by analyses of water from proposed or closely allied sources, but the analyses were frequently fragmentary, the main item being a statement from the State Health Board that water would be expected to be safe to drink. After the completion of some projects the expected revenue from water sales did not materialize, as the prospective consumers did not choose to use the new public supply and pay for it. The most common

cause of complaint was the undesirable presence of iron in the water. Questions regarding such supplies were brought to the Survey by fiscal officers not only of the PWA but also by those of the RFC as one or the other agency had financial interests in the projects. The practical question was: Should the projects be written off as errors in judgement, or should additional funds be advanced in the hope that by treating the water the consumers could be induced to purchase it. The cost of the necessary treatment was a vital factor and the final decision required not only accurate knowledge of the character of the water but also its probable action on the metals of the well equipment and pipe lines. This information was supplied by the Survey.

Robert E. Lee Memorial Foundation, Inc.- In 1933, a telephone call from the National Bureau of Standards reported that serious difficulty was being experienced at the Lee home at Stratford, Virginia, because of the solution of copper from a pipe line from a spring to the buildings. It appeared that there had always been trouble with iron dissolved from iron pipes and that someone who had read about the resistance of copper decided that in the new construction copper pipe should be used. There was so much copper in the water at the superintendent's house that the water was not suitable for drinking. Articles laundered in the water with the use of soap took on a pastel green shade that was really pleasing in articles like wash cloths and turkish towels, but not so good on table linen, shirts, and underwear. The remedy adopted was one that is in use in several places. The water is allowed to flow through a bed of marble chips before entering the copper pipe. The carbon dioxide is reduced to a harmless amount and some calcium carbonate is dissolved.

Development of Methods[782]

782/ Written by W. D. Collins.

During the period 1928 to 1929, the bulk of the analytical work on water proceeded along conventional lines as described in Water-Supply Paper 596 (h), published in 1928. The determination of fluoride was introduced and more use was made of the measurement of electrical conductance as an aid in selecting samples for composites and as a rough indication of the total salt content of samples.

Fluoride analyses.- It was believed for some years that there was some relation between the composition of drinking water and the occurrence of the dental defect known as mottled enamel, but the cause of the defect was not ascertained till about 1930. At about this time physiological chemists at the University of Arizona endeavored to establish the cause by feeding to animals residues from the evaporation of the drinking water from St. Davids, Arizona, where mottled enamel was prevalent. The experimental animals showed clearly recognized signs of fluoride poisoning which had been learned in connection with studies of fluoride in food products. Then they determined fluoride in the water from St. Davids and from there on successfully correlated the occurrence of fluoride in the water with mottled enamel.

A subsidiary of the Aluminum Company of America which had a considerable plant at Bauxite, Arkansas, put in a public water supply from deep wells to replace insanitary shallow well supplies formerly used by individuals. In a few years all the children using exclusively water from the new supply began to show the effects of mottled enamel.

Examination of the water in the laboratory of the Aluminum Company of America revealed the presence of considerable quantities of fluoride which appeared as an unusual constituent of the water. The Aluminum Company of America used for determining the quantity of fluoride a method which had been developed for use with rocks and fertilizers.

The Survey became interested in fluoride analyses and Miss Foster tried to find a method that would be suitable for use in the Water Resources Laboratory. She found a good many defects in the method which had been used by the Aluminum Company and in other methods published up to that time. She developed a method which fitted into the scheme of analysis used in the laboratory and was found generally reliable by those who have followed the method carefully. It requires rather skillful manipulation and attention to details and the Survey has not recommended it except for use by expert analysts who are regularly determining iron by the thiocynate method. The method was not used much by other laboratories and in 1941 Lamar and Seegmiller published a version of the most generally used method including some features that seemed to be improvements. This method was adopted in the Water Resources laboratories and after several years of use, Lamar published in 1945 [783] some slight

783/ Analytical Edition Industrial and Engineering Chemistry, Vol. 17, pages 148-9, March 1945.

revision of the method in the light of its use during intervening years.

Miss Foster's method was used in making the early fluoride determinations on samples of Colorado River water, and these determinations were of great value to Los Angeles. Opposition to the use of Colorado River water had developed as a result of newspaper publicity to the effect that such use would result in the occurrence of mottled enamel on the teeth of all the residents of Los Angeles. At that time there was available a fairly long record showing that the Colorado River water almost never contained as much as one-half part per million of fluoride, whereas one part per million was generally considered the safe limit to avoid mottled enamel. The fact quieted the fears of the Angelenos.

Electrical conductivity.- The Department of Agriculture had been measuring the electrical conductivity of waters and soil solutions for many years and continued the practice in its work on the Rio Grande Joint Investigation which began in 1936. The Geological Survey followed the practice in its part of the Rio Grande investigation and in subsequent investigations in the Southwest.

The conductivity is computed from the measurement of the electrical resistance between two platinum electrodes immersed in the water. The standard conductivity cell is made of glass and there was naturally considerable breakage in the course of measurements in the field. To eliminate this trouble C. S. Howard and R. L. Atkinson of the Survey's Division of Field Equipment developed a cell made of lucite which eliminated breakage in the field measurements.

Instructions regarding analyses given other agencies.

During the period the Survey on three occasions was called upon, not to make analyses, but to instruct chemists in other agencies as to the proper methods of making analyses.

