STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS

PUBLICATIONS OF THE
DIVISION OF WATER RESOURCES
EDWARD HYATT, State Engineer

Reports on State Water Plan Prepared Pursuant to
Chapter 832, Statutes of 1929

BULLETIN No. 26

SACRAMENTO RIVER BASIN

1931

80994

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GEOGRAPHICAL DISTRIBUTION
OF
WATER RESOURCES
AND
AGRICULTURAL LANDS
IN
CALIFORNIA
LEGEND
Area of Basin in Per Cent of Area of State
Agricultural Lands in Per Cent of Total of State
Water Resources in Per Cent of Total of State
OREGON
NEVADA
ARIZONA
MEXICO
PACIFIC OCEAN
NORTH PACIFIC BASIN
AREA 11.0 %
LAND 1.9 %
WATER 37.6 %
SACRAMENTO BASIN
AREA 16.8 %
LAND 26.8 %
WATER 34.8 %
SAN FRANCISCO BAY BASINS
AREA 2.2 %
LAND 2.6 %
WATER 1.2 %
SAN JOAQUIN BASIN
AREA 20.6 %
LAND 36.3 %
WATER 16.8 %
CENTRAL PACIFIC BASINS
AREA 7.5 %
LAND 4.1 %
WATER 3.1 %
GREAT BASIN
AREA 35.1 %
LAND 18.3 %
WATER 5.1 %
SOUTH PACIFIC BASINS
AREA 6.8 %
LAND 10.0 %
WATER 1.4 %
Lake Tahoe
Redding
Red Bluff
Chico
Sacramento
Stockton
Modesto
Merced
Fresno
Visalia
Bakersfield
San Francisco
Los Angeles
San Diego
Needles
Yuma
Scale of Miles
0 20 40 60 80

TABLE OF CONTENTS

CHAPTER III

CHAPTER IV

CHAPTER V

CHAPTER VI

CHAPTER VII

CHAPTER VIII

CHAPTER X

CHAPTER XI

CHAPTER XII

CHAPTER XIII

APPENDIX A

APPENDIX B

APPENDIX C

APPENDIX D

APPENDIX E

APPENDIX F

APPENDIX G

APPENDIX H

LIST OF TABLES

Table Page

LIST OF PLATES

ACKNOWLEDGMENT

In the investigation of the water resources of the Sacramento River Basin and in the preparation of a plan for their conservation, utilization and distribution, most valuable assistance and cooperation have been rendered by individuals and public and private agencies.

Many individuals, irrigation and reclamation districts, mutual water companies and public utilities have furnished data and information which were particularly useful in the preparation of this report.

Active and material aid in many phases of the investigation was received from departments of the Federal government.

Several departments of the State have cooperated and rendered substantial assistance in making studies and reports on important special subjects.

Special commendation is due the members of the Engineering Advisory Committee whose advice and assistance have been of inestimable value throughout the investigation and in the preparation of the report.

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SPECIAL CONSULTANTS

Consulting geologists and engineers rendered reports on special features of the investigation as follows:

George D. Louderback and Frederick L. Ransome, Consulting Geologists, made a detailed geologic investigation and rendered a report entitled "Geologic Report on the Kennett, Iron Canyon and Table Mountain Dam Sites on Sacramento River," which is presented as Appendix A. Dr. Louderback also made a geologie investigation and rendered a report entitled "Geologic Report on Fairview Dam Site on Trinity River," which is presented as Appendix D.

Hyde Forbes, Engineer-Geologist, made geologic investigations of dam sites on the Feather, Yuba, Bear and American rivers and Stony, Cache and Putah creeks. His report, entitled "Geologic Reports on Dam Sites in Sacramento River Basin," is presented as Appendix E. Mr. Forbes also made an investigation of the underground water conditions in the Sacramento Valley and rendered a report entitled "Geology and Underground Water Storage Capacity of Sacramento Valley," which is presented as Appendix F.

Lester S. Ready, Consulting Engineer, rendered a special report on electric power development in California dealing particularly with the value of the electric energy which could be produced at the major units of the State Water Plan and with the problem of electric power absorption. That special report is the basis for the text of Chapter VIII.

FEDERAL AGENCIES COOPERATING IN INVESTIGATION

WAR DEPARTMENT

THOMAS M. ROBINS, *Lieutenant Colonel, Corps of Engineers, Division Engineer, Pacific Division*

J. R. D. MATHESON, *Major, Corps of Engineers, District Engineer, Sacramento District of Pacific Division*

W. A. WOOD, JR., *Captain, Corps of Engineers*

Under the general direction of Colonel Robins, the general supervision of Major Matheson and the immediate direction of Captain Wood, the War Department carried out an investigation of the water resources of the Sacramento, San Joaquin and Kern rivers with a view to the formulation of general plans for the most effective improvement of navigation and the prosecution of such improvement in combination with the most efficient developments of potential water power and supplies for irrigation, and the control of floods, and rendered a report thereon. The investigation was made under authority of the River and Harbor Act of January 21, 1927, and in accordance with the provisions of House Document No. 308, 69th Congress, 1st Session. The investigations of the State and the War Department were coordinated effectively, resulting in no duplication of effort. The work of the War Department covered special important phases of the investigation, particularly flood control and navigation. Additional exploratory work also was done at the Kennett dam site and at a site on the Sacramento River near Table Mountain and a relocation survey was made for that part of the Southern Pacific railroad which would be flooded by the Kennett reservoir.

DEPARTMENT OF INTERIOR

Bureau of Reclamation
ELWOOD MEAD, *Director*

The Bureau of Reclamation assisted in the exploration of the Table Mountain dam site. Records of explorations previously made by the Bureau at the Iron Canyon dam site also were of great assistance to the geologists during this investigation.

Geological Survey, Water Resources Branch
H. D. MCGLASHAN, *District Engineer*

Studies of the water supply of the Sacramento River Basin were aided by the cooperation rendered by Mr. McGlashan in furnishing advance information on stream flows in the basin and in improving the installations of certain stream-gaging stations maintained for this purpose. Chemical analyses of the waters of several streams of the Sacramento River Basin also were made by this branch of the United States Geological Survey.

DEPARTMENT OF AGRICULTURE

Bureau of Public Roads, Division of Agricultural Engineering
W. W. McLaughlin, *Associate Chief*

Under cooperative agreement, the Division of Agricultural Engineering under the general direction of Mr. McLaughlin and the immediate supervision of Major O. V. P. Stout, made detailed measurements of the consumptive use of water by crops and natural vegetation in the Sacramento-San Joaquin Delta, covering a period of about six years. The results of these measurements played an important part in the investigation.

Weather Bureau
E. H. Bowie, *in Charge of Western States*

The bureau cooperated in furnishing unpublished precipitation records which were of great value in the investigation.

Bureau of Chemistry and Soils
M. H. Lapham, *Inspector, District 5*

The bureau furnished advance data on soil surveys which aided in the land classification.

FEDERAL POWER COMMISSION

F. E. Bonner, *Executive Secretary*

E. W. Kramer, *Regional Engineer, U. S. Forest Service, Representing the Commission in California*

In connection with the investigation of the War Department, Mr. Kramer and J. E. McCaffrey, Senior Hydroelectric Engineer, made a study of the growth of consumption of electric energy in California and the probable value of hydroelectric energy which could be generated at several units of the State Water Plan. Some of the data collected for that study were used in a similar study made for this bulletin.

STATE AGENCIES COOPERATING IN INVESTIGATION

DIVISION OF HIGHWAYS

C. H. PURCELL, *State Highway Engineer*

Under the general direction of Mr. Purcell and the immediate supervision of F. J. Grumm, Engineer of Surveys and Plans, and H. S. Comly, District Engineer. the Division of Highways prepared estimates of the cost of relocating State highways through reservoir sites on the Sacramento and Feather rivers.

RAILROAD COMMISSION OF CALIFORNIA

A. G. MOTT, *Chief Engineer*

The Railroad Commission, through Mr. Mott and N. A. Wood, Assistant Engineer, prepared reports on the economics of the railroad relocations for the Kennett and Oroville reservoirs on the Sacramento and Feather rivers, respectively.

The Commission, through A. V. Guillou, Assistant Chief Engineer, also furnished data on power production and distribution throughout the state and the costs of recent hydroelectric developments.

STATE RECLAMATION BOARD

A. M. BARTON, *Chief Engineer*

The Reclamation Board made available data on the classification of about a million acres of land in the Sacramento Valley, secured during the distribution of assessments for the Sacramento-San Joaquin Drainage District.

CHAPTER 832, STATUTES OF 1929

An act making an appropriation for work of exploration, investigation and preliminary plans in furtherance of a coordinated plan for the conservation, development, and utilization of the water resources of California including the Santa Ana River, Mojave River and all water resources of southern California.

(I object to the item of $450,000 in Section 1 and reduce the amount to $390,000. With this reduction I approve the bill. Dated June 17, 1929. C. C. Young, Governor.)

The people of the State of California do enact as follows:

SECTION 1. Out of any money in the state treasury not otherwise appropriated, the sum of four hundred fifty thousand dollars, or so much thereof as may be necessary, is hereby appropriated to be expended by the state department of public works in accordance with law in conducting work of exploration, investigation and preliminary plans in furtherance of a coordinated plan for the conservation, development and utilization of the water resources of California including the Santa Ana River and its tributaries, the Mojave River and its tributaries, and all other water resources of southern California.

SEC. 2. The department of public works, subject to the other provisions of this act, is empowered to expend any portion of the appropriation herein provided for the purposes of this act, in cooperation with the government of the United States of America or in cooperation with political subdivisions of the State of California; and for the purpose of such cooperation is hereby authorized to draw its claim upon said appropriation in favor of the United States of America, or the appropriate agency thereof for the payment of the cost of such portion of said cooperative work as may be determined by the department of public works.

SEC. 3. Upon the sale of any bonds of this state hereafter authorized to be issued to be expended for any one or more of the purposes for which any part of the appropriation herein provided may have been expended, the amount so expended from the appropriation herein provided shall be returned into the general fund of the state treasury out of the proceeds first derived from the sale of said bonds.

FOREWORD

This report is one of a series of bulletins on the State Water Plan issued by the Division of Water Resources pursuant to Chapter 832, Statutes of 1929, directing further investigations of the water resources of California. The series includes Bulletins Nos. 25 to 36, inclusive. Bulletin No. 25, "Report to Legislature of 1931 on State Water Plan," is a summary report of the entire investigation.

Prior to the studies carried out under this act, the water resources investigation had been in progress more or less continuously since 1921 under several statutory enactments. The results of the earlier work have been published as Bulletins Nos. 3, 4, 5, 6, 9, 11, 12, 13, 14, 19 and 20 of the former Division of Engineering and Irrigation, Nos. 5, 6 and 7 of the former Division of Water Rights and Nos. 22 and 24 of the Division of Water Resources.

The full series of water resources reports prepared under Chapter 832, twelve in number, are:

Bulletin No. 25—"Report to the Legislature of 1931 on State Water Plan."
Bulletin No. 26—"Sacramento River Basin."
Bulletin No. 27—"Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay."
Bulletin No. 28—"Economic Aspects of a Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers."
Bulletin No. 29—"San Joaquin River Basin."
Bulletin No. 30—"Pacific Slope of Southern California."
Bulletin No. 31—"Santa Ana River Basin."
Bulletin No. 32—"South Coastal Basin."
Bulletin No. 33—"Rainfall Penetration and Consumptive Use of Water in Santa Ana River Valley and Coastal Plain."
Bulletin No. 34—"Permissible Annual Charges for Irrigation Water in Upper San Joaquin Valley."
Bulletin No. 35—"Permissible Economic Rate of Irrigation Development in California."
Bulletin No. 36—"Cost of Irrigation Water in California."

This bulletin presents inventories of the water supplies and agricultural lands of the Sacramento River Basin; estimates of the irrigable lands and water requirements of the basin; the present status of irrigation, flood control, navigation and power development; the major units of a plan for the ultimate development and utilization of the water resources of the basin; and a recommendation of a first unit for construction in this development.

CHAPTER I

INTRODUCTION, SUMMARY AND CONCLUSIONS

The Great Central Basin of California occupies more than one-third of the area of the entire state and comprises the northern and central portions lying between the crests of the Sierra Nevada and Cascade Range on the east and the Coast Range on the west, and also the drainage basin of the Pit River lying to the east of the Cascades. Its length and average width are approximately 500 miles and 120 miles, respectively, the length being about 65 per cent and the width 60 per cent of that of the state. The two principal streams of the Great Central Basin, the Sacramento and San Joaquin rivers, form with their many tributaries the two largest stream systems of California. The Sacramento River draining the northern part of the basin, and the San Joaquin River draining the southern part, flow toward each other and through a common mouth into Suisun Bay and thence through San Francisco Bay into the ocean.

The Sacramento River Basin has an area of 26,150 square miles and occupies about one-sixth of the area of the state and 45 per cent of that of the Great Central Basin. The Sacramento Valley which occupies the central portion of the Sacramento River Basin is bounded on the north and east by the Sierra Nevada and on the west by the Coast Range. Its area is about one-fifth of that of the entire Sacramento River Basin. The remaining portion of the basin is foothill and mountain lands with some smaller valleys.

The Sacramento River Basin is devoted largely to agriculture and it is estimated that in 1930 the value of the land, buildings, equipment, and live stock utilized in the industry was about $572,500,000. Almost 6,500,000 acres of agricultural land or about 27 per cent of the total agricultural lands of the State lie in this basin. Conditions are suitable for the production of a large variety of crops among which are deciduous and citrus fruits, olives, nuts, grapes, hops, nearly every variety of vegetable, grain, alfalfa and rice. Dairying and the raising of beef cattle, sheep, hogs and poultry also are important industries. The returns from crops and live stock products from the basin in 1929 amounted to a little over $100,000,000 or about 13 per cent of the total return from these industries in the state.

While the Sacramento Valley in the early days of development was devoted largely to the raising of grain and cattle, the introduction of irrigation made possible the greater variety of crops. The area irrigated in the Sacramento River Basin increased from less than 100,000 acres in 1880 to about 860,000 acres in 1929. The latter area is about 13 per cent of that of the total agricultural lands of the basin and one-fifth of the net irrigable area. About three-fourths of the total increase from 1880 to 1929 occurred in the last two decades, due largely to the increase in orchard and rice plantings. Further increase will be controlled largely by the development of water supplies through the storage of winter run-off from the mountains.

Manufacturing in the Sacramento River Basin is second only to agriculture as a source of income and, if lumber is included in the manufactured products, produces more than 35 per cent of the basic income from all industries in the basin. The most important manufactured products are lumber and canned and preserved fruits. The income in the basin from the value added by manufacture, in 1929, amounted to about $47,340,000 or 3.5 per cent of the total for the entire state.

A large amount of both hydroelectric and steam-electric energy is also produced in the Sacramento River Basin. Some of this energy is used within the basin and the remainder is transmitted to the area around San Francisco Bay and to the San Joaquin Valley. The power plants of the basin have an installed capacity of about 600,000 kilovolt amperes and in 1929 produced about 2,480,000,000 kilowatt hours of electric energy or about 28 per cent of the total production of the state.

Mining was largely responsible for the early development of the Sacramento River Basin but it has been surpassed in importance by many other industries. However, it is still an important source of income in many parts of the basin. In the early days, the principal form of mining was the working of auriferous gravels by the hydraulic process. This form of mining sent millions of cubic yards of debris down into the streams of the valley and out over adjacent farm lands during the flood periods. To protect these streams for navigation and the agricultural lands from destruction, this form of mining was practically terminated by a Federal court decision in 1884. Some hydraulic mining is now carried on behind dams to restrain the debris and there is considerable working of auriferous gravels by gold dredgers. While gold is still the most important mineral produced, copper, silver, lead, quicksilver, building stone, limestone, pottery and brick clays, and several other minerals add to the income from the mining industry. The value of all of these mineral products from the Sacramento River Basin in 1929 amounted to about $15,000,000.

The present population of the Sacramento River Basin is about 350,000, a little more than six per cent of that of the state. It can be classified as about half urban and half rural. The largest city in the area is Sacramento, the capital of the state, and the industrial and commercial center of the Sacramento Valley and its environs. It has a population of nearly 100,000. Chico, Roseville and Marysville, the next largest urban centers, have populations of only 7900, 6400 and 5800, respectively. The population of the basin increased about 83,000 in the last decade, or 32 per cent, as compared to a 65 per cent increase for the entire state.

The basin, especially the Sacramento Valley, is well served by transportation facilities. It is traversed from north to south by the Southern Pacific Railroad, which has two main lines through the Sacramento Valley, and by the combined Western Pacific and Great Northern railroads. The main line of the Western Pacific Railroad also continues eastward by way of the Feather River Canyon across the Sierra Nevada and gives a transcontinental outlet to the east. One of the Southern Pacific Railroad's transcontinental lines also crosses the basin from east to west, crossing the Sierra Nevada between the American and Yuba

River basins. There are also numerous branches from the main line railroads into the mountains and different parts of the valley. An electric line, the Sacramento-Northern Railway, connects Sacramento, Chico, Oroville, Woodland and several other Sacramento Valley towns with the San Francisco Bay area, and another electric line connects Sacramento and Stockton. The only river on which navigation is feasible at the present time is the Sacramento. This stream is an important artery of transportation below the city of Sacramento throughout the year and above that city for a part of each year. A network of improved highways throughout practically the entire basin also provides facilities for rapid motor truck transportation, either for short or long hauls, and such transportation is now a competitor with that by both rail and water.