During the ground-water investigations being made by the Planning Board of Monroe County, New York,[784] some well trained but inexperienced

[784] p. 302.

chemists working on a WPA project were attempting to make complete analyses of water samples, and the analyses were found to be of little value. W. L. Lamar went to Rochester in August 1934 and worked with the analysts until they had learned to make a few determinations regularly made in a preliminary examination. On a return trip a few months later, Mr. Lamar found the chemists obtaining excellent results, and he then instructed them in the Survey method of making partial analyses. As Mr. Collins writes,[785]

[785] Letter to author.

> (Lamar's) two visits changed the output of analytical work from a small number of unreliable "complete" analyses to a large number of incomplete analyses that were wholly acceptable.

In the spring of 1936 a chemist of an eastern State geological survey wrote the Survey requesting instructions for analyzing brines. In its reply the Survey suggested that as such analyses were complicated, he practice a little while with such printed directions as he could find and then come to Washington with his samples for personal instructions. Ignoring this suggestion, he came to Washington without samples and spent a full day filling a notebook with the answers to many questions he asked. With that material he returned home convinced that he could instruct his associate in making the required analyses. A few months later this chemist telephoned a request that Miss Foster come to the State laboratory and show just how the Survey analyzed brines. After a month's instructions in the laboratory the two local chemists were able to make satisfactory analyses.[786]

[786] Op. cit.

As part of the work on ground water in Texas, the Geological Survey sponsored a WPA project for collecting well data, measuring water levels, and analyzing samples from many of the wells. The analytical work on the project was done by a WPA group under the leadership of an able chemist who had not done much work with water. As usual, results of a large amount of work were wanted speedily and as the WPA workers were far from being experienced analysts, the result was that some of the analyses when checked in Washington were found to be seriously in error. Much of the work was perfectly reliable, but single determinations in many analyses were in error. It was felt that someone from the Survey might pass along to the WPA workers some of the experience of the laboratory in Washington and so bring all the work on the project up to the standard of the best of it. Lohr and Collins went to Austin in October 1937 to confer with the Survey, State, WPA, and University personnel interested in the project. It was originally planned that Lohr would spend a month or two setting up standards of work and then leave the project to run itself. After about two days it became evident that Lohr or someone would have to enlist for the duration. Lohr was still there June 30, 1939. The WPA workers were completely cooperative. They were only looking for some encouragement to put quality ahead of quantity on their

production program. Some of the determinations were turned over to Lohr and such assistants as he could employ directly; a system of checks and duplications was set up for handling the mass of WPA samples; and Lohr undertook to inspect all results before they were released. Lohr also took over the examination of the samples collected in the course of the regular cooperative ground-water studies in Texas. He was able to give much more prompt service than could be given by the Washington laboratory.

The need for adequate supervision appeared in other WPA projects, a part of the trouble being that in some instances the original plan of the supervisors or sponsors proposed to obtain more analyses than should have been expected from the available personnel and supervision. In the struggle to keep up with the schedule accuracy was sacrificed.[787]

787/ Water-Resources Bulletin, Aug. 10, 1937.

Colorado River investigation[788]

788/ Written chiefly by W. D. Collins.

Study of the dissolved and suspended matter in the Colorado River was continued throughout the period. Throughout the investigation the key station has been the gaging station at Bright Angel Creek near Grand Canyon. The excellent discharge records at this station and the hearty cooperation of resident engineers in the collection of samples have made it possible to obtain a better record of the dissolved and suspended matter than could have been obtained under less favorable conditions. The fundamental plan for the study of the load of dissolved and suspended matter at a station included the collection of daily samples for chemical analyses and the collection of adequate samples for computation of the load of suspended matter.[789] Daily samples were collected for

789/ Water-Resources Bulletin, May 10, 1939.

analysis of composites at Bright Angel Creek on the Colorado and near Bluff on the San Juan. Loads of suspended matter were also determined. For 4 years ending September 30, 1935, analyses were made of composites of daily samples from the Colorado at Grand Junction and from the Gunnison at Grand Junction. Daily samples were collected at Lees Ferry for 2 years ending September 30, 1930. Because the results obtained from 1925 to 1928 indicated very little difference in composition of the Colorado River water from Bright Angel Creek to Yuma, the analysis of the dissolved matter in the river at Topock and Yuma was discontinued September 30, 1928, and the collection of daily samples from the Colorado at Cisco, and the Green at Green River, was begun October 1, 1928. Analysis of composites of samples from these two stations was discontinued September 30, 1935.

As the construction of Boulder Dam progressed it became desirable to check again the relation between the composition of the water at Bright Angel Creek and at Topock, so the collection of daily samples at Topock was resumed October 1, 1932. Only sulphate and chloride were determined on the daily samples through September 30, 1933. Beginning October 1, 1933, complete analyses were made of composites of the daily samples from Topock for a year, and partial analyses were made of composites of daily samples collected through December 10, 1934. Beginning

July 1, 1934, daily samples were collected from the Colorado River at the Willow Beach gaging station for analysis of composites. This sampling continued through June 30, 1939.

In general the water let down from Lake Mead has been clear, but at times turbid water has been released for short times. At first these occurrences were attributed to work still being done behind the dam, but later observations showed that at times turbid water was flowing 70 to 80 miles through the lake under the clear water and coming out through the tunnels at the dam. A paper by N. C. Grover and C. S. Howard giving some of the facts about this phenomenon was published in the Proceedings of the American Society of Civil Engineers for April 1937, and brought out a discussion from some 18 contributors.790/ Partly as a result of

790/ Trans. Am. Soc. C.E., Vol. 103, pp. 720-790 (1938).

the interest aroused by the paper and its discussion the Division of Geology and Geography of the National Research Council set up a committee on density currents which is coordinating the efforts of various agencies that are interested in the study of stratification in lakes and of currents through lakes. An appreciable part of the work of the Division of Quality of Water on the Colorado River since 1937 has been the analysis of samples of water taken from different depths at various points in Lake Mead. The Bureau of Reclamation has cooperated by collecting the samples.

Before the construction of Hoover Dam it was the general custom to assume that the water in the reservoir behind the dam would be pretty well mixed and computations were made on the basis that users of water below the dam would uniformly receive water of the composition shown by the weighted average of analyses of the water passing Bright Angel Creek. In 1932 the Survey published791/ a weighted average analysis for

791/ Water-Supply Paper 638, pp. 145-158.

the 5-year period ending September 30, 1930. This showed a content of dissolved matter of 571 parts per million. From the time the dam was closed, February 1, 1935, the composition of the river water at Willow Beach was about the same as the composition at Grand Canyon until July, when the incoming water began to be decidedly more concentrated than the outflow. In October 1935 the outflow began to show an increase in content of dissolved matter, going from 290 parts per million, September 21-30, 1935, to 890 parts per million, February 1-10, 1936. The content of dissolved matter gradually decreased to about 400 parts per million by July 11-20 and remained at about that amount until October 1-30, 1936. The content of dissolved matter of the outflow increased to 750 parts per million by January 11-20, 1937, and since that time has been in the range from 700 to 750 parts per million most of the time. This is about 25 or 30 per cent more dissolved matter than might be expected from the weighted average for the five years ending September 30, 1930, or for the fourteen years ending September 30, 1939. With the quality of the water being nothing to brag about on the basis of the 5-year weighted average the increase was a serious matter to those who were making plans for the use or treatment of the water. They have not blamed the Survey much for misleading them, because hardly anyone had any idea that there would be so serious and persistent stratification of the lake water. Now that the conditions in Lake Mead are fairly well known, everyone will

be more careful in the future about predicting the quality of the water that will flow from a large artificial lake.

At one time or another almost every chemist who has been employed in the Division of Quality of Water has made analyses of Colorado River water. During the period Mr. Howard put in some time in the laboratory each year and altogether did 20.9 per cent of the laboratory work. During 4 years he carried the main burden of the laboratory work or a major share. For 3 years Williams carried the main load. They, with Love, put in over 50 per cent of the time spent on Colorado River laboratory work. Brannock, Kinser, Lamar, and Lohr together did about 30 per cent of the work, putting in approximately equal amounts of time, but spread over 2, 4, 7, and 5 years, respectively. Mr. Howard spent most of August, September, and October 1928 at the gaging station on the San Juan River near Bluff, studying various methods of sampling for the determination of the suspended load. There was not much rain in the basin and so he did not have a chance to sample heavy loads of suspended matter in swiftly flowing water. The next summer, S. K. Love spent about 3 months at the station and he had plenty of experience with heavy loads of suspended matter. It was during this period that he took the series of samples in the section which gave an average of 42 per cent of suspended matter by weight. This is one of the highest of the reliable figures for suspended matter.

From June to October 1931, Mr. Love was at the gaging station on the Little Colorado at Grand Falls, Arizona, for the purpose of studying the suspended matter and collecting samples for analysis of the dissolved matter.

In the early part of 1934, Love spent about a month on the study of deposits along the Colorado River.

The cost of this work was paid from the annual appropriations for the Colorado River stations, the annual expenditures being:

1929	$2,000	1933	$7,007	1937	$7,237
1930	5,755	1934	4,825	1938	7,284
1931	9,000	1935	4,420	1939	10,297
1932	7,400	1936	6,788		

Rio Grande Joint Investigation.

When the Rio Grande Joint Investigation was planned early in 1936, [792]

792/ pp. 78-79.

it was found necessary to analyze the water of the Rio Grande for salinity at various points, as the many irrigation drains entering the river increased the salinity progressively downstream. The investigation being a joint undertaking, the services of all federal agencies in any way concerned with water and irrigation were enlisted and the Bureau of Plant Industry was given the task of analyzing the waters for salinity chiefly. The electrical conductivity method as described by C. S. Scofield of that Bureau was used.[793] Owing to the lack of personnel in

793/ Water-Supply Paper 839, p. 5.

the Bureau's Rubidoux laboratory, the Survey made many of the electric conductivity analyses in field laboratories in Albuquerque and Alamosa, and also in the Washington laboratory, all under Mr. Howard's supervision. Mr. Scofield interpreted the results for the Rio Grande Joint Investigation report.

More than 5,000 measurements of electric conductivity, including surface and ground water, were made in Colorado and New Mexico during the investigation, and some of these, together with analyses of other samples, as Mr. Collins expresses it,[794]

794/ Letter to author.

> went in with others to build up the picture which resulted in the section of the Rio Grande Compact defining limits of chemical character beyond which water would not be water.

That reference is to the last section of Article III, which states

> In event any works are constructed after 1937 for the purpose of delivering water into the Rio Grande from the Closed Basin, Colorado shall not be credited with the amount of such water delivered, unless the proportion of sodium ions shall be less than forty-five per cent of the total positive ions in that water when the total dissolved solids in such water exceeds three hundred fifty parts per million.

The results of the Rio Grande analyses were published in Water-Supply Paper 839.