Previous Investigations.

Investigations of the water resources of the Great Central Basin with a view of utilizing the water for the greatest beneficial uses have been made at various times over a long period of years. Some of the more important of these are enumerated in the following paragraphs:

In 1873 an investigation was made by the United States War Department and a plan was outlined for utilizing the water supply to the greatest advantage for irrigation purposes.

The first effort of the State to launch a comprehensive investigation of its water resources and offer a solution of the problem concerning water utilization was made in 1878 and resulted in "an act to provide a system of irrigation, promote rapid drainage and improve navigation on the Sacramento and San Joaquin river." Under this act, investigations were carried out by the State Engineer, William Ham. Hall. He, like the Army engineers in 1873, suggested that the water of the Great Central Valley be developed in a systematic manner. Several reports and maps were published by the State Engineer between 1880 and 1888.

In 1900, the United States Department of Agriculture, Office of Experiment Stations, made an investigation of irrigation conditions and recommended certain changes in the water laws of the State.

In 1906, a report on hydrographic investigations in the Sacramento Basin, California, was prepared by S. G. Bennett, engineer for the United States Reclamation Service. This report summarized data on irrigation and reclamation from other reports and described a number of reservoir sites and possible storage and irrigation projects in the basin.

Another State investigation was made in 1911 through a special board called the "Conservation Commission," which issued a report on its findings.

In 1912, the United States Department of Agriculture made an investigation and issued a bulletin dealing with the irrigation resources and their development.

The State investigations known as "The California Water Resources Investigations" were initiated in 1921. These investigations were carried out under the direction of the State Engineer. Further investigations were authorized by the Legislature of 1925.

Scope of Present Investigation.

Irrigation development of the lands in the Sacramento River Basin has now reached the point where in dry years with present storage facilities there is insufficient water for full requirements. The important water problem in this and the upper San Francisco Bay basins is the invasion of saline water into the Sacramento-San Joaquin Delta channels and upper San Francisco Bay, which renders the water unfit for irrigation and industrial process uses. Also, flows in the upper Sacramento River in some of the recent dry years have been so low that navigation on that stream has been impaired. These unfavorable conditions could be improved by the construction and operation of storage facilities above the valley floor. These storage facilities could also be utilized effectively to reduce flood flows that now menace productive and improved lands and urban centers in the valley.

In the San Joaquin Valley, a very serious water situation now exists. Highly developed lands are overdrawing the water supplies which are naturally available to them. Water must be obtained from an outside source if these lands are to be maintained in production. Furthermore, in the San Joaquin River Basin the total water supply is insufficient to meet the ultimate water requirements for full development of that basin. There is and will be a deficiency in water supplies therein. In the Sacramento River Basin, on the other hand, the water supply if adequately regulated and conserved, is larger than will be required for ultimate development of that basin. The Sacramento River Basin, therefore, is the logical source of an additional supply for the San Joaquin River Basin.

The present investigation, therefore, has been directed primarily toward the formulation of a plan for a system of works which would conserve and make available water supplies for the present and ultimate needs of the Sacramento River Basin for all purposes and also for supplemental supplies for needs in the San Joaquin River and San Francisco Bay basins. Because of the close interrelation between the basins, they have been considered as one geographic division in the formulation of this State Water Plan for the Great Central Valley.

In the formulation of the State Water Plan, studies were made covering the San Joaquin River Basin; the salinity and irrigation conditions in the Sacramento-San Joaquin Delta and upper San Francisco Bay Basin, including a study of the economy of constructing a barrier at some point below the lower end of the delta to prevent the invasion of saline water into it; and the Sacramento River Basin. This bulletin presents for the Sacramento River Basin, the available water supply, an inventory of the agricultural lands, the present irrigation development and an estimate of the area of lands suitable for irrigation, the ultimate water requirements for all purposes, the present status of flood control and navigation and the effect of the State Water Plan on these items, the present power development and the value of hydroelectric energy, the major units of an engineering plan for the ultimate development of the water resources of the basin, and the unit of the ultimate plan which should be initially constructed. A discussion of the relation of the State Water Plan to the resumption of hydraulic mining and data on the riparian lands along the Sacramento and American rivers also are presented.

The water supply studies were made to estimate the run-offs at various points for the 40-year period 1889–1929. These estimates were based on records of precipitation in the basin for the entire period and on stream flow measurements which were started as early as 1895 and which are available for about 25 years on streams contributing approximately 90 per cent of the run-off from the mountain areas. Estimates of full natural run-offs were made for all of the major streams and groups of minor streams. Full natural run-offs and those under present and ultimate conditions of development, at the dam sites of the major reservoir units in the Sacramento River Basin, also were estimated. The present and ultimate net run-offs, estimated for the 40-year period 1889–1929, were used in the reservoir studies. Studies also were made of the distribution of the run-off and the occurrence and distribution of return waters and ground water.

In order to determine the water requirements of the entire Sacramento River Basin and especially those portions of the basin which could be served from the major reservoir units of the State Water Plan in the basin, a classification was made of all agricultural lands in the Sacramento Valley and adjacent foothills on the basis of their adaptability for irrigation. This classification covered an area of about 8,750,000 acres of which 7,750,000 acres were classified in the field, utilizing soil surveys, where available, as a guide. The other 1,000,000 acres were classified from data previously obtained by the State Reclamation Board. The areas of agricultural and irrigable lands in the mountain valleys were obtained from former surveys.

Coincidently with the classification of the agricultural lands, a survey was carried on to determine the crops now grown on the lands classified. This survey was made for the purpose of determining the areas of the different kinds of crops, the locations in which they are grown and the adaptability of certain localities to the growing of different types of crops.

An independent survey also was made to determine the number of acres irrigated in 1929 in the Sacramento River Basin and the portions of this area which were irrigated from surface water supplies and from ground water, respectively. Data also were obtained on the water requirements for these irrigated lands by crops and the losses incident to the application of the water.

Based on the data obtained from the foregoing surveys, estimates were made of the net areas suitable for irrigation in the Sacramento River Basin and the ultimate water requirements for the full development of these lands. The requirements were estimated for the mountain and foothill areas above the major reservoir units, for the area which would be served by each reservoir, for the lower Sacramento Valley area which could be served from both the Sacramento and Feather rivers, and for the entire Sacramento-San Joaquin Delta. For each division, estimates were made of the gross allowance or diversion, the net allowance or water delivered to the fields, and the net use of water or the amount from which no return would be available.

Since the major reservoir units of the State Water Plan would be strategically located for the control of floods, estimates were made of maximum flood flows which might occur at certain intervals of time at the foothill gaging stations on the major streams and the effect of the reservoirs in reducing the sizes of these flows before they reach the valley floor. Estimates also were made of the effects of the reservoirs in reducing the sizes of concentrated flood flows at certain points on the valley floor and the benefits to be derived from these reductions in decreasing the cost of works for flood control and in increasing the degree of protection now afforded by the works of the Sacramento Flood Control Project.

Navigation on the Sacramento River is an important element in the transportation facilities in the Sacramento Valley. However, on account of the large upstream diversions and the recent abnormally low run-offs, navigation above Sacramento has been greatly impaired. Navigation conditions, above Sacramento, however, could be improved either by installing dams and locks in the river to form pools or by increasing the stream flows by releasing water stored in upstream reservoirs. Studies, therefore, were made to estimate the effect of the operation of the major reservoir units of the State Water Plan, and especially the Kennett reservoir, on the improvement of navigation by the latter method.

The production of electric energy in connection with the operation of the major reservoir units of the State Water Plan, and the use of the revenue from the sale of this energy to help defray the cost of the project are important elements in the economic feasibility of the plan. Studies, therefore, were made to determine the amounts of energy which would be generated, the rate at which the energy could be absorbed by the power market, the unit value of the energy, and the returns from the reservoir units under different methods of operation.

The major units of the State Water Plan for the Sacramento River Basin comprise eleven reservoirs, three afterbays, a diversion conduit from the Trinity River, power plants at some of the reservoirs and several power drops. Many studies were made to determine the best location for, and the most economic size of, each unit for inclusion in the State Water Plan. Topographic surveys were made of all reservoirs and dam sites for which maps were not available and of conduit lines for the Trinity River diversion. Field examinations of reservoir sites were made to appraise the values of lands and improvements which would be submerged and these values were checked by comparison with data from county assessors and other sources. Some of the dam sites were explored by shafts, tunnels and core drillings, and geologic studies by competent geologists were made of all sites. From these geologic data, estimates were made of the depths of excavation necessary to obtain satisfactory foundations for the dams. Data also were obtained on unit costs of materials and all parts of the construction work and on the probable length of time required for construction. With these data and the estimated quantities involved in different parts of the construction, estimates were made of the costs of the dams, reservoirs, power plants and conduits. Data also were obtained on the costs of operation and maintenance of the different features of the units and with these data and assumed interest and amortization charges, estimates were made of annual costs.

Studies were made to estimate the total seasonal irrigation yields and the yields in new water which would have been available from each major reservoir unit during the 40-year period 1889–1929, and, where power plants would be included in the units, the incidental yield of electric energy. Other studies were made to estimate the electric energy outputs with the units operated primarily for the generation of power, and the incidental yield of water for irrigation. With these data and the annual costs, the gross and net annual unit costs of total irrigation yields and yields in new water were estimated. These unit costs were used for comparing the different units on the basis of the cost of irrigation water.

Analyses were made of the coordinated operation of all of the major units of the State Water Plan in the Great Central Basin under conditions of ultimate development of the Sacramento River Basin and two different degrees of development of the San Joaquin River Basin. These studies covered the period of abnormally low run-off, 1918–1929, and were made to show the accomplishments in controlling floods, controlling salinity in the Sacramento-San Joaquin Delta, providing a supplemental supply to the San Francisco Bay Basin, providing irrigation supplies for the Sacramento and San Joaquin River basins, improving navigation on the Sacramento and San Joaquin rivers, and generating hydroelectric energy incidental to the other accomplishments. These studies were made to show, also, the amounts of surplus water from the Sacramento River Basin with the major units in operation and with the water requirements of the basin fully supplied.

The studies of amounts and costs of irrigation yields from the Sacramento River Basin units of the State Water Plan were analyzed for the purpose of selecting a unit for initial development in the basin. These studies showed that the most likely development would be the Kennett or American River unit. These units, therefore, were analyzed for accomplishments and costs and were compared on these bases to determine which would be the more favorable initial development. In making this comparison, each unit was operated to control floods; to furnish water for the irrigation of lands along the stream on which it would be located and the lands in the Sacramento-San Joaquin Delta; to furnish water for salinity control; to improve navigation; to furnish water which would be surplus to these uses for exportation to lands having a deficiency in supply; and to generate hydroelectric energy incidental to all the other uses. Estimates also were made of the annual costs of the units, the average annual returns from the sale of electric energy, and the net costs chargeable to the benefits. Analyses also were made of each unit operated coordinately with the initial units in the San Joaquin River Basin, to estimate the flows into the Sacramento-San Joaquin Delta, the requirements from these flows, the surplus water above all requirements in both valleys, and the flows into Suisun Bay. The units were then compared on the bases of accomplishments and net annual costs for these accomplishments and from these comparisons the unit for initial development was selected.

The construction of certain major reservoir units in the Sacramento River Basin would afford an opportunity for the resumption of hydraulic mining of auriferous gravels in the foothills of the Sierra

Nevada, if these reservoirs were used for the storage of mining debris. Data, therefore, were obtained from published reports on the amounts of gravels remaining on the different streams and the storage space required to restrain the debris from the hydraulic mining of these gravels. Studies were then made of the effect of the utilization of storage space in certain major reservoir units on the conservation values of these reservoirs, and also of the effect of some of the major reservoir units on other debris storage sites.

In order to give a general conception of the magnitude of the problem presented by the riparian doctrine with reference to the Sacramento River Basin developments, studies were made to estimate the extent of the lands riparian by contact with the Sacramento and American rivers, the present use of water on these lands, and the ultimate water requirements for their full development.

The water supply studies pertaining to the State Water Plan in the Sacramento River Basin, and contained in the body of this report, are based on the estimated surface run-offs which occurred in the 40-year period 1889–1929. This period is one of wide variability of run-off. It includes the dry years of 1920 and 1924, the flood years of 1907 and 1909, and the season of exceptionally large run-off 1889–1890. Since the completion of the studies which were based on the available water supplies for the 40-year period 1889–1929, and on which the major units of the State Water Plan for initial and ultimate development are proportioned, two seasons of low run-off have occurred, 1929–1930 and 1930–1931. Therefore, it was deemed desirable to test the adequacy of the plans proposed for initial and ultimate developments of the Sacramento River Basin by the inclusion of these years in the water supply analyses, and if either plan were found inadequate, to point out wherein, if possible, a modification of it could be made which would assure dependable supplies to all areas served by the plan. This has been done and the results of the analyses and investigations are given in Appendix H.

Summary.

In the following chapters of this report, somewhat detailed presentations are given of the studies and results obtained in evolving the portion of the State Water Plan for the Sacramento River Basin. A summary of the results of the investigation is given in the remaining portion of this chapter.

Water Supply.—The Sacramento River Basin, while occupying only 16.8 per cent of the total area of California, yields from its mountainous portion 34.8 per cent of the total water supply from the entire mountainous area of the state. The basin is drained by the Sacramento River and its numerous tributaries. The major streams and groups of minor streams are shown in the following table. This table also shows the areas of the drainage basins and the mean seasonal full natural run-offs from the mountain and foothill areas. The contributions to the surface run-off and ground water replenishment, from rainfall on the valley floor, are not included because of the lack of definite knowledge on this subject.

FULL NATURAL RUN-OFFS

Stream	Drainage area, in square miles	Seasonal full natural run-off, in acre-feet (Season October 1 to September 30)			
		Mean for 40-year period 1889–1929	Mean for 20-year period 1909–1929	Mean for 10-year period 1919–1929	Mean for 5-year period 1924–1929
Sacramento River at Kennett dam site	[1]6,649	[1]6,149,000	[1]5,379,000	[1]4,745,000	[1]5,060,000
Sacramento River at Red Bluff	9,258	9,354,000	7,898,000	6,775,000	7,351,000
Feather River at Oroville	3,627	5,201,000	4,271,000	3,594,000	3,652,000
Yuba River at Smartsville	1,200	2,653,000	2,240,000	2,083,000	2,143,000
Bear River at Van Trent	262	402,000	328,000	298,000	298,000
American River at Fairoaks	1,919	3,069,000	2,624,000	2,267,000	2,285,000
Stony Creek at mouth of canyon	710	514,000	379,000	316,000	386,000
Cache Creek at Capay dam site	996	762,000	595,000	531,000	634,000
Putah Creek at Winters	655	442,000	332,000	273,000	324,000
Mill Creek group	971	1,131,000	903,000	809,000	872,000
Butte Creek group	251	464,000	357,000	332,000	337,000
Honcut Creek group	314	194,000	144,000	125,000	138,000
Dry Creek	79	48,600	38,800	35,600	37,100
Coon Creek group	210	34,700	25,500	23,300	23,300
Red Bank Creek group	109	79,400	68,700	67,500	79,300
Elder Creek group	414	352,000	302,000	305,000	368,000
Willow Creek group	394	100,000	86,900	85,300	99,600
Trinity River at Fairview dam site	[2]667	[2]1,201,000	[2]1,021,000	[2]900,000	[2]1,064,000
Totals for Sacramento River Basin	21,369	24,800,700	20,592,900	17,919,700	19,027,300

[1] Amount included is that for Sacramento River at Red Bluff and therefore is not added in obtaining total.
[2] Not added in obtaining totals.