The amount of federal funds expended during the fiscal year 1937 was $5,229.

Water-Supply Paper 658

The persistent requests for specific information regarding the chemical character of waters for domestic and industrial uses, which had practically forced the publication of Water-Supply Paper 496[795] in 1923,

795/ Collins, W. D., The industrial utility of public water supplies in the U. S.

continued in growing volume. In 1930, a beginning of the revision of that report was made. The information including analyses and water samples was obtained chiefly by correspondence but, human nature being what it is, Collins states that various district engineers "contributed by prodding municipal waterworks officials and by obtaining information and samples not obtainable by correspondence." E. W. Lohr made many of the analyses, W. L. Lamar prepared the text of the table of descriptions and analyses, and Collins wrote the report, which was published as Water-Supply Paper 658[796] in 1934. The extent of the revision or perhaps

796/ The industrial utility of public water supplies in the U. S., 1932.

more properly the additions to the earlier publication is indicated by the fact that the later publication contained analyses from 670 places containing 46 per cent of the total population of the country as compared

with 307 places containing 37 per cent of the population, contained in the earlier report.

A notable feature of Water-Supply Paper 658 was a map showing by States the average hardness of the water. Referring to the report, Collins writes in 1943: [797]

797/ Letter to author.

> The hardness map continues to be widely used in books and journal articles and in advertising. One Washington company advertised "Water flavor affects coffee flavor. U. S. Geological Survey map proves that Washington water is different from water in other cities. Wilkins coffee is blended for Washington water."

In addition to analyses of the water delivered to consumers the report also gives analyses of the raw water for places where the treatment makes changes in the composition, as by softening. This feature gives coverage for natural waters which are not represented by the analyses of the supplies as delivered.

The 670 supplies for which analyses are given serve about 57,000,000 consumers. By the exercise of some judgment the results can be used to give general information about the character of waters available at many places for which analyses are not available.

Water-Supply Paper 659-C

Water-Supply Paper 560-C containing an index of analyses of natural waters in the United States had been published in 1925, [798] and this

798/ p. 185 (1919-1928).

index had proved so helpful to those interested in the quality of water in the United States that in 1932, Collins and Howard prepared a supplemental index of analyses published from 1926 to the early part of 1932, which was published as Water-Supply Paper 659-C. This paper contained indexes of analyses of surface, and ground waters, and so-called mineral waters, supposed to have some particular medical properties. Regarding the latter, Collins writes: [799]

799/ Water-Supply Paper 659-C, p. 194.

> For many of the best known of these waters there is nothing in the analytical results to suggest any explanation for their supposed remarkable characteristics. Several of the publications that contain collections of analyses recognize this point * * * Practically all the books seem to have ignored this consideration in the material printed about individual springs. In general, the analyses of mineral waters are reliable. Many of the statements regarding the therapeutic properties of the waters appear to have been taken by the authors of the books from advertising circulars * * * and have not been confirmed by observation and experience of the authors.

Springs in Virginia

In December 1927, Wilbur A. Nelson, State Geologist, conceived the plan of making a study of the springs in Virginia, with special reference to the thermal springs. With insufficient State funds to finance the project, he induced the Virginia Hot Springs Co. to contribute to the State Geological Survey $2,000 to pay the salary of a chemist to make analyses at Hot Springs, and elsewhere in the State. In addition, the company spent directly an additional $2,000 for the installation of a gaging station at War Springs, the installation of equipment for recording the temperature of some of the hot springs and the purchase of apparatus to measure the radioactivity of the waters.

The project involved not only an intensive study of the Hot Springs region, but also a general survey of a much larger area. It was started in February 1928 by Frank Reeves of the Geologic Branch, and during the next few months he visited 337 springs in the southern part of the "Great Valley," noted the geologic formations, estimated flows, measured the temperatures, and collected samples. R. P. Meacham visited 229 springs in the northwestern part of the State, and Mr. Collins visited the springs in the vicinity of Warm Springs and Hot Springs, both obtaining similar data. From this field work, 527 analyses were made by Miss Foster during the years 1929 to 1931, and the results published by the State Commission on Conservation and Development as Bull. 1, of the Division of Water Resources and Power, Springs of Virginia, 1930, and Bull. 36 of the Virginia Geological Survey, Thermal Springs of Virginia.

Collins and Lamar measured the radioactivity of the waters at Hot Springs and found that they agreed with measurements obtained by the former in 1911, while with the Bureau of Chemistry. Referring to the radioactivity feature of the waters, Collins states:[800]

800/ Letter to author.

> The waters were slightly more radioactive than most ground or surface waters. The radioactivity was, however, much below the limit commonly reported to have any physiological effect, either good or bad.

California surface waters

During the comprehensive study of California's water resources by the State Engineer,[801] the latter desired to know what changes, if any,

801/ p. 43 (1919-1928).

had occurred in the character of the surface waters since they were analyzed during the period 1906-8 by the Survey.[802] Extensive irriga-

802/ Follansbee, Robert, History of the Water Resources Branch of the U. S. Geol. Survey to June 30, 1919, pp. 180, 300.

tion development had taken place in the meantime, and many storage reservoirs had been constructed. In 1930, Edward Hyatt, State Engineer, under the general cooperative agreement with the Survey for surface-water investigations, requested the Survey to make a preliminary investigation. A total of 145 samples were collected at 69 points on 56 streams, the

samples in the northern part of the State being collected by H. D. McGlashan, and those in the southern part by F. C. Ebert. The samples were sent to Washington for partial analysis by the Survey. In connection with the partial analysis the Survey's report containing the results of these analyses stated: 803/

803/ Calif., Div. of Water Resources: Bull. 29, appendix E, pp. 637-8, 1931.