All of the full natural run-off of any stream, at the site for the major reservoir unit of the State Water Plan on that stream, is not now available, and in the future probably even less will be available, for conservation by the reservoir. The "present net run-offs" at any point are those which would occur under present conditions of development in the tributary drainage basin. The "ultimate net run-offs" are those which would occur with ultimate, instead of present conditions of development in the tributary drainage basin. These present and ultimate net run-offs were used in the reservoir studies to obtain yields under present or ultimate conditions. The mean seasonal amounts at the reservoir sites are set forth in the following tables:

PRESENT NET RUN-OFFS

Stream	Drainage area, in square miles	Seasonal present net run-off, in acre-feet (Season October 1 to September 30)			
		Mean for 40-year period 1889–1929	Mean for 20-year period 1909–1929	Mean for 10-year period 1919–1929	Mean for 5-year period 1924–1929
Sacramento River at Kennett dam site	6,649	5,963,000	5,193,000	4,558,000	4,874,000
Sacramento River at Red Bluff	9,258	9,076,000	7,620,000	6,498,000	7,073,000
Feather River at Oroville	3,627	4,910,000	4,033,000	3,383,000	3,414,000
Yuba River at Narrows dam site	1,108	2,240,000	1,846,000	1,700,000	1,734,000
American River at Folsom dam site	1,875	3,058,000	2,618,000	2,264,000	2,283,000
North Fork of American River at Auburn dam site	965	1,818,000	1,562,000	1,359,000	1,378,000
South Fork of American River at Coloma dam site	708	1,024,000	891,000	769,000	768,000

ULTIMATE NET RUN-OFFS

Stream	Drainage area, in square miles	Seasonal ultimate net run-off, in acre-feet (Season October 1 to September 30)			
		Mean for 40-year period 1889–1929	Mean for 20-year period 1909–1929	Mean for 10-year period 1919–1929	Mean for 5-year period 1924–1929
Sacramento River at Kennett dam site	6,649	5,725,000	4,987,000	4,339,000	4,648,000
Sacramento River at Red Bluff	9,258	8,567,000	7,166,000	6,053,000	6,581,000
Feather River at Oroville	3.627	4,647,000	3,791,000	3,155,000	3,190,000
Yuba River at Narrows dam site	1,108	2,032,000	1,639,000	1,492,000	1,529,000
Bear River at Van Trent	262	370,000	299,000	273,000	268,000
American River at Folsom dam site	1,875	2,918,000	2,477,000	2,124,000	2,142,000
North Fork of American River at Auburn dam site	965	1,667,000	1,411,000	1,20[illegible],000	1,227,000
South Fork of American River at Coloma dam site	708	932,000	841,000	718,000	718,000
Stony Creek at Millsite dam site	597	364,000	254,000	203,000	253,000
Cache Creek at Capay dam site	996	484,000	331,000	270,000	344,000
Putah Creek at Monticello dam site	620	385,000	282,000	227,000	273,000
Trinity River at Fairview dam site	667	1,149,000	972,000	855,000	1,013,000

In the Sacramento River Basin, a large potential water supply is that which, once used for irrigation, domestic or other purposes, would return to the streams either as direct drainage or as inflow from the ground water basins. The return waters from the mountain and foothill areas would be available for reregulation in the major reservoir units of the State Water Plan. The return waters from valley floor lands would enter the streams or artificial drains, from which they could be diverted for reuse on lands at lower elevation in the valley. All return waters not used in the Sacramento Valley would flow into the Sacramento-San Joaquin Delta where they would be available for use or for exportation to other areas. Studies made of this return water indicate that about four-tenths of all water diverted for irrigation on the Sacramento Valley floor, under a condition of ultimate development, would reach the streams as return water. It also was estimated that 75 per cent of this return water would reach the valley streams during the irrigation months of April to October, inclusive, with a regimen that would approximately synchronize with the irrigation demand. The water returning at such times that it could be reused would be equivalent to additional run-off in so far as water supply for lands on the lower reaches of the streams is concerned. Under conditions of ultimate development, the return waters which could not be regulated by the major reservoir units would amount to 4,190,000 acre-feet per year.

Another source of supply is water collected and stored in underground basins. It is estimated that in the Sacramento Valley there are approximately 3,000,000 acre-feet of available storage space in such basins. In proportioning the physical works of a plan for the utilization of the water resources of the Sacramento River Basin, however, no account was taken of the availability of the underground storage capacity in the basin. If the underground storage were operated in conjunction with surface storage, a greater use could be made of the run-offs of the tributary streams since some of the water which would be wasted into the ocean in the winter season could be stored in these underground reservoirs and used in seasons or cycles of low surface run-off.

Agricultural Lands.—The agricultural lands in the Sacramento River Basin include about 28.6 per cent of those of the entire state. The classification of agricultural lands on the basis of their adaptability for irrigation made during the present investigations covered those lands lying in the Sacramento Valley and adjacent foothills and also all of the lands in the entire Sacramento-San Joaquin Delta, the San Joaquin portion being included with the Sacramento Valley since a large part of the water supply for the entire delta naturally comes from the Sacramento River Basin. The lands were divided into five classes, the first four of which are considered as agricultural and the fifth as having no present or potential agricultural value. The character of the soil and topographic and surface features determined the class in which each parcel of land was placed. A certain percentage of each class of agricultural land was estimated to be capable of irrigation and these percentages applied to the areas of the respective classes of land in any tract, gave the irrigable area of that tract. The gross agricultural and net irrigable areas in the basin, estimated during this investigation, are shown in the following table:

AREAS OF AGRICULTURAL AND IRRIGABLE LANDS

Section	Gross agricultural area		Net irrigable area	
	In acres	In per cent of total	In acres	In per cent of total
Valley floor	3,499,000	54.4	2,640,000	61.9
Foothill area	2,099,000	32.6	922,000	21.6
Mountain valleys	416,000	6.5	312,000	7.3
Sacramento Delta	142,000	2.2	135,000	3.2
San Joaquin Delta	279,000	4.3	257,000	6.0
Totals	6,435,000	100 0	4,266,000	100.0

A crop survey which was made of the classified area of the Sacramento Valley and adjacent foothills to determine the areas of different kinds of crops, the locations in which they are grown, and the adaptability of certain localities to the growing of different types of crops, showed that on the 2,222,000 acres planted in 1929 in the counties lying wholly or partly in the Sacramento River Basin, the crops were distributed as follows:

Citrus and olives	0.7 per cent	Field crops	5.5 per cent
Deciduous orchard	13.7 per cent	Cotton	0.5 per cent
Vines	3.1 per cent	Truck	5.9 per cent
Grain	55.0 per cent	Rice	10.1 per cent
Alfalfa and sudan grass	5.5 per cent		

The inventory value of all farm lands and buildings, farm implements and machinery, and live stock, in the Sacramento River Basin in 1930 was estimated from the Fourteenth Census of the United States to be $572,551,000. The total value of crops and live stock products from the basin in 1929 was estimated from the same census to be $102,272,000.

Irrigation Development.—Irrigation development in the Sacramento River Basin has increased greatly in the last two decades, about 65 per cent of the area now irrigated having been brought under irrigation in that period. A survey and other data collected during the present investigation indicate that there were about 857,000 acres irrigated in 1929 in the Sacramento River Basin. These lands were distributed as follows: 550,000 acres on the valley floor outside of the Sacramento-San Joaquin Delta, 103,000 acres in the Sacramento Delta, 66,000 acres in the Sierra Nevada foothills adjacent to the valley, and 138,000 acres in the mountain valleys. The survey and study made to estimate the area irrigated on the Sacramento Valley floor and in the surrounding foothills showed that of the 719,000 acres irrigated in these areas in 1929, about 203,000 acres received water by pumping from underground supplies and the remainder received a water supply from surface streams.

Irrigation water is furnished in the Sacramento River Basin by irrigation districts, public utility companies, mutual water companies, the United States Bureau of Reclamation, reclamation districts, individuals and private companies.

Water Requirements.—While water is required in the Sacramento River Basin for domestic, municipal, irrigation, industrial, salinity control and navigation purposes, the use for irrigation does and probably will continue to predominate. It, therefore, was used as the principal basis in estimating the water requirements of the basin. A considerable amount of water, in addition to that used for irrigation, would be required to maintain flows in the Sacramento River for navigation and to control salinity to the lower end of the Sacramento-San Joaquin Delta. The requirement for salinity control would be a minimum continuous flow of 3,300 second-feet past Antioch into Suisun Bay, which would amount to 2,390,000 acre-feet annually. The requirement for navigation would be a minimum flow of 5000 second-feet in the Sacramento River.

ULTIMATE SEASONAL WATER REQUIREMENTS OF IRRIGABLE LANDS IN SACRAMENTO RIVER BASIN, INCLUDING THE SACRAMENTO-SAN JOAQUIN DELTA

Section	Net irrigable area, in acres	Gross allowance, in acre-feet		Net allowance, in acre-feet		Net use, in acre-feet	
		Total	Average per acre	Total	Average per acre	Total	Average per acre
Mountain valleys	312,000	936,000	3.00	562,000	1.80	562,000	1.80
Foothill areas	922,000	2,305,000	2.50	1,383,000	1.50	1,383,000	1.50
Valley floor	2,640,000	9,033,000	3.42	6,025,000	2.28	5,190,000	1.97
Sacramento Delta	135,000	376,000	(1)	376,000	(1)	376,000	(1)
San Joaquin Delta	257,000	824,000	(1)	824,000	(1)	824,000	(1)
Totals	4,266,000	13,474,000		9,170,000		8,335,000	

[1] Value for net use per unit of area is not given since ultimate total requirements and use are divided among irrigation use, evaporation from delta channels, transpiration from tules and other natural vegetation and evaporation from levees and uncultivated land surfaces.

The estimated seasonal water requirements for irrigation use under a condition of ultimate development of all irrigable lands in the Sacramento River Basin and the entire Sacramento-San Joaquin Delta, are given in the foregoing table. The different terms in the table covering allowances and use of water are defined as follows:

> "Gross allowance" designates the amount of water diverted at the source of supply.
> "Net allowance" designates the amount of water actually delivered to the area served.
> "Net use" designates the sum of the consumptive use from artificial supplies, and irrecoverable losses.
> "Consumptive use" in the foregoing definition designates the amount of water actually consumed through evaporation, and transpiration by plant growth.

Flood Control.—A plan for flood control in the Sacramento Valley has been adopted by the State of California and the United States Government and is the one under which all flood control and protection works must now be constructed. Under this plan, flood waters are carried in the stream channels and in by-passes which are provided to carry flows in excess of the capacities of the natural channels. Levees along the natural channels and by-passes protect the lands which are subject to inundation. Works under this plan have been largely completed but some areas are still unprotected. Recent studies also indicate that the quantities of flow provided for in the plan may be exceeded on an average of two to seven times in 100 years in different parts of the system.

Floods also may be controlled by storing flows in excess of channel capacities in reservoirs in the foothills and releasing the stored water after the flood crest has passed. This means of control also may be utilized to increase the degree of protection afforded by works already constructed or to be constructed under the adopted flood control project.

The reservation and utilization of storage space for flood control are proposed in the Kennett reservoir and in each of the major reservoir units of the State Water Plan on the east side of the Sacramento Valley. These reservoirs, the space which would be reserved during the flood season and the control which would be obtained are shown in the following table:

RESERVOIR SPACE TO BE RESERVED FOR CONTROLLING FLOODS TO CERTAIN SPECIFIC AMOUNTS

Reservoir	Stream	Point of control	Maximum reservoir space reserved, in acre-feet	Controlled flow, in second-feet	Number of times controlled flow would be exceeded on the average
Kennett	Sacramento River	Red Bluff	512,000	[1]125,000	Once in 14 years
Oroville	Feather River	Oroville	521,000	100,000	Once in 100 years
Narrows	Yuba River	Smartsville	272,000	70,000	Once in 100 years
Camp Far West	Bear River	Van Trent	50,000	20,000	Once in 100 years
Folsom	American River	Fairoaks	[2]175,000	[2]100,000	One day in 100 years

[1] Mean daily flow on day of flood crest. Floods would be controlled to 125,000 second-feet maximum flow exceeded once in 100 years on the average, except when this amount is exceeded by the uncontrolled run-off between Kennett reservoir and Red Bluff. Flows greater than 125,000 second-feet would continue for only a short time.

[2] With space reserved for flood control as follows: Folsom reservoir, 175,000 acre-feet; Auburn reservoir, 90,000 acre-feet; Coloma reservoir, 35,000 acre-feet; flows at Fairoaks could be controlled to 80,000 second-feet exceeded one day in 250 years on the average.

The flows at six points of concentration in the Sacramento Valley, without and with flood control by the reservoirs shown in the preceding table, would be as follows:

FLOOD FLOWS IN SACRAMENTO VALLEY WITHOUT AND WITH RESERVOIR CONTROL

Stream and point of concentration	Maximum mean daily flow, in second feet		Number of times flow would be exceeded, on the average
	Without reservoir control	With reservoir control	
Sacramento River at Red Bluff	303,000	[1]187,000	Once in 100 years
Sacramento River at Red Bluff	218,000	[1]125,000	Once in 14 years
Sacramento River and Sutter-Butte By-pass opposite Colusa	370,000	250,000	Once in 100 years
Sacramento River and Sutter-Butte By-pass opposite Colusa	254,000	170,000	Once in 14 years
Sacramento River at Sacramento and Yolo By-pass at Lisbon	670,000	535,000	Once in 100 years
Feather River below confluence with Yuba River	400,000	201,000	Once in 100 years
Feather River below confluence with Bear River	430,000	226,000	Once in 100 years
American River at Fairoaks	185,000	80,000	Once in 250 years

[1] Floods would be controlled to 125,000 second-feet maximum flow exceeded once in 100 years on the average, except when this amount is exceeded by the uncontrolled run-off between Kennett reservoir and Red Bluff. Flows greater than 125,000 second-feet would continue for only a short time.

With flood flows controlled to the amounts shown in the second preceding table, the amounts of flow provided for in the flood control project in the Sacramento Valley would be greatly reduced, or the average length of the period between their probable times of occurrence would be increased. The effect, at five points, of this reservoir control is shown in the following table:

FREQUENCIES OF EXCEEDENCE OF SACRAMENTO FLOOD CONTROL PROJECT QUANTITIES

	Points of concentration on Sacramento Valley floor				
	Sacramento River and Sutter-Butte By-pass opposite Colusa	Sacramento River at Verona and Yolo By-pass at Fremont Weir	Sacramento River at Sacramento and Yolo By-pass at Lisbon	Feather River below confluence of	
				Feather and Yuba rivers	Feather and Bear rivers
Flood control project quantity, in second-feet	260,000	470,000	600,000	277,000	295,000
Probable number of times quantity may be exceeded in 100 years on the average—					
Without reservoir control	6.5	2.5	1.8	7.3	6.3
With reservoir control	Less than once	Less than once	Less than once	Less than once	Less than once

It is estimated that with floods in the American River controlled to 100,000 second-feet at Fairoaks, a channel 1000 feet in width would be sufficient to protect the lands along the river from overflow, whereas, without control to this amount, a channel 2400 feet in width is required. The net saving in the cost of flood protection with the 1000-foot channel plan, taking into account the cost of flood control works in the Folsom dam, would be about $250,000 and over 3300 acres more land would be protected.

The control of floods to 100,000 second-feet by the Oroville reservoir would permit the construction of lower levees from Oroville to Marysville than are proposed in the Sacramento Flood Control Project, or if the project levees were constructed, would give a greatly increased degree of protection to the lands along this section of the Feather River. This control also would increase the degree of protection of lands already protected by the works of the flood control project downstream from Marysville.

The control of floods by the Kennett reservoir would increase the degree of protection of all lands in the Sacramento Flood Control Project along the Sacramento River and would permit the protection of the lands in Butte Basin at a reasonable cost. It is estimated that the operation of the Kennett reservoir for flood control would reduce the flood flows in the Sacramento River so that works for the protection of Butte Basin against these flows could be constructed at a cost $9,430,000 less than that for works required to care for the quantities proposed in the Sacramento Flood Control Project, with the same degree of protection to the lands in the basin.

Navigation.—The Sacramento River is the only important navigable stream in the Sacramento Valley outside of the Sacramento Delta, but the Feather River and the lower mile or two of the American River also could be made navigable. The water-borne commerce of the Sacramento River Basin is large, and substantial investments have been made in floating equipment and in terminal facilities. However, on account of recent low run-offs and the development of irrigation in the Sacramento Valley, the navigability of the upper Sacramento River has been greatly impaired.

Navigation above Sacramento can be improved in either of two ways, by ''canalization'' or by ''stream flow regulation.'' With the canalization method, the necessary navigable depths would be secured by the installation of dams across the stream channel to form pools. Locks would be incorporated into the dams to provide for the passage of vessels. The other method would be to supplement the stream flow by the release of water stored in upstream surface reservoirs, in sufficient amounts and at the proper time, to provide the required depths for navigation. With this latter method, some channel rectification also would be necessary.

Under the stream-flow regulation method, an opportunity is afforded to improve and restore navigation on the Sacramento and Feather rivers by the utilization of the reservoirs of the State Water Plan for that purpose. The reservoirs which could be so utilized are the Kennett on the upper Sacramento River, Oroville on the Feather River, Narrows on the Yuba River and Folsom, Auburn and Coloma on the American River. The American River reservoirs would be useful only in aiding navigation on the Sacramento River below the city of Sacramento and for a short distance up the American River. The Oroville and Narrows reservoirs could be utilized toward restoring navigation on the Feather River to a certain extent, and in aiding navigation on the Sacramento River below its confluence with the Feather River. The Kennett reservoir would be strategically located to improve the Sacramento River for navigation from its mouth upstream to Red Bluff, a distance of 249 miles.

The economic importance of maintaining navigation on the Sacramento River is recognized generally by the local shippers, the State and the Federal Government. The latter agency, in accord with its well established policy, has expended substantial sums in maintaining and improving the navigability of this stream. A ten-foot depth is now maintained below the city of Sacramento but the low stream flows during recent years and increased irrigation diversions, have resulted in the reduction of depths above Sacramento in the summer and fall months to such an extent that there was no navigation on this section of the river during these months. Studies have recently been made by the Army engineers to estimate the economic value of further improvement of navigation on the section of the Sacramento River above Sacramento. The estimated economic value as published in a preliminary report * by the Division Engineer, Pacific Division, United States War Department, however, is believed to be too low and it is thought that further study will indicate a much greater value, probably as much as the cost of canalization of the river from Sacramento to Red Bluff. Furthermore, it is believed that the same improvement could be accomplished by the operation of the Kennett reservoir, combined with some open channel improvement, as by canalization and that the value of the reservoir for the improvement of navigation would be equal to the necessary expenditure for canalization from Sacramento to Red Bluff.

Power Development.—It is feasible in connection with the operation of the major reservoir units of the State Water Plan, to develop hydroelectric energy, the sale of which would partially defray the cost of the project. Power plants are not proposed for construction in connection with all of the major reservoirs in the Sacramento River Basin but, for those plants which are proposed, studies were made to estimate the amounts of hydroelectric energy produced with different methods of operation of the reservoirs.

It was estimated that the annual increase in requirements for electric energy in northern California would vary from 324,000,000 kilowatt hours in 1935 to 464,000,000 kilowatt hours in 1950. The estimated average annual output from the Kennett reservoir unit would vary with the method of operation from 1,285,000,000 to 1,622,800,000 kilowatt hours per year with the output for the immediate initial development averaging about 1,592,000,000 kilowatt hours. On account of the characteristics of this output, however, a market somewhat in excess of the estimated plant outputs would have to be developed to absorb them. The length of time required to absorb the output of the Kennett reservoir unit would depend upon the year in which it is brought into production. It is believed that the period of absorption would not be more than four to six years. The outputs from the other units in the Sacramento River Basin would be considerably smaller and the problem of their absorption, therefore, correspondingly less.

That the revenue from the sale of the energy produced might be estimated, studies also were made to estimate the unit value of this

* House Document No. 791, 71st Congress, 3d Session.

energy at each of the power plants. Three bases of estimating the value of energy from the proposed plants are available:

1. Cost of energy from other hydroelectric plants.
2. Wholesale prices of energy as indicated by existing contracts.
3. Cost of energy from steam-electric plants.

The analyses of values under each of these three bases required that consideration be given to relative characteristics of power from different sources and that adjustment be made to reflect transmission cost to a common or equivalent delivery point at or near the load center.

Since the most important element affecting the present and future value of electric energy is the cost of that produced by steam, this basis was adopted for estimating the value of the energy from the major unit power plants of the State Water Plan. The estimated values of the hydroelectric energy at the power plants, therefore, were based on the cost of producing an equivalent amount of electric energy of the same characteristics with a steam-electric plant located in the area of consumption, taking into account the cost of transmission from the point of generation to the load center, and are the lowest values resulting from this or any of the other methods of evaluation. In estimating the cost of steam-electric energy, the present prices of fuel oil, or its equivalent in natural gas, and present efficiencies of steam plants were used. With this method as a basis, the values of the hydroelectric energy which would be produced at the major unit power plants were estimated. These values would be fixed by the characteristics of the electric energy output, which in turn would be determined by the method of operation of the reservoir.

The estimated values for the different methods of operation, at the power plants, are as follows:

VALUES OF ELECTRIC ENERGY

Unit	Method of operation	Value of electric energy per kilowatt hour at plant switchboard
Kennett reservoir	Primarily for generation of power	$0.00272
	Immediate initial development	.00265
	Complete initial development	.00242
	Primarily for irrigation	.00193
Oroville reservoir	Primarily for generation of power	.00310
	Primarily for irrigation	.00225
Narrows reservoir	Primarily for generation of power	.00298
	Primarily for irrigation	.00235
Trinity River diversion	Primarily for generation of power	.00250
Complete American River	Primarily for generation of power	.00327
	Immediate initial development	.00331
	Complete initial development	.00292
	Primarily for irrigation	.00256
Partial American River	Immediate initial development	.00327
	Complete initial development	.00250

Ultimate Major Units of State Water Plan.—In the Sacramento River Basin, only surface storage reservoirs and the Trinity River diversion are included in the State Water Plan. It is considered that a distribution system to convey water to the areas of use is a feature for local development. Also, the underground storage is not included in the present plan although it may in the future become an important means of holdover storage for use in dry cycles. Although all reservoirs constructed and to be constructed are considered as ultimate units of the State Water Plan, only those on the major streams are included in the plan at the present time.

The major reservoirs would be located on the lower reaches of the streams near the edge of the valley floor. On account of their locations, they would be in positions to regulate the maximum water supply for uses on the valley floor. They would not interfere physically with power, irrigation or other developments on the upper reaches of the streams and in this investigation it was assumed that no water rights would accrue to the major reservoirs which would in any way interfere with these upper developments. The reservoirs could reregulate water returned to the streams by the upstream developments as well as the unused waters of the streams. They also would be ideally located to control floods at the point where they would debouch onto the valley floor, thereby reducing the cost of protecting lands which now have no protection and increasing the degree of protection afforded by the present flood control system.

The ultimate major units for the Sacramento River Basin comprise ten storage reservoirs in the basin, one on the Trinity River, the Trinity River diversion to the Sacramento River Basin, three afterbays, power plants at some of the reservoirs, and several power drops. The storage reservoirs are Kennett on Sacramento River; Oroville on Feather River; Narrows on Yuba River; Camp Far West on Bear River; Folsom, Auburn and Coloma on American River; Millsite on Stony Creek; Capay on Cache Creek; Monticello on Putah Creek; and Fairview on Trinity River. Two power drops, Pilot Creek and Webber Creek dams, are proposed on the American River. Afterbays are proposed at Keswick, below the Kennett dam, near Oroville, below the Oroville dam, and at Folsom, below the Folsom dam. Power plants are proposed at the Kennett, Fairview, Oroville, Narrows, Folsom, Auburn and Coloma reservoirs, the Keswick, Oroville and Folsom afterbays, and the Pilot Creek and Webber Creek power drops, and three plants are proposed on the Trinity River diversion conduit. All of the reservoirs, afterbays, power drops and power plants on the American River are considered to constitute the American River unit.

The value of a reservoir in the lower canyon of the upper Sacramento River, near Red Bluff, in controlling the run-off of that stream, has long been recognized and diligent search was made during this investigation for a favorable dam site, but none was found. No reservoir below Kennett, therefore, is included in the State Water Plan.

Another reservoir site investigated in the upper Sacramento River Basin is one whose dam site is on the Pit River below the mouth of the McCloud River. It is designated the Baird site. This site lies within the area which would be flooded by the Kennett reservoir and could be developed only as an alternate for it. The principal advantage of the Baird reservoir over the Kennett reservoir would be that the relocation of the Southern Pacific railroad would be obviated. However, the uncertainty of constructing a safe dam at the Baird site to a height which would create a reservoir of capacity adequate to meet immediate and ultimate water requirements in accord with the State Water Plan, together with other disadvantages, led to the conclusion that a reservoir at this site should not be considered as an alternate for the Kennett reservoir.

Estimates of both the capital and annual costs were made for each reservoir and power plant, based on the costs of labor and materials as of 1929 and 1930 and on the assumption that each unit would be completely constructed in one step. These costs, and data pertaining to the reservoirs, are shown in the table on page 46.

The estimated total yield in irrigation water, yield in new water and electric energy output from each major unit of the State Water Plan for the Sacramento River Basin, under two methods of operation, are set forth in the table on page 47. The new water is the supply which would be available through the development of storage, over and above present possible uses from the stream, under an irrigation demand schedule. The data are shown for the unit operated primarily for the generation of power, where power plants are included, with the irrigation water yield being incidental to such operation, and with the unit operated primarily to supply irrigation water, with the production of electric energy being incidental to that operation. The average net annual cost of new water was obtained by deducting from the gross annual cost of the unit the estimated revenue from the sale of the electric energy produced.

Comparing the major units on the basis of the cost of new water, they may be listed in the order of cost, from lowest to highest, as follows:

Unit operating primarily for power	*Unit operating primarily for irrigation*
Kennett reservoir unit	Kennett reservoir unit
American River unit	American River unit
Trinity River diversion	Monticello reservoir
Narrows reservoir	Capay reservoir
Oroville reservoir unit	Narrows reservoir
	Millsite reservoir
	Camp Far West reservoir
	Oroville reservoir unit

The Kennett reservoir unit, therefore, would yield the largest volume of new water at the lowest unit cost with either of the methods of operation. The American River unit would be next lowest in unit cost but would be surpassed by the Oroville reservoir unit in the amount of new water. Irrigation yield from the latter unit, however, would be higher in unit cost than that from any major unit in the Sacramento River Basin, under both methods of operation.

Coordinated Operation and Accomplishments of Ultimate Major Units.—The Great Central Valley, including both the Sacramento and San Joaquin River basins, was considered as one geographic division in formulating the State Water Plan. In the San Joaquin River Basin there is insufficient water supply for the full development of all of the irrigable land, while in the Sacramento River Basin there is a surplus of water over its ultimate needs. The logical source of an additional supply for the San Joaquin River Basin, therefore, is in the surplus water of the Sacramento River Basin. Both basins were analyzed as

ULTIMATE MAJOR UNITS OF STATE WATER PLAN FOR SACRAMENTO RIVER BASIN

Unit	Stream on which unit is located	Height of dam, in feet	Capacity of storage reservoir, in acre-feet	Installed capacity of power plant, in kilovolt amperes	Capital cost including power features	Annual cost
Kennett reservoir	Sacramento River	520	5,967,000	400,000	$117,000,000	$7,236,000
Keswick afterbay	Sacramento River	95		50,000	5,500,000	396,000
Kennett reservoir unit	Sacramento River		5,967,000	450,000	122,500,000	7,632,000
Trinity River diversion	Trinity River	[1]365	1,436,000	193,000	62,000,000	4,018,000
Oroville reservoir	Feather River	580	1,705,000	280,000	142,600,000	8,641,000
Oroville afterbay	Feather River	69		34,000	5,100,000	360,000
Oroville reservoir unit	Feather River		1,705,000	314,000	147,700,000	9,001,000
Narrows reservoir	Yuba River	580	853,000	160,000	53,000,000	3,364,000
Camp Far West reservoir	Bear River	180	151,000	0	6,500,000	403,000
Folsom reservoir	American River	190	355,000	100,000	15,200,000	1,053,000
Folsom afterbay	American River	84		25,000	4,300,000	300,000
Auburn reservoir	North Fork American River	440	831,000	85,000	27,900,000	1,752,000
Pilot Creek power drop	North Fork American River	110		25,000	2,700,000	197,000
Coloma reservoir	South Fork American River	345	766,000	40,000	15,900,000	999,000
Webber Creek power drop	South Fork American River	85		20,000	2,500,000	183,000
American River unit	American River		1,952,000	295,000	68,500,000	4,484,000
Millsite reservoir	Stony Creek	135	115,000	0	3,200,000	212,000
Capay reservoir	Cache Creek	170	378,000	0	5,500,000	338,000
Monticello reservoir	Putah Creek	150	130,000	0	2,600,000	174,000
Totals			12,687,000	1,412,000	471,500,000	29,626,000

[1] Fairview dam—Lewiston diversion dam would be 98 feet high.

YIELDS OF ULTIMATE MAJOR UNITS OF STATE WATER PLAN FOR SACRAMENTO RIVER BASIN

Unit	Operating primarily for power				Operating primarily for irrigation			
	Average annual electric energy output, in kilowatt hours	Seasonal yield in irrigation water, in acre-feet		Average net annual cost per acre-foot of new water	Seasonal yield in irrigation water, in acre-feet		Average annual electric energy output, in kilowatt hours	Average net annual cost per acre-foot of new water
		Total	New water		Total	New water		
Kennett reservoir unit	[2]1,622,800,000	[1, 2]2,085,000	[1, 2]595,000	[2]$1 48	[1]5,386,000	[1]3,896,000	1,459,000,000	$1 24
Trinity River diversion	1,063,900,000	[1]2,045,000	[1]555,000	2 45	([4])	([4])	([4])	([4])
Oroville reservoir unit	1,409,100,000	1,117,000	547,000	8 47	2,480,000	1,910,000	1,172,200,000	3 33
Narrows reservoir	570,300,000	377,000	271,000	6 14	975,000	869,000	528,100,000	2 44
Camp Far West reservoir	([3])	([3])	([3])	([3])	192,000	130,000	([3])	3 10
American River unit	1,052,400,000	658,000	524,000	1 99	1,790,000	1,656,000	898,800,000	1 32
Millsite reservoir	([3])	([3])	([3])	([3])	92,000	77,000	([3])	2 75
Capay reservoir	([3])	([3])	([3])	([3])	155,000	155,000	([3])	2 18
Monticello reservoir	([3])	([3])	([3])	([3])	96,000	96,000	([3])	1 81
Totals	6,217,700,000	6,452,000	2,662,000		11,166,000	8,789,000	4,058,100,000	

[1] Yield at Red Bluff from unregulated flow of Sacramento River supplemented by regulated water from Kennett Reservoir or Trinity River diversion.
[2] Data are for the initial development (420 foot Kennett dam), since it is assumed that the ultimate development would never be operated primarily for generation of electric energy.
[3] No power plant included with reservoir.
[4] No study made with diversion operated primarily for irrigation.

a unit in order that the greatest use might be made of all of the available water supply in the great Central Valley. The major units of the plan in both basins, including surface and ground water storage reservoirs and conduits to convey the surplus water from the areas in which it originates to those having a deficient supply, were used in the analysis. The major units for the San Joaquin River Basin are described in another report.*

The operation of the units in the Great Central Valley was analyzed under three methods, through the eleven-year period 1918 to 1929. This period was one of subnormal run-off and included the extremely dry season of 1923–24. The details, accomplishments and surplus water with one of these methods of operation, Method II, are given in the following summary. Method I is the same as Method II except as follows: In (e) under 3, there would have been a 35 per cent deficiency only in those areas dependent upon local supplies; in (g) under 3, a supply of only 520,000 acre-feet per season, with a deficiency of 14 per cent in 1924, would have been made available for the irrigation of 260,000 acres lying on the westerly slope of the upper San Joaquin Valley; and in (i) under 3, the supply of 323,000 acre-feet per season for irrigation use in the San Francisco Bay Basin would have had a deficiency of only 18.5 per cent in 1924. Method III is the same as Method II except that an additional supply of 1,500,000 acre-feet annually, with a deficiency of 35 per cent in 1924, would have been made available in the Sacramento-San Joaquin Delta in accordance with a uniform demand and there would have been a maximum deficiency of 22 per cent in the supply to the Sacramento Valley.

The operation and accomplishments under Method II are as follows:

1. The amount of water utilizable for storage and regulation in the major reservoir units was obtained by deducting from the full natural run-off of the streams entering the Great Central Valley, the net use of 2,283,000 acre-feet per season for an adequate and dependable irrigation supply for 1,439,000 acres of land, being the net irrigable mountain valley and foothill lands lying at elevations too high to be irrigated by gravity from the major reservoir units, thus providing for the ultimate needs of these areas, and also deducting from the flow of the Tuolumne River 448,000 acre-feet per year for the water supply of the city of San Francisco. An additional amount of 224,000 acre-feet per year also was deducted for the San Francisco Bay Basin from Pardee Reservoir on the Mokelumne River.
2. Space in the principal reservoirs would have been reserved for flood control. This space, operated in a specified manner, would materially reduce flood flows on the major streams, resulting in an increased degree of protection to areas subject to overflow in both the Sacramento and San Joaquin valleys and a decrease in potential annual flood damages in these areas. The sizes of floods which probably would be exceeded on the average of once in 100 years (except as noted), without and with the space reserved, at

* Bulletin No. 29, "San Joaquin River Basin," Division of Water Resources, 1931.

several of the principal points in the Sacramento and San Joaquin valleys are as follows:

Stream	Maximum mean daily flow, in second feet		Number of times flow would be exceeded, on the average
	Without reservoir control	With reservoir control	
Sacramento River at Red Bluff	303,000	[1]187,000	Once in 100 years
Sacramento River at Red Bluff	218,000	[1]125,000	Once in 14 years
Sacramento River and Sutter Butte By-pass opposite Colusa	370,000	250,000	Once in 100 years
Sacramento River and Sutter Butte By-pass opposite Colusa	254,000	170,000	Once in 14 years
Sacramento River at Sacramento and Yolo By-pass at Lisbon	670,000	535,000	Once in 100 years
Feather River below confluence with Yuba River	400,000	201,000	Once in 100 years
Feather River below confluence with Bear River	430,000	226,000	Once in 100 years
American River at Fairoaks	185,000	80,000	One day in 250 yrs.
San Joaquin River below confluence with Merced River	70,000	50,000	Once in 100 years
San Joaquin River below confluence with Tuolumne River	103,000	64,000	Once in 100 years
San Joaquin River below confluence with Stanislaus River	133,000	82,000	Once in 100 years
Sacramento and San Joaquin rivers at confluence	780,000	596,000	Once in 100 years

[1] Floods would be controlled to 125,000 second-feet maximum flow exceeded once in 100 years, except when this amount is exceeded by uncontrolled run-off between Kennett reservoir and Red Bluff. Flows greater than 125,000 second-feet would continue for only a short time.