> These partial analyses are almost as valuable as complete analyses for single samples of surface waters. Such occasional samples cannot show the character of a water throughout the year, but they give reasonably clear indication of changes or lack of changes in composition of the water since the earlier work was done.

Following the preliminary investigations, the State Engineer collected samples of Sacramento River water at Sacramento twice a week from July 20 to December 31, 1931, and once a week from January 1 to July 13, 1932. These were sent to Washington for complete analysis, which gave the same degree of reliability as the samples analyzed 25 years previously, except for some slightly greater accuracy due to improvement in analytical methods.804/ The various analyses indicated that some streams had much the same character as previously, but in other streams the character had changed materially.

804/ Op. cit.

To repay for the cost of analyzing the Sacramento River samples, $1,500 of surface water funds allocated for cooperation with the State Engineer were transferred to the Quality of Water Division.

Foreign water supplies

Several years before the outbreak of World War II the Survey was made aware of the "military mindedness" of two of the Axis partners. In 1932 and 1933, S. K. Love worked over some material on foreign water supplies which was collected largely in 1925 through the cooperation of the Department of State. A questionnaire was sent to all consular offices requesting similar information to that given in Water-Supply Paper 658 for public water supplies of the United States. The analyses furnished in response to that request were expressed in many different units and styles, and the translation of some statements required editing. Information was obtained from all but three countries. At the time the United States had not recognized the current government of the U.S.S.R. and so had no representative there. The German officials were reported as unwilling to supply the detailed information requested because of its military significance, and the same response was obtained in Japan. It later seemed of interest that in 1925 these two countries were loath to pass out "military" data about their public water supplies. A large part of the desired information was obtainable from published journal articles describing improvements in plants, or from personal correspondence with individuals who had the information.

The collection of descriptions and analyses of foreign water supplies was not published. It served as a source of information used to answer

correspondents and was made available for consultation by persons who had need for the data. The original reports were used extensively by the Survey Military Geology Unit and by other Federal agencies before and during the participation of the United States in World War II.

Personnel

During the period the division had the following technical personnel:

W. D. Collins	July 1, 1928 to June 30, 1939
C. S. Howard	July 1, 1928 to June 30, 1939
Margaret D. Foster	July 1, 1928 to June 30, 1939
S. K. Love	July 1, 1928 to June 30, 1939
F. S. MacNeil	Aug. 27, 1928 to Sept.15, 1929
Thomas Judson	Apr. 29, 1929 to Sept.27, 1929
K. T. Williams	June 1, 1929 to Aug. 31, 1933
W. L. Lamar	July 19, 1929 to June 30, 1939
L. G. Davidson	Aug. 14, 1929 to Aug. 31, 1933
C. A. Kinser	Sept.16, 1929 to Sept.10, 1937
E. W. Lohr	Oct. 14, 1929 to June 30, 1939
H. S. Haller	July 17, 1930 to May 31, 1931
O. C. Kenworthy	Aug. 27, 1930 to May 28, 1931
L. A. Shinn	Sept. 4, 1930 to May 31, 1931
G. J. Petretic	June 16, 1936 to June 30, 1939
M. D. Reeves	Sept.28, 1936 to June 30, 1939
A. T. Ness	Apr. 21, 1937 to June 30, 1939
N. A. Talvitie	May 25, 1937 to June 30, 1939
W. E. Duncan	June 15, 1937 to June 15, 1939
W. W. Hastings	July 20, 1937 to June 30, 1939
D. P. Marble	Aug. 23, 1937 to Aug. 22, 1938
W. W. Brannock	Nov. 16, 1937 to June 30, 1939
W. M. Noble	Dec. 1, 1937 to June 30, 1939
H. A. Swenson	Nov. 16, 1938 to June 30, 1939
J. D. Hem	Jan. 3, 1939 to June 30, 1939
F. H. Davis	June 16, 1939 to June 30, 1939

DIVISION OF WATER UTILIZATION

This period witnessed the reappearance of the Division of Water Utilization which had been virtually merged with the Division of Enlarged and Stock-raising Homesteads in 1917. In 1922 the name of that Division was changed to the Division of Land-classification Investigations, and its functions were gradually reduced to investigations for power and irrigation. Reduction in available funds curtailed the work to such an extent that by 1928 R. R. Woolley constituted the personnel of the Division of Land-classification Investigations. E. E. Jones, although nominally a member of the Division, was actually detailed to the Topographic Branch until his retirement on October 1, 1931.

Cooperation with the State Department, started in 1923 and with the first specific appropriation in 1927, 80/ brought about consideration of

80/ pp. 53 and 55. (1919-1928)

international problems on the Canadian Boundary, and it was necessary to assign an engineer in the Washington Office to this work. R. W. Davenport, who had been detailed to the Federal Power Commission, returned to

the Survey in May 1928 and was made the liaison officer with the State Department with reference to the stream-gaging program and allied investigations. Theretofore, the supervision of Federal Power Commission projects (which came to the Branch through the Conservation Branch) had been handled by the Chief Hydraulic Engineer. Davenport's long service with the Federal Power Commission made him the logical man to handle such supervision, and this was given him after his return. These were the prominent features of the background of the re-created Division of Water Utilization, although the Division was not recognized as such until April 8, 1931, when a chart showing the Branch activities, including the Division of Water Utilization, was prepared. In describing the new division, the Chief Hydraulic Engineer stated:[806]

806/ Memo. to Acting Director, Aug. 7, 1931.