3. Stored water would have been drawn from the major surface reservoir units, and underground basins, in such amounts and at such times as to supplement unregulated flows and return waters, to make water available for:
   a. A supply of 9,033,000 acre-feet per season, gross allowance without deficiency, available in the principal streams, for the irrigation of all of the net area of 2,640,000 acres of irrigable lands of all classes on the Sacramento Valley floor.
   b. A supply of 1,200,000 acre-feet per season, without deficiency, for the irrigation of all the net area of 392,000 acres of irrigable lands, and for unavoidable losses, in the Sacramento-San Joaquin Delta.
   c. The improvement of navigation on the Sacramento River to Red Bluff.
   d. A fresh water flow of not less than 3300 second-feet past Antioch into Suisun Bay, which would have controlled salinity to the lower end of the Sacramento-San Joaquin Delta.
   e. A surface supply of 5,342,000 acre-feet per season, gross allowance, with a maximum seasonal deficiency of 35 per cent, for the irrigation of all the net area of 1,810,000 acres of irrigable land of all classes in the lower San Joaquin Valley, including 134,000 acres of foothills below the major reservoirs on the eastern side of the valley. The deficiency could have been reduced by the utilization of the available underground storage capacity.

f. A supply of 4,700,000 acre-feet per season, without deficiency, for the irrigation of a net area of 2,350,000 acres of class 1 and 2 lands on the eastern and southern slopes of the upper San Joaquin Valley. This would have been accomplished by utilization of underground storage capacity in conjunction with the major reservoir and conveyance units proposed.

g. A supply of 1,570,000 acre-feet per season, with a maximum seasonal deficiency of 35 per cent, for the irrigation of all the net irrigable area of 785,000 acres of class 1 and 2 lands on the western slope of the upper San Joaquin Valley.

h. A water supply and channel depth in the San Joaquin River sufficient to provide a navigable depth of six feet as far upstream as Salt Slough, nine miles above the Merced River.

i. A supply of 403,000 acre-feet per season in the Sacramento-San Joaquin Delta, for use in the San Francisco Bay Basin. There would have been a deficiency of 35 per cent in 1924 in the 323,000 acre-foot portion of this supply allotted to use for irrigation. This amount of 403,000 acre-feet per season, together with full practical development of local resources and annual importations of 224,000 acre-feet from the Mokelumne River and 448,000 acre-feet from the Tuolumne River, and an importation from the Eel River, would have given an adequate and dependable supply for the ultimate development of this basin.

j. The generation of more than five billion kilowatt hours of electric energy, on the average, annually.

With all of the major units of the State Water Plan in the Great Central Valley operated for the foregoing purposes, substantial amounts of water over and above the requirements would have wasted into Suisun Bay during the eleven-year period 1918–1929, as follows:

Year	*Amount in acre-feet*	*Year*	*Amount in acre-feet*
1918	3,885,000	1924	1,002,000
1919	4,112,000	1925	2,860,000
1920	2,288,000	1926	2,925,000
1921	8,071,000	1927	9,469,000
1922	8,434,000	1928	7,498,000
1923	2,934,000	Average	4,862,000

The largest amounts of waste would have occurred in years of large run-off and in the winter months of other years. Part of the waste water would have been contributed by unregulated run-off and return water and part by spill from the reservoirs. During the summer months there would have been just sufficient water released from the reservoirs to care for all needs. The average monthly distribution of waste water for the period 1918–1929 would have been as follows:

Month	*Amount in acre-feet*	*Month*	*Amount in acre-feet*
January	722,000	July	0
February	1,320,000	August	0
March	1,486,000	September	0
April	167,000	October	33,000
May	219,000	November	328,000
June	113,000	December	474,000
		Total	4,862,000

Part of the waste waters could have been conserved by reservoirs other than the major units of the State Water Plan or by larger major units. Studies showed, however, that these additional regulated waters would not have been necessary during the eleven-year period 1918–1929, for the accomplishments set forth for Methods I, II, and III.

Surplus Water in Sacramento River Basin Under Conditions of Ultimate Development.—The same analysis from which the foregoing results for Method II were obtained shows that by the utilization of the physical works proposed herein for the Sacramento River Basin, including the Trinity River diversion, regulated supplies, without deficiency in amount and dependable in time could have been made available in the principal streams to irrigate all of the 2,640,000 acres of net irrigable lands in the Sacramento Valley, after allowing a gross annual diversion of 3,241,000 acre-feet, with a net use of 1,945,000 acre-feet per year, for the irrigation of a net irrigable area of 1,234,000 acres of foothill and mountain valley lands in the Sacramento River Basin. The analysis also shows that there would have been a large surplus of water in every year, over and above these needs, in the basin above the Sacramento-San Joaquin Delta. A part of this surplus water would have been contributed directly by releases and spill from the reservoirs, a part would have been return water from irrigation on the valley floor and foothills at elevations higher than the reservoirs but draining directly to the valley floor, and a part would have been unregulated run-off. The portion of this surplus water not used in or diverted from the Sacramento-San Joaquin Delta would have wasted into the ocean. A large part of the surplus, however, could have been put to beneficial use in all years, except in winter months when a portion would have wasted. The following tabulation gives the amounts of water contributed by the reservoirs, the surplus available in the delta in the maximum and minimum years, and the average annual surplus for the eleven-year period 1918–1929.

SURPLUS WATER IN SACRAMENTO RIVER BASIN

Exclusive of Sacramento-San Joaquin Delta requirements

	Amount of water, in acre-feet		
	Maximum year, 1927	Minimum year, 1924	Average annual for period 1918–1929
Releases and spill from major reservoir units, and unregulated run-off	19,837,000	10,608,000	15,141,000
Gross requirements for lands on Sacramento Valley floor	9,033,000	9,033,000	9,033,000
Surplus from releases and spill and unregulated run-off	10,804,000	1,575,000	6,108,000
Return water—from valley floor	3,843,000	3,843,000	3,843,000
Return water—from foothills above reservoirs	341,000	341,000	341,000
Total surplus available in delta from Sacramento River Basin	14,988,000	5,759,000	10,292,000

The ultimate average annual requirements for the Sacramento-San Joaquin Delta and salinity control would amount to 3,590,000 acre-feet. A portion of this would be contributed by water from the San Joaquin Valley streams, but if the entire amount had been obtained from Sacramento Valley waters during the eleven-year period 1918–1929, there still would have been surpluses in the maximum and minimum years of 11,399,000 and 2,164,000 acre-feet respectively, and an average annual surplus for the period of 6,702,000 acre-feet.

Initial Unit of State Water Plan in Sacramento River Basin.—The greatest water problem in the Sacramento River Basin at the present time is that of invasion of saline water into the delta region. Although this is the principal immediate problem, others are quite important. During the summer and fall months of subnormal years, the flow in the Sacramento River has been so low that navigation has been greatly impaired and distance of navigability has been much reduced. Also, during several of the past dry years, particularly in 1920 and 1924, the irrigators drawing their supplies from the Sacramento River had hardly enough water for their needs and increased pumping costs resulted from the additional lifts caused by low discharge in the stream. An initial unit in the Sacramento River Basin should correct as many as possible of these conditions.

It has been determined that only three units in the Sacramento River Basin, each by itself, would be able to meet the salinity control requirements in a year like 1924, with existing irrigation and storage developments in the Sacramento and San Joaquin river basins. These are the Kennett and Oroville reservoirs and the American River unit. The cost per acre-foot of yield from the Oroville reservoir was found to be much greater than from the other two units and it, therefore, was eliminated as a possible initial unit. The Kennett reservoir for an initial development would have only a 420 foot dam and a capacity of 2,940,000 acre-feet but the reservoirs in the American River unit would have their ultimate capacities. The Kennett reservoir unit would have advantages not possessed by the American river unit and vice versa. The Kennett reservoir unit, however, would be the only one which would improve navigation and irrigation conditions on the Sacramento River above the city of Sacramento.

Both the Kennett reservoir unit (420 foot Kennett dam) and American River unit were analyzed under various conditions of operation as initial units in the State Water Plan. For the American River unit, analyses were made for a complete unit and for a partial development in which the Coloma reservoir and Webber Creek power drop were omitted. Two analyses were made for the Kennett reservoir unit and the complete American River unit for the 40-year period 1889–1929; first, with the reservoirs operated primarily for the production of hydroelectric energy, designated Method I, and second, for making available the maximum irrigation supply, designated Method IV. Analyses also were made for the ten-year period 1919–1929, for the same two units and for the partial American River unit, under two other methods, brief descriptions of which follow. Under the first of these methods, designated Method II for the Kennett reservoir and complete American River units and Method I for the partial American River unit, the reservoirs would have been operated to control floods, and water would have been released in sufficient amounts to supplement the flows from the unregulated streams or those regulated by present developments, and return water, to provide a supply for the improvement of navigation on the Sacramento River (Kennett reservoir only); a supply, without deficiency, for the present irrigation rights along the river; a supply, without deficiency, for the present irrigation requirements of the Sacramento-San Joaquin Delta; sufficient flow to control salinity each year to the lower end of the delta; and a supply for the developed agricultural and industrial areas along the south shore of Suisun Bay in Contra Costa County. Also, a large amount of hydroelectric energy would have been generated, the sale of which would have helped to defray the cost of the project. Under the second of the two methods last mentioned, designated Method III for the Kennett reservoir and complete American River units and Method II for the partial American River unit, the units would have been operated to accomplish the same things just outlined and also to make available a supply for the San Joaquin Valley to supplement any unused or return waters in that valley and provide a supply for the irrigation of the lands suitable for growing crops now being served from the San Joaquin River above the mouth of the Merced River, thereby releasing the water now used on these lands for exportation from the San Joaquin River at Friant. In this second method, 896,000 acre-feet of water, without deficiency would have been made available in each season with the Kennett reservoir unit or complete American River unit operated, but only 500,000 acre-feet, with a deficiency of 31 per cent in 1924, would have been made available annually with the operation of the partial American River unit.

A financial comparison of the Kennett reservoir unit and the American River units operated under the various methods just described gives the following results:

FINANCIAL COMPARISONS OF POSSIBLE INITIAL UNITS

Unit	Method of operation	Average net annual cost not covered by revenue from the sale of electric energy[1]
Kennett reservoir	I	$883,000
	II	1,079,000
	III	1,471,000
	IV	2,817,000
Complete American River	I	1,043,000
	II	1,265,000
	III	1,705,000
	IV	2,183,000
Partial American River	I	809,000
	II	1,474,000

[1] No deductions made for revenues from sale of water.

The advantages of the American River unit over the Kennett reservoir unit are:

1. The capital investment for partial development would be $34,000,000 less and for complete development $15,500,000 less.
2. It could be constructed progressively.

3. The initial block of hydroelectric energy would be 48 per cent of that at Kennett, thus lessening the problem of power absorption.
4. It would be in a position to control floods on the American River to a degree that would greatly benefit the project of the American River Flood Control District and to a lesser extent the Sacramento Flood Control Project. With either the partial or complete unit, floods would be controlled to 100,000 second-feet or less, exceeded not oftener than one day in 250 years, on the average, whereas the crest flow of the March 25, 1928 flood was 184,000 second-feet.
5. Water would be released below all of the riparian lands in the Sacramento River Basin above the city of Sacramento. The riparian acreage along the American River is small.
6. No major improvements would be flooded and, therefore, there would be less interference with existing interests.
7. The partial development would have furnished a water supply, during the ten-year period 1919–1929, for present irrigation requirements in the Sacramento-SanJoaquin Delta, for salinity control, and for immediate agricultural and industrial requirements along the south shore of Suisun Bay in Contra Costa County, at a net annual cost $270,000 less than the Kennett reservoir unit, if revenues from the sale of electric energy alone had been credited against the annual costs, and there had been no contributions toward the costs of the reservoirs by the Federal and State governments or other interests or agencies.

The advantages of the Kennett reservoir unit over the American River unit are:

1. It would be in a position to control floods on the Sacramento River,thus giving an added degree of protection to a large portion of the lands in the Sacramento Flood Control Project. Flows would be reduced to 125,000 second-feet mean daily flow on the day of the flood crest, measured at Red Bluff, exceeded once in fourteen years, on the average. The controlled flow exceeded once in 100 years, on the average, would be 187,000 second-feet due to the uncontrolled run-off between Kennett reservoir and Red Bluff, but flows in excess of 125,000 second-feet would be of short duration. The maximum flood flow of record at Red Bluff was 278,000 second-feet on February 3, 1909.
2. It would improve navigation on the Sacramento River for 190 miles above the city of Sacramento.
3. It would furnish a full water supply to lands along the Sacramento River above Sacramento now under irrigation or having water rights. There would have been over 700,000 acre-feet more water available, distributed in accordance with the irrigation demand, for these lands in 1924. The sale of that portion of this supply which would be new water made available by the operation of the Kennett reservoir would provide a revenue which would decrease the net annual cost of the reservoir. No

such revenue, or at least a very much smaller one, would be available to the American River unit from the sale of water along the American River.

4. It would have furnished a water supply, during the ten-year period 1919–1929, for present irrigation requirements in the Sacramento-San Joaquin Delta, for salinity control, and for immediate agricultural and industrial requirements along the south shore of Suisun Bay in Contra Costa County, and would have made available 896,000 acre-feet more water for irrigation in the San Joaquin Valley, at $234,000 less net annual cost than the complete American River unit, if revenues from the sale of electric energy only had been credited against the gross annual cost and no contributions had been made toward the costs of the reservoirs by the Federal and State governments or other interests or agencies. Revenues from the sale of water for the foregoing uses would have been the same for the Kennett reservoir and complete American River units and therefore do not enter into their comparison.
5. It would have furnished a water supply, during the ten-year period 1919–1929, for delta, salinity control and immediate upper San Francisco Bay requirements and would have made available 896,000 acre-feet of water for irrigation in the San Joaquin Valley, at a net annual cost of $1,471,000, as compared to $1,474,000 for the partial American River unit, if revenues from the sale of electric energy alone had been credited against the gross annual costs. While the Kennett reservoir would have made available 896,000 acre-feet of water, without deficiency, for irrigation in the San Joaquin Valley, the partial American River unit would have made available only 500,000 acre-feet, with a deficiency of 31 per cent in 1924. The amounts of water furnished for the other uses would have been the same. If revenues from the sale of water for the foregoing uses had been deducted from the gross annual costs, the net annual cost would have been even more in favor of the Kennett reservoir unit. If there were no demand for eleven years or more for water from the Sacramento Valley for irrigation in the San Joaquin Valley, the American River unit would be the economic unit to construct, but if the water would be required in less than eleven years, the Kennett reservoir unit would be the better. This period of deferment is based on capital costs without direct contributions, average annual costs for a forty-year amortization period and average annual revenues from power estimated for the 40-year period 1889–1929.
6. Both navigation and flood control benefits would be greater than with the American River unit. On account of these greater benefits accruing to the general public, it would be reasonable to expect larger direct contributions toward the cost of the Kennett reservoir unit in the interests of navigation and flood control, than toward the cost of the American River unit.
7. It would develop one and three-fourths times as much new water as the American River unit at three-fourths the cost per acre-foot, if the reservoirs were operated primarily for irrigation.

Selection of Unit for Initial Development.—After careful consideration of all the foregoing advantages and disadvantages of each unit and in view of the possibility that water, in addition to that necessary for initial uses, would be required for exportation to the San Joaquin Valley during the earlier years of operation of the plan, and of the greater benefits that would accrue to the greater number of interests, particularly irrigation, navigation and flood control, from the construction of the Kennett reservoir, it is believed the first development under the State Water Plan in the Sacramento River Basin should be the Kennett reservoir unit with a 420-foot Kennett dam.

Financial Aspects of Kennett Reservoir Unit.—The foregoing financial analyses of the Kennett reservoir unit have been made on the basis of interest at 4½ per cent per annum, amortization of capital investment in 40 years, and revenues from the sale of electric energy only. No allowances were made for possible direct contributions without repayment from the Federal and State governments, or possible revenues from the sale of stored water. It may be noted that on this basis the unit is not economically feasible. For the unit to be financially feasible, the annual cost must be reduced. This can be accomplished by lowering the rate of interest, extending the period of amortization of capital investment, or by obtaining such direct contributions to the cost of the unit, without repayment, as may be justified by National and State benefits, or the annual cost may be reduced by a combination of these methods.

It is possible that in financing the unit, funds could be borrowed at a lower rate of interest, particularly if arrangements were made for a loan from the Federal government. It is possible also that the State could obtain money at an interest rate less than 4½ per cent. For the purpose of illustrating the effect interest rates, both higher and lower than 4½ per cent, would have on the capital and gross and net annual costs of the initial development of the Kennett reservoir unit, the table on page 57 has been prepared. The gross annual costs comprise amounts for operation and maintenance, depreciation, and amortization of the capital investment in 40 years on a 4 per cent sinking fund basis, in addition to those for interest. The effect of extending the amortization period from 40 years to 50, 60, and 70 years in reducing the annual costs also is illustrated by the figures presented in the table. The present legal limitation for State bond issues is 75 years.

Direct revenues from the unit would be derived from the sale of hydroelectric energy and water. While it is uncertain as to the amount of stored water which could be sold immediately upon the completion of the project, and the price that could be obtained, it is estimated that a revenue of at least $400,000 annually should be obtained from the sale of this water in the Sacramento Valley and Sacramento-San Joaquin Delta alone. No deductions have been made for this possible revenue, however, in obtaining the net annual costs in the following table. The estimated average annual revenue from the sale of the electric energy at the switchboard, with the unit operated under the conditions of the immediate initial development of the State Water Plan, would be $4,218,000.