> Division of Water Utilization, R. W. Davenport, chief. Investigates utilization and control of water; supervises field operations incident to administration of power resources.

There was still considerable investigational work in connection with power sites, chiefly for the Federal Power Commission, and R. R. Woolley devoted his time to such work in the Great Basin area, reporting directly to the Chief Hydraulic Engineer. He became a member of the newly-created division.

The functions of the Division continued without notable change until 1934. During that time Mr. Davenport supervised the field work connected with the Kootenai River investigations and the boundary waters in Montana, North Dakota, and Minnesota, and also supervised the special studies involved in those investigations. Numerous reports and testimony for hearings pertinent to international questions were prepared by the Division and in collaboration with the district engineers. The district engineers were in direct charge of the investigations in their respective districts. In February 1934, the National Resources Committee obtained a PWA allotment which enabled the Division to compile data showing flood magnitude and frequency, and study the relation between rainfall and run-off.[807] These projects were continued until June 1935. Under the

807/ pp. 76-77.

technical supervision of the Division, a WPA project was set up in New York City in November 1935 and continued through June 1936,[808] in which

808/ pp. 85.

hydrologic data were compiled and analyzed. G. R. Williams was the resident supervisor of the project.

Serious floods in various parts of the country, beginning in 1935, led to an enlargment of the functions of the Division of Water Utilization to include the supervision of flood investigations and resulting reports. In most instances these investigations were made by the districts in which the floods occurred under the guidance of the Division. The preparation of the reports was supervised and performed by the Division. So flood-conscious had the country become that after several of the major floods PWA funds were allotted for the purpose of

investigating and preparing reports on specific floods. The first allotment so made was in March 1936, when $125,000 was provided to investigate and report on severe floods which had just occurred through the northeastern part of the country. Severe floods in central Texas during the fall of 1936 resulted in an allotment of $10,000, and the unprecedented flood of February-March 1937 in the Ohio and lower Mississippi Rivers brought forth an allotment of $78,000. From funds made available by the Recovery Act of 1938, the Public Works Administration allotted, in July 1938, $100,000 for surveys of floods and droughts. From 1934 onward, the studies of rainfall and run-off were generally made under the direction of W. G. Hoyt of the Conservation Branch, who was detailed to the Division of Water Utilization for that purpose. The flood investigations and reports are described on pp. 818 to 840.

Although reports on the Colorado River had been published in 1916 and again in 1929-30, the development of that basin was proceeding so rapidly that in 1938 it was decided to make a further study, particularly of the water supply, and W. E. Dickinson was transferred to the Division, with headquarters in Los Angeles.

In describing the work of the Division, Davenport stated:[809]

[809] Minutes of conference of district engineers, Water Resources Branch, Geol. Survey, Oct. 24-29, 1938, pp. 211-12.

> The program of the division has involved to a notable degree the coordination of activities with other organizations and interests and adaptation to established organizations and agencies with a view to obtaining results efficiently and harmoniously. It is the desire to recognize generously that any successes must often be attributed in large part to such other organizations and agencies as well as individuals.
>
> A large part of the work * * * requiring field investigations is performed by the field organization of the Division of Surface Waters. This procedure makes use of the personnel of the Division of Surface Waters on matters on which they are well qualified and promotes efficiency * * *. Engineers of the Division of Surface Waters are assigned to the Division of Water Utilization from time to time and for intervals of varying length. * * *

In addition to the detail of engineers from the Division of Surface Waters, the Division had a small personnel of its own. The regular civil service personnel during the period was:

R. W. Davenport	July 1, 1928 to June 30, 1939
L. L. Harrold	Mar. 8, 1934 to July 15, 1935
W. I. Travis	Apr. 14, 1934 to July 3, 1937
G. R. Williams	Mar. 26, 1934 to Apr. 16, 1939
G. H. Wood	June 4, 1934 to July 11, 1935
W. B. Langbein	Nov. 2, 1936 to June 30, 1939
L. C. Crawford	Aug. 1, 1938 to June 30, 1939
W. S. Eisenlohr, Jr.	Mar. 1, 1939 to June 30, 1939

Salt Lake City

R. R. Woolley	July 1, 1928 to June 30, 1939

Los Angeles

W. E. Dickinson	May 27, 1938 to June 30, 1939
Alfonso Wilson	Jan. 1, 1939 to June 30, 1939

Prior to 1935 the annual expenditures by the Division of Water Utilization are not available but from 1935 to 1939, the annual expenditures from all funds were:

1935	$48,600	1938	$51,200
1936	37,104	1939	55,460
1937	50,460		

Several engineers served in the Division for intervals of varying length in connection with the Public Works projects under so-called Public Works appointments. Among these engineers were the following:

C. S. Jarvis
Merrill M. Bernard
H. Alden Foster
Thorndike Saville
J. J. Slade, Jr.
Benjamin F. Heidel
A. L. Alin
F. F. Snyder
D. M. Paul
G. D. Freeman
J. I. Speert

DIVISION OF POWER RESOURCES

The Division of Power Resources continued the publication of monthly reports of power generated, and in 1928 began the publication of statistics of power imported from, and exported to, Canada. This information was obtained from the Canadian Department of Trade and Commerce. To give a complete picture of the consumption of public utility electric power in the United States, similar information regarding Mexico was published beginning in 1931, obtained from the Edison Electric Institute. Another addition, started in the March 1933 report, was the inclusion of stocks of coal held by the electric public utilities. This information, obtained from the Bureau of Mines, was of considerable value in connection with the effect of coal strikes on industries: during a strike, no coal, no industry.

In 1930, the Institute of Economics of the Brookings Institution, established by the Carnegie Corporation of New York for the sole purpose of studying current economic problems and interpreting them to the public, made a study in cooperation with the Geological Survey of the sources of coal and types of burners used by electric public utility power plants. Because of its close contact with the electric public utilities, the Division of Power Resources obtained the desired information for the Brookings Institution by means of special questionnaires.

Various government agencies seeking information on different phases of the electric utility industry, and industry in general, were making requests, sometimes for the same information. To avoid needless, irritating, and costly duplication of requests, the President in 1936 appointed a committee whose duty it was to require all government agencies collecting statistical data to collaborate in soliciting information and thus avoid such duplication of requests and the resulting duplication in publication of reports. The Federal Power Commission which had been created to cover all phases of the power question, had its organic act amended to include authority to obtain practically all information it desired from power companies. In accordance with the committee's action the statistical data and the monthly power reports were taken over by the Federal Power Commission on July 1, 1936.[810] At that time A. H.

810/ Letter from A. H. Horton to author.

Horton was offered the position of chief of the new section in the Federal Power Commission but declined to leave the Survey, a decision easily understood at least by the older members of the Survey.

Consolidation of power companies continued during the years of the present period prior to 1937, and the 1,800 companies operating 3,700 plants had been reduced to 1,604 companies with 3,745 plants in 1936. The electric power generated by electric public utilities had increased 22.7 per cent in 8 years, from 87,800,000,000 kwh in 1928 to 113,600,000,000 kwh in 1936. Water power represented 40 per cent in 1928 but had declined to 36 per cent of the total in 1936, due largely to the succession of dry years.

The annual inventory of developed water power which had been published by the Division since 1924 was taken over by the Federal Power Commission, which issued its first inventory on January 1, 1938.

In 1936 the Division prepared a new inventory of potential water power, making use of the additional river surveys and stream-flow records which had been made available since the publication of the previous inventory in 1935. The new inventory, like that of 1935, presented the potential water power in units of horsepower with storage at 70 per cent efficiency for both 90 per cent, and 50 per cent of the time. To this inventory was added one prepared by the Conservation Branch in which power was expressed in units of thousands of kilowatts at 100 per cent efficiency for flow available 95 and 50 per cent of the time, and for mean flow. This latter inventory was prepared for use at an impending World Power Conference, and conformed to the power units and standards recommended by the International Commission on the Rating of Rivers.[811]

811/ Letter from B. E. Jones to author.

In 1938 the National Resources Committee prepared a report on "Energy resources and national policy" and in that connection A. H. Horton writes:[812]

812/ Letter to author.

* * * Mr. Ralph J. Watkins and an assistant came to Washington from the University of Pittsburgh and started

the preparation of the report, which is a volume of some 430 pages, 9 x 12 inches. As this report had to do with water power, steam power, etc., he contacted everybody in Washington who he thought would help him. I gave him all the information that I could about what the Power Resources Division was doing and also what the Geological Survey was doing in the way of obtaining information about water power and, so far as I was able, I directed him to the people who I believed to be experts and authorities on the different subjects on which Mr. Watkins was working. I spent a great deal of time discussing certain matters with him and furnishing him with information. Somehow or other I got the idea that I was one of the main guys in his report, but after I saw the report I realized my importance would probably rate about 1 per cent. The contact with Mr. Watkins and discussing his work was very pleasant and satisfying, and I believe that I was able to render him considerable valuable assistance and also furnish him with valuable information, and, as I have said, probably there were many others doing the same thing. * * *

Mr. Horton explains further that this letter was intended to express only his surprise at and appreciation of the quality and proportions of the Watkins report which is a veritable encyclopedia of valuable information related to the sources of power.

During the last two years of the period, the Division prepared reports on the construction of water-power plants throughout the world, information regarding foreign plants being obtained by the Bureau of Foreign and Domestic Commerce through the consular agencies. The reports were published in the year books of the Encyclopedia Britannica.

A. H. Horton was in charge of the Division throughout the period on a part-time basis as he was also district engineer of the Middle Atlantic States district.

Annual expenditures of the division, wholly from Survey funds, were:

1929	$10,750	1933	$7,210	1937	$3,400
1930	10,000	1934	5,100	1938	3,000
1931	8,819	1935	6,006	1939	3,000
1932	5,449	1936	7,001		

Evaluation of the years 1928 to 1939

by Nathan C. Grover

The period, 1928 to 1939, which Mr. Follansbee has called "years of 50-50 cooperation," is in many respects the most important in the 51 years, 1888 to 1939, of the Water Resources Branch and its predecessors,- the Irrigation Survey, 1888-1889; the "bulldog" (hanging on) years, 1890-1894; the Division of Hydrography, 1894-1902; the Hydrographic Branch, 1902-1906; and the Water Resources Branch, 1906-1939. In the eleven years from June 30, 1928 to June 30, 1939, the stabilization of cooperation with States and municipalities and the final recognition by Congress of joint responsibility with lesser governmental units for studying and recording the fluctuations in amounts and chemical qualities of water and for reporting on the best methods of utilizing the Nation's water resources, brought great increases in funds and personnel. Those increases, and the occurrence of disastrous floods and droughts, led to the preparation of interpretative reports for which specialists in engineering and hydrology were needed. The resulting increases in size of the Branch and in the availability of specialists in water problems led to recognition, not only by States and municipalities but also by other Federal agencies, of the field of operation of the Water Resources Branch and of the service it could render, and that recognition led to requests for service and brought the funds needed to enable the Branch to render reasonably adequate service. So, the "years of 50-50 cooperation" became years of growth, expansion, recognition and accomplishment along all lines of water investigations and reports. They serve as a striking example of the value of cooperative effort for a valuable purpose along sound lines.