CAPITAL AND ANNUAL COST OF KENNETT RESERVOIR UNIT

Immediate Initial Development

Kennett Reservoir—
Height of dam, 420 feet
Capacity of reservoir, 2,940,000 acre-feet
Installed capacity of power plant, 275,000 kilovolt amperes

Keswick Afterbay—
Height of dam, 95 feet
Capacity of reservoir, 14,000 acre-feet
Installed capacity of power plant, 50,000 kilovolt amperes

Item	Interest rate, in per cent					
	6	5	4½	4	3½	3
Capital cost	$87,200,000	$85,100,000	$84,000,000	$82,900,000	$81,900,000	$80,800,000
Gross annual cost (40-year, 4 per cent sinking fund amortization) [1]	$6,807,000	$5,792,000	$5,297,000	$4,813,000	$4,475,000	$4,106,000
Revenue from sale of electric energy	4,218,000	4,218,000	4,218,000	4,218,000	4,218,000	4,218,000
Net annual cost in excess of revenue	$2,589,000	$1,574,000	$1,079,000	$595,000	$257,000	$[2]112,000
Gross annual cost (50-year, 4 per cent sinking fund amortization) [1]	$6,462,000	$5,456,000	$4,965,000	$4,486,000	$4,131,000	$3,752,000
Revenue from sale of electric energy	4,218,000	4,218,000	4,218,000	4,218,000	4,218,000	4,218,000
Net annual cost in excess of revenue	$2,244,000	$1,238,000	$747,000	$268,000	$[2]87,000	$[2]466,000
Gross annual cost (60-year, 4 per cent sinking fund amortization) [1]	$6,257,000	$5,256,000	$4,768,000	$4,291,000	$3,923,000	$3,530,000
Revenue from sale of electric energy	4,218,000	4,218,000	4,218,000	4,218,000	4,218,000	4,218,000
Net annual cost in excess of revenue	$2,039,000	$1,038,000	$550,000	$73,000	$[2]295,000	$[2]688,000
Gross annual cost (70-year, 4 per cent sinking fund amortization) [1]	$6,131,000	$5,133,000	$4,646,000	$4,171,000	$3,789,000	$3,386,000
Revenue from sale of electric energy	4,218,000	4,218,000	4,218,000	4,218,000	4,218,000	4,218,000
Net annual cost in excess of revenue	$1,913,000	$915,000	$428,000	$[2]47,000	$[2]429,000	$[2]832,000

[1] For interest rates of 3½ and 3 per cent on capital investment, the sinking fund interest rate is assumed as 3½ and 3 per cent, respectively.
[2] Net annual revenue in excess of cost.

It is also anticipated that there would be direct contributions toward the cost of the unit by the Federal and State governments, of the amounts justified by National and State benefits. Due to the fact that it is not definitely known at this time what these contributions would be, no deductions have been made from the capital costs shown in the table in calculating the annual costs. However, the Chief of Engineers, United States War Department, has recommended * that the Federal government contribute $6,000,000 to the cost of the Kennett reservoir unit in the interest of navigation and it is generally considered that the State would relocate, at an estimated cost of $3,400,000, the State highway through the reservoir site without charge to the project. If these amounts were deducted from the capital costs, the annual costs shown in the table would be reduced by $323,000 to $663,000, depending upon the rate of interest and the amortization period.

In calculating the net annual costs set forth in the table, deductions were made only for revenues from the sale of the hydroelectric energy. With this revenue only, the unit could be financed with an interest rate of four per cent and amortization in a 70-year period on a four per cent sinking fund basis. If there were direct contributions by the Federal and State governments and deductions were made for revenues from the sale of water, the project could be financed on a higher rate of interest, a shorter period of amortization, or both.

Relation of State Water Plan to Hydraulic Mining.—It has been estimated by various mining authorities that there are remaining in the Feather, Yuba, Bear and American river watersheds more than 1000 million cubic yards of gold-bearing gravels which could be mined by the hydraulic process if adequate water supplies were available and facilities provided for the storage of the debris. The construction of certain major reservoir units of the State Water Plan on these streams would afford the facilities for this storage if such procedure should be proven warranted and economically justified. There are, however, other debris storage sites on some of the streams which could be used in place of the State's major reservoir units.

The major reservoir units of the State Water Plan are important primarily for the regulation of the run-offs from the mountain watersheds, to make as much of this water as is feasible available for irrigation and other uses in the Great Central Valley. Space used in each major reservoir unit for the storage of debris would impair the conservation value of the reservoir to the extent that storage space for water would be occupied by the debris. The space occupied in a reservoir by the debris might not be equal to the volume of the gravels mined since some debris would be stored in the stream channels above the reservoir. A large proportion might eventually work down into the reservoir, however, and in estimating costs of storage for gravels which may be worked in the first 20 years, the California Debris Commission has estimated storage space for the entire volume to be mined.

If space in the major reservoir units of the State Water Plan is to be used for the storage of mining debris, the capacities of the units would have to be increased, or other sites developed, if the ultimate

* House Document No. 791, 71st Congress, 3d Session.

water requirements of the Great Central Valley are to be supplied. It is estimated that by increasing the height of the Auburn dam fifteen feet, the debris from all of the workable gravels on the North and Middle Forks of the American River could be stored in the Auburn reservoir. The Bear River gravels can be stored at sites above the Camp Far West reservoir without conflict with the conservation value of this major unit of the State Water Plan. On the Yuba River, storage sites above the Narrows reservoir would care for about 23 per cent of the debris, leaving the remainder to be stored in the Narrows reservoir. The dam proposed for this reservoir would be 580 feet high, which is about as high as is believed to be practicable at this site, but a twenty-foot increase in height would provide storage for about 40 per cent of the gravels which could not be stored in the upstream sites. It is believed that debris from hydraulic mining operations on the Feather River could all be stored in sites above the Oroville reservoir.

Riparian Lands on Sacramento and American Rivers.—The developments proposed under the State Water Plan for the Sacramento River Basin, when put in operation, would effect material changes in the regimen of the major streams. A plan involving such important alterations of natural flow is widely at variance with well known tenets of the doctrine of riparian water rights and in particular with the declared right of the riparian owner to insist upon maintenance of stream flow undiminished and unaltered except by usage of other riparian owners and under rights which have been established by prescription or prior appropriations. In order to ascertain the magnitude of this conflict, an approximation of the extent of riparian ownerships along the Sacramento and American rivers, on which the first major reservoir units would probably be constructed and operated, and the ultimate water requirements for such riparian ownerships, was attempted. These approximations were predicated upon certain factors concerning some of which much controversy will probably occur and the final determination of which may rest in judicial decisions. The results obtained, however, are deemed sufficiently accurate to show the extent of lands riparian by contact with these two streams, and the ultimate water requirements for these lands, as compared to the total area of irrigable lands in, and the total ultimate water requirements for, the entire Sacramento Valley.

The estimates made indicate that there are 184,920 acres of riparian lands along the Sacramento River above the city of Sacramento and 79,600 acres along the river and its connecting channels in the Sacramento Delta, or a total of 264,520 acres along the Sacramento River, and 13,460 acres along the American River from Folsom to its mouth. Of these lands, 145,680 acres along the Sacramento River above Sacramento, 60,070 acres along the same river in the delta, and 8710 acres along the American River are estimated to be irrigable. Compared to these acreages, there are 2,640,000 acres of net irrigable land in the Sacramento Valley outside of the delta, and 135,000 acres in the Sacramento Delta.

It is estimated that the ultimate net allowance of water for the foregoing irrigable acreage along the Sacramento River above Sacramento would be about 326,000 acre-feet per year or 5.4 per cent of the ultimate annual net allowance for the entire Sacramento Valley exclusive of the delta. The ultimate net allowance for the 60,070 acres of irrigable riparian lands along the Sacramento River and connecting channels in the delta was estimated to be 137,000 acre-feet per year or 36 per cent of the ultimate annual net allowance for the entire Sacramento Delta. The ultimate net allowance for the lands riparian by contact with the American River below Folsom was estimated to be 16,000 acre-feet per year or less than three-tenths of one per cent of the ultimate annual net allowance for the Sacramento Valley exclusive of the delta.

Conclusions.

The principal conclusions of this investigation may be summarized as follows:

1. Under present conditions of storage development in the Sacramento River Basin, there is insufficient water in dry seasons for present irrigation requirements and the prevention of harmful incursion of saline water into the channels of the Sacramento-San Joaquin Delta.
2. Water supplies for the Sacramento River Basin predicated upon the requirements for irrigation and salinity control will be adequate for all uses in the full development of the basin.
3. With stream flows equivalent in character and amounts to those of the 40-year period 1889-1929, regulated water supplies can be made available in the Sacramento River Basin, by the construction of surface storage reservoirs and diversion works, to meet fully the ultimate water requirements in that basin and the irrigation, salinity control and other requirements in the Sacramento-San Joaquin Delta, and to adequately supplement the insufficient supplies for full practicable development in the San Joaquin Valley and San Francisco Bay Basin.
4. Sufficient storage capacity can be obtained at known and feasible major reservoir sites on the principal streams of the Sacramento River Basin and on the Trinity River to effect the required regulation for making water available for the foregoing regulated water supplies. Additional existing storage sites could be developed to increase the regulated water supplies in the Sacramento River Basin. Furthermore, greater use could be made of underground storage in the Sacramento Valley to increase the degree of utilization of available water supplies. Also, it is physically feasible to obtain additional water supplies from the Klamath and Eel rivers to supplement further the supplies in the Great Central Valley.
5. The completed works of the Sacramento Flood Control project, under present conditions, will be endangered by floods exceeding the channel capacities with frequencies of from once in fourteen years to once in 55 years, on the average, in different parts of the system. A greatly increased degree of protection to lands in the project may be obtained by the coordinated operation of several major reservoir units of the State Water

Plan in the Sacramento River Basin for flood control and conservation purposes. The use of the reservoirs for flood control will only slightly decrease their conservation values.

6. Improvement of navigation on the Sacramento River is desirable to the head of navigation at Red Bluff. The best method of obtaining such improvement is by regulation of stream flow by reservoirs, rather than by canalization, since this method can be most effectively coordinated with the uses of regulated stream flow for irrigation, salinity control and the generation of power.
7. The operation of the Kennett reservoir to maintain a flow of not less than 5000 second-feet in the Sacramento River, if combined with open channel improvements, would provide required depths for navigation as far upstream as Chico Landing and improve present depths upstream to Red Bluff.
8. It is believed the amount of $6,000,000, estimated by the United States War Department as the economic value of navigation improvement on the Sacramento River, would be substantially greater if due consideration were given to all factors affecting the potential commerce tributary to the waterway.
9. The installation of hydroelectric power plants at reservoir units of the State Water Plan to generate electric energy is economically justified. The net revenue from the sale of such energy would assist materially in paying the cost of the units of the plan.
10. The absorption of the electric energy outputs from the units of the State Water Plan by the northern California power market would not be a serious problem. With proper coordination of power development, the output from the Kennett plant, largest producing unit, could be absorbed in a period of five to six years.
11. The estimated values of electric energy at the hydroelectric power plants, based on present conditions, would range from 2.0 to 3.3 mills, depending upon the characteristics of the energy, the location of the plant with reference to the load center, and the cost of steam produced electric energy delivered to the same load center. The values of electric energy from the Kennett power plant under conditions of initial development would vary from 2.42 to 2.65 mills at the plant switchboard.
12. The major units of the State Water Plan in the Great Central Valley operated coordinately with ground water storage in the upper San Joaquin Valley, and with stream flows at the reservoir sites equivalent in character and amounts to those of the dry period 1918–1929 after making deductions for ultimate use in the mountain and foothill areas above the major reservoir units, would furnish adequate and dependable irrigation supplies for all irrigable lands in the Great Central Valley, would control flood flows in the major streams to specified amounts, would improve navigation on the Sacramento and San Joaquin rivers, would maintain a flow past Antioch into Suisun Bay sufficient to control the salinity content of the water

in the Sacramento-San Joaquin Delta channels to harmless amounts, and would furnish a supply of water to the San Francisco Bay Basin to supplement water supplies in that basin for irrigation and industrial uses.

13. With all of the major units of the State Water Plan in the Sacramento River Basin, including the Trinity River diversion, in operation, and with stream flows equivalent in character and amount to those of the dry period 1918–1929, there would be average surpluses from the Sacramento River Basin, over and above the full requirements of the 3,874,000 acres of net irrigable land in the basin excluding the delta area, varying from 5,800,000 acre-feet in the driest year to 15,000,000 acre-feet in the year of greatest run-off. These surpluses would be sufficient to provide the water required for the ultimate irrigation of the entire Sacramento-San Joaquin Delta and the water required for salinity control and still leave surpluses varying from 2,000,000 to 11,400,000 acre-feet per year for exportation to the San Joaquin Valley and the San Francisco Bay Basin.
14. The debris from the hydraulic mining of auriferous gravels in the Sacramento River Basin could be stored in some of the reservoirs of the State Water Plan. If the reservoirs were used for this purpose, however, their conservation values would be impaired.
15. Regulated water could be obtained at less cost from the Kennett reservoir and American River units than from any of the other major units of the State Water Plan in the Sacramento River Basin.
16. After careful consideration of all the advantages and disadvantages of the Kennett reservoir and the American River units, including the greater benefits that would accrue to the greater number of interests, particularly irrigation, navigation and flood control, from the operation of the Kennett reservoir, it is believed that this reservoir should be the first unit constructed under the State Water Plan in the Sacramento River Basin.
17. The Kennett reservoir, with a capacity of 2,940,000 acre-feet, when operated in conjunction with the initial units proposed in the San Joaquin River Basin, is adequate with stream flows equivalent in character and amount to those of the dry period 1918–1929, to furnish regulated water supplies to meet the requirements of the initial development of the State Water Plan for the Great Central Valley.
18. The Kennett reservoir unit is economically and financially feasible with State or Federal financing if the direct revenues from the project are not less than those estimated in this report and if the Federal and State governments contribute directly toward the cost of the unit the amounts justified by National and State benefits.

CHAPTER II

WATER SUPPLY

The water supply of the Sacramento River Basin is considered in this report as the run-off available from the mountain and foothill areas only. It does not include contributions to surface run-off and ground water from rainfall on the valley floor. These latter contributions have been omitted because of lack of definite knowledge of their amounts and because they are not subject to regulation except in underground reservoirs which have not been included in this report as a part of the State Water Plan in the Sacramento River Basin.

Description of Basin.

The Sacramento River Basin occupies that portion of the State lying between the Sierra Nevada and Cascade Range on the east, the Coast Range on the west, Mount Shasta on the north and the watersheds of the San Joaquin, Mokelumne and Cosumnes rivers on the south. It also includes the area drained by the Pit River lying to the east of the Cascade Range in the northeast corner of the State. The basin is approximately 250 miles long and 150 miles wide and has an area of about 26,150 square miles or 16.8 per cent of the total area of the State. The annual water yield from its mountainous area is 34.8 per cent of the total water supply from the mountainous area of California and is second only to that from the North Pacific Coast Basin which is the watershed along the Pacific coast from San Francisco Bay north to the Oregon line. The relation of this basin to the remainder of the State in area, area of agricultural lands, and water resources is shown on the frontispiece, "Geographical Distribution of Water Resources and Agricultural Lands in California."

The basin is drained by the Sacramento River and its numerous tributaries which may be separated into sixteen drainage basins of which eight are those of streams of major importance and eight are groups of those of minor streams. In grouping these streams, the Sacramento River north of Red Bluff, including the Pit, McCloud and upper Sacramento rivers, and Churn, Cow, Bear, Battle, Inks, Paynes, Backbone, Clear, Cottonwood and other minor creeks have been considered as one unit. The other streams of major importance are the Feather, Yuba, Bear and American rivers on the Sierra Nevada side of the basin and Stony, Cache and Putah creeks on the Coast Range side. The minor stream units are Mill, Butte, Honcut and Coon Creek groups and Dry Creek on the Sierra Nevada side and Red Bank, Elder and Willow Creek groups on the Coast Range side. The mountain and foothill watersheds of these streams, exclusive of the valley floor, have a total area of 21,369 square miles or 82 per cent of the total area of the Sacramento River Basin.

The Sacramento River watershed north of Red Bluff has an area of 9258 square miles, which is about 43 per cent of the mountainous area of the Sacramento River Basin. Practically all of the watershed is rugged but there are estimated to be about 367,000 acres of agricultural lands in the Pit and upper Sacramento River basins above Redding and about 500,000 acres in the foothills and plains between Redding and Red Bluff of which about 32,000 acres are located in the Anderson-Cottonwood Irrigation District. Elevations in the watershed range from 300 feet near Red Bluff to 14,161 feet at the summit of Mount Shasta.

The second most important stream in the basin is the Feather River, the largest tributary of the Sacramento River. Its drainage system includes the Yuba and Bear rivers, Dry Creek and the Honcut Creek group. Only that portion of the area lying above Oroville has been considered in this report as constituting the Feather River watershed. Three main forks, the North, Middle and South, join to form the main stream a short distance above Oroville. The area of the watershed above this point is 3627 square miles which is 16.9 per cent of the mountainous area of the Sacramento River Basin. Large valleys exist at high elevations in the watershed but for the most part the basin is rugged in character. Elevations in the watershed range from about 150 feet near Oroville to 10,453 feet at the summit of Mount Lassen. It may be noted from Table 1 that more than half of the watershed lies at elevations in excess of 5000 feet and only 7 per cent at elevations less than 2500 feet.

The Yuba River, the largest tributary of the Feather River, enters the latter river at Marysville. It emerges from the lower canyon at "the Narrows" near the town of Smartsville, about 20 miles upstream from Marysville. The area of the watershed above the Narrows is 1200 square miles, or about 6 per cent of the mountainous area of the Sacramento River Basin. There are some valleys in the watershed but most of it is rugged. Elevations range from 270 feet at the Narrows to about 9000 feet in the high Sierra Nevada.

The Bear River, the second largest tributary of the Feather River, has a long narrow watershed lying between those of the Yuba and American rivers. It enters the valley floor at a point about eight miles above Wheatland and joins the Feather River near the town of Nicolaus. The area of the watershed above the United States Geological Survey gaging station near Van Trent is 262 square miles, or about one per cent of the mountainous area of the Sacramento River Basin. This watershed does not rise to as high elevations as the two adjoining it and a larger percentage of its area is of the low mountain or foothill type. Elevations range from about 150 feet to 6000 feet.

The second largest tributary of the Sacramento River below Red Bluff is the American River. It leaves the foothills near the town of Folsom and joins the Sacramento River at the city of Sacramento. The main river is formed by three forks, the South, Middle and North. All of these rise at high elevations at the crest of the Sierra Nevada, Round Top Mountain lying on the boundary of the watershed rising to an elevation of 10,430 feet. The area of the watershed upstream from Fairoaks, the location of the United States Geological Survey gaging station, 7.5 miles downstream from Folsom, is 1919 square miles, or 9 per cent of the mountainous area of the Sacramento River

Basin. The basin contains rugged mountainous land, rolling foothills and plains areas.

The distribution of the areas in the watersheds of the foregoing five streams, above the United States Geological Survey gaging stations, for three ranges of elevation, is shown in Table 1.

TABLE 1

DISTRIBUTION OF AREAS IN WATERSHEDS FOR THREE RANGES OF ELEVATION

River	Gaging station	Area above gaging station, in square miles	Area					
			Above 5,000 feet		Between 2,500 and 5,000 feet		Below 2,500 feet	
			In square miles	In per cent of toatl	In square miles	In per cent of total	In square miles	In per cent of total
Sacramento	Red Bluff	9,258	2,538	27.4	4,620	49.9	2,100	22.7
Feather	Oroville	3,627	2,009	55.4	1,364	37.6	254	7.0
Yuba	Smartsville	1,200	515	42.9	470	39.2	215	17.9
Bear	Van Trent	262	5	1.9	102	38.9	155	59.2
American	Fairoaks	1,919	795	41.4	600	31.3	524	27.3

Three major streams, Stony, Cache and Putah creeks, enter the Sacramento Valley from the Coast Range. The average seasonal discharge of each is more than that of the Bear River but less than that of each of the other larger streams entering the valley from the Sierra Nevada. Only one of these streams, Stony Creek, enters the Sacramento River direct. The other two flow into Yolo Basin through which their waters eventually find their way into the Sacramento River near Rio Vista. The area of the Stony Creek watershed above its foothill gaging station at Simpson Bridge is 636 square miles; the area of the Cache Creek watershed above its gaging station at Yolo, which, however, includes about 200 square miles of valley land, is 1195 square miles; and the area of the Putah Creek watershed above its foothill gaging station near Winters is 655 square miles.

The drainage basins of the eight groups of minor tributary streams lie, in general, at lower elevations than those of the major streams. A few of them such as the Mill and Butte Creek groups on the Sierra Nevada side and the Red Bank and Elder Creek groups on the Coast Range side rise at relatively high elevations, but the larger portions of their areas lie in the low foothills adjacent to the valley floor. Although these streams are not as important in a general plan for the conservation of water as the major streams, since their run-offs are relatively small, they will be important in the development of local areas.

The Sacramento Valley floor is a comparatively flat body of land, with an area of about 4800 square miles, extending for about 150 miles from Suisun Bay to Red Bluff and averaging about 30 miles wide. Elevations range from below sea level in the Sacramento-San Joaquin Delta area to as high as 300 feet at the foothill line. Near the center of the valley, the Sutter Buttes, an old volcanic formation, rise to an elevation of 2132 feet.

5—80994

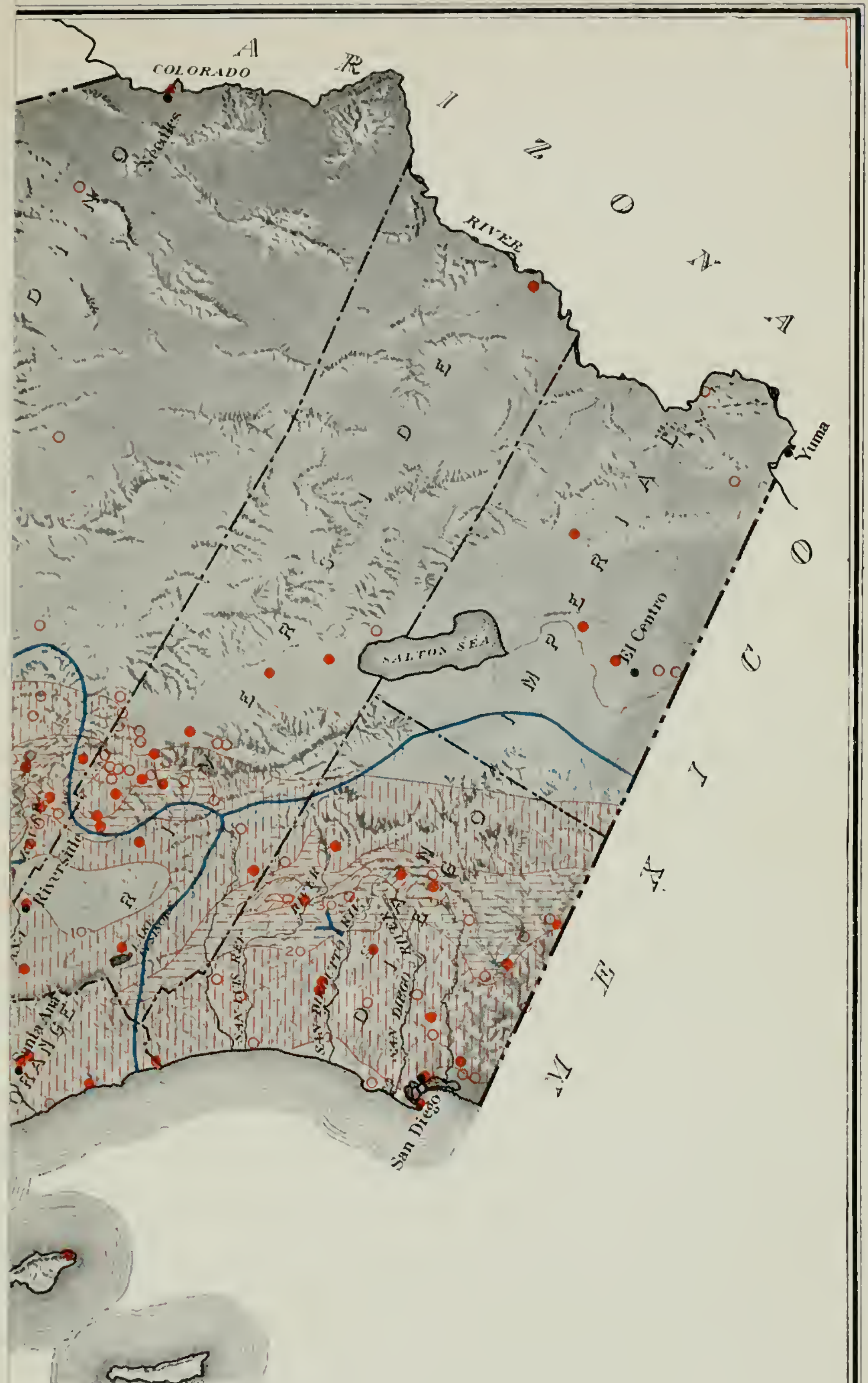
Precipitation.

Records of the precipitation at the city of Sacramento have been kept continuously since 1849, a period of 80 years. A number of stations distributed throughout the Sacramento River Basin have continuous records extending back to the early seventies. Some of the older stations were discontinued and others have taken their places. These long-time records are a great aid in estimating the probable run-offs of streams for the periods prior to those of stream flow measurements and of streams for which no measurements are available. A list of the precipitation stations in the basin, their periods of record and the stream basins in which they are located are given in Table 2. The locations of these stations are shown on Plate I, "Geographical Distribution of Precipitation in California." The solid red dots indicate stations at which records are now being taken, and the red open circles those stations which were discontinued.

During a previous investigation* a careful study and analysis were made of precipitation records of the entire state. Inquiry was made into the geographical distribution, magnitude and variation in occurrence, both seasonal and periodic, of precipitation in all sections of the state. An important part of the study was the relation of precipitation in any one year to normal or mean precipitation. From the results of the study the state was divided into 26 precipitation groups or divisions, having similar precipitation characteristics, which are shown by the blue lines on Plate I. The precipitation in a particular year at a station was expressed by a number representing the precipitation in per cent of normal and defined as the "index of seasonal wetness." The indices for each division were calculated from precipitation records at stations within the division. For stations with missing records, indices were estimated from records at other stations within the same or adjacent divisions. The index for each season in a particular division was taken as the arithmetical mean of the seasonal indices of wetness of the several stations in that division. Indices were calculated for the 26 precipitation divisions for the period 1871 to 1921. In the present investigation, they were extended through the season 1928–1929. In making the extensions, the mean seasonal precipitation for each station was assumed as that for the 50-year period 1871–1921, used in the previous study. The indices of seasonal wetness for the period 1871–1929, for the seven divisions, A, B, F, G, H, J and M, which lie wholly or partly in the Sacramento River Basin, are given in Table 3.

The indices are useful not only in showing the wide variation of precipitation by seasons, during the 58-year period, but also in estimating run-off from unmeasured streams and measured streams with missing records, by developing a relation between seasonal run-off and seasonal index of wetness. They also show the wet and dry cycles. An inspection of the data in Table 3 shows that the period 1916 to 1929 was in a cycle of low precipitation, only three years in the period showing amounts generally greater than the mean. One year in the period 1923–1924 was the dryest in the 58 years, the precipitation being less than one-half the mean over practically the entire basin.

* Bulletin No. 5, "Flow in California Streams," Division of Engineering and Irrigation, 1923.



GEOGRAPHICAL

DISTRIBUTION OF PRECIPITATION

IN

CALIFORNIA

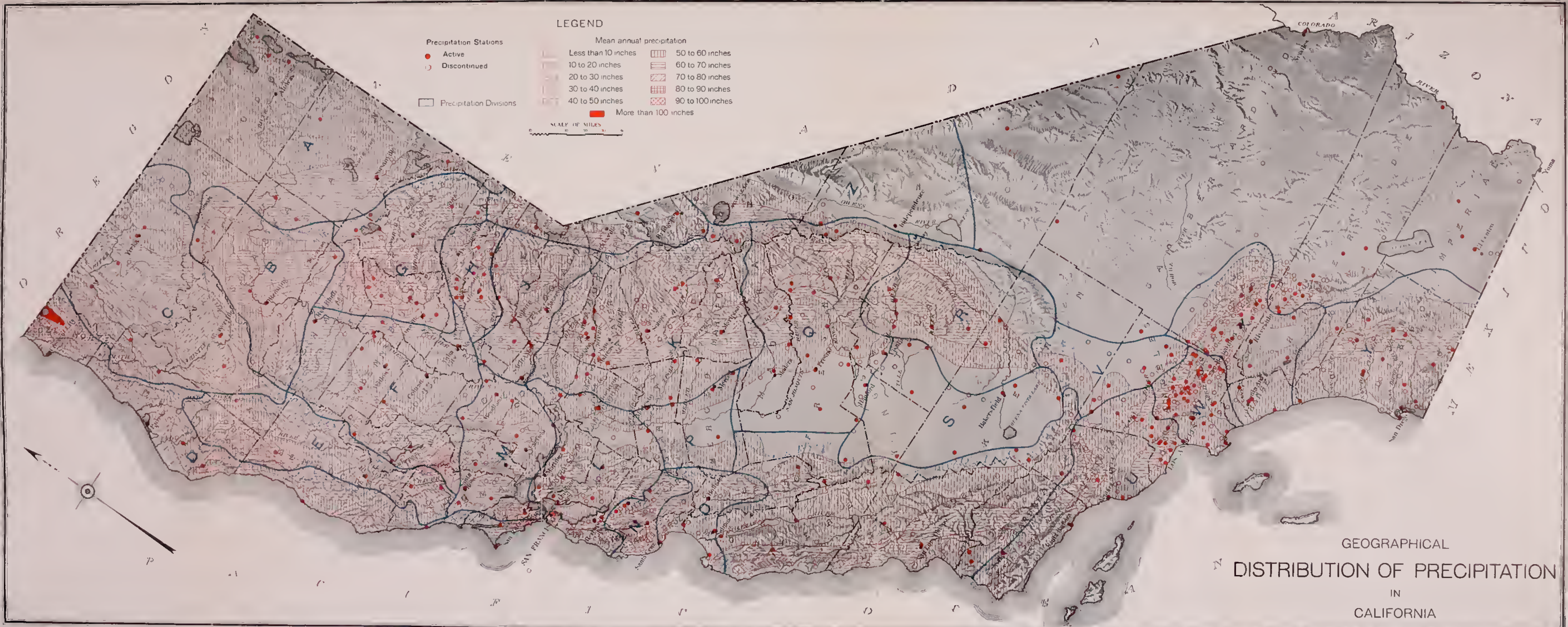

LEGEND
Precipitation Stations
Active
Discontinued
Precipitation Divisions
Mean annual precipitation
Less than 10 inches
10 to 20 inches
20 to 30 inches
30 to 40 inches
40 to 50 inches
50 to 60 inches
60 to 70 inches
70 to 80 inches
80 to 90 inches
90 to 100 inches
More than 100 inches
SCALE OF MILES
GEOGRAPHICAL
DISTRIBUTION OF PRECIPITATION
IN
CALIFORNIA

TABLE 2

PRECIPITATION STATIONS IN SACRAMENTO RIVER BASIN

Records Published by United States Weather Bureau

Station	Stream basin	Period of record	Record available to June 30, 1929, in years
Upper Sacramento River—			
Alturas	Pit River	Jan. 1904–Dec. 1919	15
Adin	Pit River (Clear Creek)	April 1894–Aug. 1897	3⅓
Pittville	Pit River	July 1909–July 1910	1
Fort Crook	Pit River	Jan. 1858–April 1869	10¼
Fall River Mills	Pit River	Jan. 1924–June 1929	5½
Hat Creek	Pit River (Hat Creek)	Jan. 1921–June 1929	8½
Burney	Pit River (Burney Creek)	Jan. 1910–June 1918	8½
Montgomery Creek	Pit River (Montgomery Creek)	July 1908–Dec. 1919	11½
McCloud	McCloud River	Sept. 1910–June 1929	18¾
Mt. Shasta (Sisson)	Sacramento River	Mar. 1888–June 1929	41
Dunsmuir	Sacramento River	Jan. 1889–Dec. 1916	28
Delta	Sacramento River	July 1882–Sept. 1916	34¼
Kennett	Sacramento River	Jan. 1907–June 1929	22½
Shasta	Sacramento River	July 1895–June 1912	17
Sims	Sacramento River	Mar. 1888–Oct. 1894	7
Redding	Sacramento River	Jan. 1875–June 1929	54
Anderson	Sacramento River	Feb. 1886–Dec. 1894	6¾
Churn Creek	Sacramento River	Jan. 1915–May 1927	12⅓
Rosewood	Sacramento River	Jan. 1894–Oct. 1904	10¾
Red Bluff	Sacramento River	July 1877–June 1929	52
Knob	Sacramento River (Cottonwood Creek)	Jan. 1909–Sept. 1910	1¾
Mineral	Sacramento River (Battle Creek)	Jan. 1927–June 1929	2½
Sierra Nevada—			
Magalia	Butte Creek	Jan. 1904–May 1918	14⅓
De Sabla (Nimshew)	Butte Creek	Jan. 1904–June 1929	25½
Centerville Power House	Butte Creek	April 1914–June 1929	15¼
Stirling City	West Branch Feather River	July 1903–May 1918	14¾
West Branch	West Branch Feather River	Jan. 1907–June 1929	22½
Inskip	West Branch Feather River	Jan. 1907–June 1929	22½
Chester	North Fork Feather River	May 1910–June 1929	19
Westwood	North Fork Feather River	Feb. 1921–June 1929	8⅓
Nevis	North Fork Feather River	Jan. 1913–Dec. 1913	1
Prattville	North Fork Feather River	Jan. 1911–Dec. 1912	2
Canyon Dam	North Fork Feather River	Jan. 1914–June 1929	15½
Greenville	North Fork Feather River	Jan. 1894–June 1914	20½
Butt Valley	North Fork Feather River	Nov. 1903–Nov. 1912	8½
Quincy	North Fork Feather River	Jan. 1895–June 1929	34½
Meadow Valley	North Fork Feather River	Jan. 1861–Mar. 1917	6½
Edmanton	North Fork Feather River	July 1892–June 1905	13
Mumford Hill	North Fork Feather River	Jan. 1877–Aug. 1882	5⅔
Las Plumas	North Fork Feather River	Jan. 1914–June 1929	15½
Cherokee	North Fork Feather River	Sept. 1871–Aug. 1884	12⅓
Cherokee Reservoir	North Fork Feather River	Sept. 1873–Aug. 1879	6
Stanwood	North Fork Feather River	July 1903–Oct. 1920	17⅓
Beckwith	Middle Fork Feather River	Feb. 1908–Dec. 1909	1¾
Portola	Middle Fork Feather River	Mar. 1915–June 1929	13⅓
Sierraville	Middle Fork Feather River	July 1909–June 1929	20
La Porte	South Fork Feather River	April 1894–June 1929	34¼
Thermalito	Feather River	Sept. 1898–July 1901	2¾
Oroville	Feather River	Sept. 1884–June 1929	44¾
Palermo	Honcut Creek	Jan. 1891–Dec. 1914	24
Sierriterre	Honcut Creek	Nov. 1919–June 1929	9⅔
Dobbins	North Fork Yuba River	Jan. 1904–June 1929	25½
Colgate	North Fork Yuba River	Jan. 1907–June 1929	22½
Chute Camp (Head Dam)	North Fork Yuba River	Jan. 1907–June 1929	22½
Woodleaf	North Fork Yuba River	Jan. 1906–Oct. 1910	4
Camptonville	North Fork Yuba River	Jan. 1907–June 1929	22½
Downieville	North Fork Yuba River	July 1908–June 1929	21
North San Juan	Middle Fork Yuba River	Jan. 1897–Dec. 1903	6¾
North Bloomfield	South Fork Yuba River	July 1870–June 1929	51¼
Malakoff Mine	South Fork Yuba River	July 1886–Dec. 1896	3⅔
Bowman Dam	South Fork Yuba River (Canyon Creek)	July 1871–June 1929	46
Cisco	South Fork Yuba River	Jan. 1870–Oct. 1916	46¾
Lake Spaulding	South Fork Yuba River	July 1894–June 1929	35
Fordyce Dam	South Fork Yuba River	July 1894–June 1929	35
Summit No. 1 (Norden)	South Fork Yuba River	Jan. 1870–June 1929	58¼
Deer Creek	Yuba River (Deer Creek)	Jan. 1907–June 1929	22½
Nevada City	Yuba River (Deer Creek)	Sept. 1863–June 1929	65¾
Smartsville	Yuba River	Sept. 1870–Aug. 1880	9¾
Grass Valley	Bear River (Wolf Creek)	Sept. 1872–June 1929	55½
Camp Far West	Bear River	Jan. 1850–Mar. 1852	2¼
Colfax	North Fork American River	Jan. 1870–June 1929	59½
Iowa Hill	North Fork American River	Jan. 1879–June 1910	31½
Gold Run	North Fork American River	Jan. 1899–Dec. 1919	21