No year or period stands alone. Each rests on the past and builds for the future. The ability to do today and next year depends on what was done yesterday and last year; it depends on the number and abilities of the trained men, and on the stages of development of instruments, equipment, methods and theories. In this period came the test of ability to expand rapidly for greater tasks and heavier responsibilities. In meeting this test successfully, the Branch showed the excellent results accomplished in the development of methods and in the selection and training of men which had been in progress since the organization of the camp at Embudo in December 1888.

Within the eleven years 1928 to 1939, the total funds of the Branch increased $2,675,000 or 466 per cent, from $575,000 in 1928 to $3,050,000 in 1939. This increase in funds is a fairly accurate measure of growth. Such growth necessarily brought many problems in organization and personnel; many new field offices were established; engineers, geologists and chemists were selected and assigned for greater responsibilities; and many new professional recruits were trained and made effective in a highly specialized organization. In this period of growth the Branch capitalized, of course, on the sound work of previous periods in the development of and experience with methods, instruments and equipment. It was able to grow and accomplish only because of the availability of men who have been broadly trained by service in many regions of diverse climatic, geologic and topographic conditions. Without that background of experience and the availability of a large group of trained men, the growth during this period would have been much more difficult, if not impossible.

However, the problems of the period have not related exclusively to growth and expansion. They included also those that are much more difficult to administer which came as the result of a great financial depression during part of the period with attendant problems related to curtailment of funds, reductions in salaries and activities, and resulting reductions, adjustments and transfers of personnel. As Follansbee has indicated, this was a period of floods and droughts which were record breaking and which had to be properly reported for the information of future generations. The reporting on these unusual and important events involved the testing and development of emergency methods for measuring flood flows, and for the compilation and presentation of pertinent information, especially in relation to "cloudburst" floods which come and go so quickly, often on ungaged streams, that stage-discharge relations cannot be established by the usual methods. For such emergency uses, slope-area and contracted-opening methods have been developed and utilized in the computation of flood discharges and the extension of rating curves, in addition to the estimation of peak discharges from observed heads on existing dams. Davenport, ably assisted by W. G. Hoyt, Hollister Johnson, W. S. Eisenlohr, Jr., W. B. Langbein, and others, has kept this important phase of the work of the Branch on a sound basis and has produced reports under difficult conditions that are of great value to the Nation, and a credit to the Branch and the Geological Survey.

The disasters led, therefore, to a much-needed and long-delayed expansion of interpretative reports in which the Division of Surface Water especially had been noticeably deficient. With the availability of more funds, the pressure to spend every dollar in the collection of statistical data was somewhat eased. The floods and droughts, tragic though their effects were, served to force the Branch to expand its interpretative work in compiling and interpreting hydrologic data needed in connection with the wise control and best use of the Nation's water resources.

Coincident with the expansion of cooperation with States and municipalities and the concurrent increase of funds, there has been rapid expansion of activities that are not directly related to such cooperation, but that are an essential part of the Federal program. These activities have related to international and interstate problems, to navigation, flood control, general hydrologic problems and other aspects of water that, although important, are not properly a part of an investigational program in which States and municipalities would be so intimately concerned as to cause them to share in the financing. They led to "Federal-type" stations which are supported entirely by Federal funds,- first, for stations in the Colorado River basin where Federal problems related to international and interstate interests, trans-mountain diversions, and large irrigation developments predominate; later for "308" stations; and still later for the establishment, maintenance and operation of stations related specifically to navigation, flood control and conservation.

Great as has been the progress within this period along several lines, much remains to be done; many more Federal-type stations should be established; the observational well program should be expanded into a well-balanced and well-coordinated system for the long-time, systematic recording of ground-water fluctuations in all parts of the country, needed not only as a record of fluctuations in an important part of the

Nation's supply of water, but also as a basis or background for the intensive but generally short-time programs of cooperative investigations of ground water. Broad, regional studies of fluctuations in the chemical quality of water should also be made, and the preparation of interpretative reports thereon should be expanded and systematized. Much development of both cooperative and non-cooperative work remains, therefore, for the future. The pioneer work of education, organization, development of methods, instruments, and equipment has been, I believe, well accomplished; the patterns of organization and cooperation have been developed; the broad, sound base built in earlier years has been tested by expansion during this period and shown to be effective for future and larger programs.

In closing the evaluation for this period, I take the opportunity to congratulate Robert Follansbee on the results of his arduous and self-sacrificing efforts in preparing this history of the half-century of the Water Resources Branch from the inception of the study of water by the Geological Survey in 1888 to the end of the 1939 fiscal year, and to thank him, on behalf of the Branch and the Survey, for the excellent work he has done in its preparation.