TABLE 2

PRECIPITATION STATIONS IN SACRAMENTO RIVER BASIN

Records Published by United States Weather Bureau

Station	Stream basin	Period of record	Record available to June 30, 1929, in years
Upper Sacramento River—			
Alturas	Pit River	Jan. 1904–Dec. 1919	15
Adin	Pit River (Clear Creek)	April 1894–Aug. 1897	3⅓
Pittville	Pit River	July 1909–July 1910	1
Fort Crook	Pit River	Jan. 1858–April 1869	10¼
Fall River Mills	Pit River	Jan. 1924–June 1929	5½
Hat Creek	Pit River (Hat Creek)	Jan. 1921–June 1929	8½
Burney	Pit River (Burney Creek)	Jan. 1910–June 1918	8½
Montgomery Creek	Pit River (Montgomery Creek)	July 1908–Dec. 1919	11½
McCloud	McCloud River	Sept. 1910–June 1929	18¾
Mt. Shasta (Sisson)	Sacramento River	Mar. 1888–June 1929	41
Dunsmuir	Sacramento River	Jan. 1889–Dec. 1916	28
Delta	Sacramento River	July 1882–Sept. 1916	34¼
Kennett	Sacramento River	Jan. 1907–June 1929	22½
Shasta	Sacramento River	July 1895–June 1912	17
Sims	Sacramento River	Mar. 1888–Oct. 1894	7
Redding	Sacramento River	Jan. 1875–June 1929	54
Anderson	Sacramento River	Feb. 1886–Dec. 1894	6¾
Churn Creek	Sacramento River	Jan. 1915–May 1927	12⅓
Rosewood	Sacramento River	Jan. 1894–Oct. 1904	10¾
Red Bluff	Sacramento River	July 1877–June 1929	52
Knob	Sacramento River (Cottonwood Creek)	Jan. 1909–Sept. 1910	1¾
Mineral	Sacramento River (Battle Creek)	Jan. 1927–June 1929	2½
Sierra Nevada—			
Magalia	Butte Creek	Jan. 1904–May 1918	14⅓
De Sabla (Nimshew)	Butte Creek	Jan. 1904–June 1929	25½
Centerville Power House	Butte Creek	April 1914–June 1929	15¼
Stirling City	West Branch Feather River	July 1903–May 1918	14¾
West Branch	West Branch Feather River	Jan. 1907–June 1929	22½
Inskip	West Branch Feather River	Jan. 1907–June 1929	22½
Chester	North Fork Feather River	May 1910–June 1929	19
Westwood	North Fork Feather River	Feb. 1921–June 1929	8⅓
Nevis	North Fork Feather River	Jan. 1913–Dec. 1913	1
Prattville	North Fork Feather River	Jan. 1911–Dec. 1912	2
Canyon Dam	North Fork Feather River	Jan. 1914–June 1929	15½
Greenville	North Fork Feather River	Jan. 1894–June 1914	20½
Butt Valley	North Fork Feather River	Nov. 1903–Nov. 1912	8½
Quincy	North Fork Feather River	Jan. 1895–June 1929	34½
Meadow Valley	North Fork Feather River	Jan. 1861–Mar. 1917	6½
Edmanton	North Fork Feather River	July 1892–June 1905	13
Mumford Hill	North Fork Feather River	Jan. 1877–Aug. 1882	5⅔
Las Plumas	North Fork Feather River	Jan. 1914–June 1929	15½
Cherokee	North Fork Feather River	Sept. 1871–Aug. 1884	12⅓
Cherokee Reservoir	North Fork Feather River	Sept. 1873–Aug. 1879	6
Stanwood	North Fork Feather River	July 1903–Oct. 1920	17⅓
Beckwith	Middle Fork Feather River	Feb. 1908–Dec. 1909	1¾
Portola	Middle Fork Feather River	Mar. 1915–June 1929	13⅓
Sierraville	Middle Fork Feather River	July 1909–June 1929	20
La Porte	South Fork Feather River	April 1894–June 1929	34¼
Thermalito	Feather River	Sept. 1898–July 1901	2¾
Oroville	Feather River	Sept. 1884–June 1929	44¾
Palermo	Honcut Creek	Jan. 1891–Dec. 1914	24
Sierriterre	Honcut Creek	Nov. 1919–June 1929	9⅔
Dobbins	North Fork Yuba River	Jan. 1904–June 1929	25½
Colgate	North Fork Yuba River	Jan. 1907–June 1929	22½
Chute Camp (Head Dam)	North Fork Yuba River	Jan. 1907–June 1929	22½
Woodleaf	North Fork Yuba River	Jan. 1906–Oct. 1910	4
Camptonville	North Fork Yuba River	Jan. 1907–June 1929	22½
Downieville	North Fork Yuba River	July 1908–June 1929	21
North San Juan	Middle Fork Yuba River	Jan. 1897–Dec. 1903	6¾
North Bloomfield	South Fork Yuba River	July 1870–June 1929	51¼
Malakoff Mine	South Fork Yuba River	July 1886–Dec. 1896	3⅔
Bowman Dam	South Fork Yuba River (Canyon Creek)	July 1871–June 1929	46
Cisco	South Fork Yuba River	Jan. 1870–Oct. 1916	46¾
Lake Spaulding	South Fork Yuba River	July 1894–June 1929	35
Fordyce Dam	South Fork Yuba River	July 1894–June 1929	35
Summit No. 1 (Norden)	South Fork Yuba River	Jan. 1870–June 1929	58¼
Deer Creek	Yuba River (Deer Creek)	Jan. 1907–June 1929	22½
Nevada City	Yuba River (Deer Creek)	Sept. 1863–June 1929	65¾
Smartsville	Yuba River	Sept. 1870–Aug. 1880	9¾
Grass Valley	Bear River (Wolf Creek)	Sept. 1872–June 1929	55½
Camp Far West	Bear River	Jan. 1850–Mar. 1852	2¼
Colfax	North Fork American River	Jan. 1870–June 1929	59½
Iowa Hill	North Fork American River	Jan. 1879–June 1910	31½
Gold Run	North Fork American River	Jan. 1899–Dec. 1919	21

TABLE 2—Continued

PRECIPITATION STATIONS IN SACRAMENTO RIVER BASIN

Records Published by United States Weather Bureau

Station	Stream basin	Period of record	Record available to June 30, 1929, in years
Sierra Nevada—Continued			
Alta	North Fork American River	Feb. 1870–June 1885	15
Towle	North Fork American River	July 1885–June 1920	32¾
Blue Canyon	North Fork American River	Jan. 1899–June 1929	30⅓
Emigrant Gap	North Fork American River	Mar. 1870–Oct. 1924	46¼
Pilot Creek	Middle Fork American River	April 1894–Dec. 1914	20⅔
Georgetown	Middle Fork American River	Nov. 1872–Mar. 1923	50⅓
Wire Bridge	Middle Fork American River	Nov. 1893–Aug. 1902	8¾
Twin Lakes	South Fork American River	June 1919–June 1929	9
Shingle Springs	South Fork American River (Webber Creek)	Sept. 1849–June 1912	39½
Eldorado	South Fork American River (Webber Creek)	Dec. 1888–Dec. 1904	14⅓
Placerville	South Fork American River (Webber Creek)	Jan. 1874–June 1929	52¾
Orangevale	American River	Aug. 1891–Mar. 1898	6⅓
Folsom	American River	July 1871–June 1929	58
Repressa	American River	Mar. 1893–June 1929	36⅓
Auburn	Auburn Ravine	Mar. 1870–June 1929	58¾
Newcastle	Auburn Ravine	Sept. 1891–April 1911	17
Rocklin	Auburn Ravine	Jan. 1870–June 1929	57½
Coast Range—			
Fruto	Stony Creek	Sept. 1888–Dec. 1911	23⅓
Stony Gorge	Stony Creek	Nov. 1926–June 1929	2⅔
Little Stony	Stony Creek	Dec. 1884–April 1886	1⅓
East Park	Stony Creek	Jan. 1911–June 1929	18½
Fouts Springs	Stony Creek	Oct. 1885–Feb. 1913	12⅓
Upper Lake	Cache Creek	Jan. 1886–May 1915	29⅓
Lakeport	Cache Creek	Jan. 1901–June 1929	28
Lakeport (near Kono Tayee)	Cache Creek	Jan. 1874–Sept. 1904	21⅓
Twin Valley	Cache Creek	Jan. 1915–Mar. 1923	8
Clear Lake Park	Cache Creek	Jan. 1911–June 1929	15½
Sulphur Banks	Cache Creek	July 1911–Dec. 1917	6½
Rumsey	Cache Creek	Aug. 1888–Aug. 1893	5½
Guinda	Cache Creek	Jan. 1893–June 1918	23¾
Brooks	Cache Creek	July 1921–June 1929	8
Esparto	Cache Creek	Sept. 1888–Sept. 1894	6
Helen Mine	Putah Creek	July 1900–June 1922	22
Middletown	Putah Creek	Nov. 1879–Sept. 1897	11⅓
Winters	Putah Creek	July 1885–Dec. 1903	14¾
Vacaville	Alamo Creek	Jan. 1869–June 1929	59⅓
Elmira	Alamo Creek	Dec. 1885–Dec. 1903	16⅓
Valley Floor—			
Tehama	Sacramento Valley Floor	Jan. 1871–June 1916	45½
Los Molinos	Sacramento Valley Floor	Jan. 1911–Dec. 1912	2
Corning	Sacramento Valley Floor	July 1880–Dec. 1916	35
Vina	Sacramento Valley Floor	Oct. 1888–Aug. 1903	12⅔
Orland	Sacramento Valley Floor	Jan. 1883–June 1929	46½
Hamilton City	Sacramento Valley Floor	July 1927–June 1929	2
St. John	Sacramento Valley Floor	Jan. 1917–June 1929	12⅓
Chico	Sacramento Valley Floor	Nov. 1870–June 1929	58⅔
Durham	Sacramento Valley Floor	Jan. 1895–June 1920	25½
Dodgeland	Sacramento Valley Floor	Oct. 1918–Dec. 1922	4¼
Willows	Sacramento Valley Floor	Dec. 1878–June 1929	50½
Princeton	Sacramento Valley Floor	Sept. 1873–April 1887	12⅓
Biggs	Sacramento Valley Floor	Jan. 1899–Dec. 1916	17
College City	Sacramento Valley Floor	July 1883–Mar. 1887	2⅓
Gridley	Sacramento Valley Floor	Jan. 1884–Dec. 1917	34
Colusa	Sacramento Valley Floor	Jan. 1871–June 1929	50
Williams	Sacramento Valley Floor	Jan. 1877–Dec. 1905	29
Yuba City	Sacramento Valley Floor	Jan. 1892–Dec. 1902	10¾
Marysville	Sacramento Valley Floor	Jan. 1871–June 1929	58½
West Butte	Sacramento Valley Floor	Nov. 1879–Dec. 1894	12½
Wheatland	Sacramento Valley Floor	Dec. 1886–Aug. 1917	30¾
Lincoln	Sacramento Valley Floor	Jan. 1899–Dec. 1899	1
Nicolaus	Sacramento Valley Floor	July 1877–June 1929	23
Dunnigan	Sacramento Valley Floor	Jan. 1877–Dec. 1916	40
Knights Landing	Sacramento Valley Floor	Jan. 1878–June 1929	51½
Woodland	Sacramento Valley Floor	Jan. 1873–June 1929	47
Davis	Sacramento Valley Floor	Nov. 1871–June 1929	57⅔
Sacramento	Sacramento Valley Floor	July 1849–June 1929	80
Brighton	Sacramento Valley Floor	July 1877–Dec. 1899	20½
Elk Grove	Sacramento Valley Floor	Jan. 1892–Dec. 1899	2⅓
Grand Island	Sacramento Valley Floor	Nov. 1896–June 1901	4⅔
Rio Vista	Sacramento Valley Floor	Dec. 1878–June 1929	37½

TABLE 3

INDICES OF SEASONAL WETNESS FOR SACRAMENTO RIVER BASIN

Season	Index of wetness in division						
	A	B	F	G	H	J	M
1871-72	81	111	116	126	141	120	124
1872-73	75	53	63	74	74	75	79
1873-74	71	85	120	106	118	100	101
1874-75	62	51	82	66	72	64	72
1875-76	73	154	112	122	124	124	112
1876-77	197	69	60	61	63	62	52
1877-78	84	182	142	96	98	93	143
1878-79	81	92	78	104	105	104	100
1879-80	150	107	91	123	125	125	109
1880-81	181	127	83	107	112	108	111
1881-82	121	75	65	95	88	103	70
1882-83	74	75	70	80	79	82	83
1883-84	158	98	99	113	112	118	107
1884-85	119	58	54	77	92	73	62
1885-86	165	124	125	116	114	115	128
1886-87	118	60	64	63	72	75	71
1887-88	91	55	66	64	54	68	73
1888-89	116	104	91	100	73	76	96
1889-90	162	198	177	180	182	169	195
1890-91	95	66	93	77	77	77	85
1891-92	89	77	92	103	83	90	90
1892-93	128	117	138	125	121	123	117
1893-94	93	92	80	89	95	104	96
1894-95	100	125	149	125	136	128	138
1895-96	116	120	117	131	125	114	115
1896-97	113	97	110	106	111	110	110
1897-98	67	60	54	66	60	59	62
1898-99	71	68	80	74	84	86	82
1899-00	93	112	110	117	109	111	94
1900-01	102	102	108	114	106	112	105
1901-02	85	131	129	107	95	100	113
1902-03	77	108	95	95	94	99	95
1903-04	118	144	126	140	139	137	128
1904-05	80	121	141	109	103	100	122
1905-06	99	117	132	130	133	138	122
1906-07	131	123	119	153	138	150	131
1907-08	73	85	75	73	71	71	73
1908-09	102	147	126	136	130	124	135
1909-10	77	82	83	87	99	95	85
1910-11	113	100	110	126	127	129	110
1911-12	65	76	61	59	60	60	59
1912-13	80	81	79	77	72	67	68
1913-14	123	140	156	130	120	120	152
1914-15	62	130	143	99	101	111	128
1915-16	86	106	105	99	104	104	109
1916-17	88	76	81	83	87	89	75
1917-18	58	66	66	58	61	67	54
1918-19	69	86	94	80	85	91	99
1919-20	60	48	57	54	64	70	53
1920-21	108	119	133	105	112	110	107
1921-22	80	72	87	84	100	105	85
1922-23	70	75	101	74	83	103	96
1923-24	52	39	55	42	43	44	45
1924-25	82	116	136	83	94	98	126
1925-26	75	77	104	81	75	76	99
1926-27	87	134	124	106	115	116	127
1927-28	80	89	97	85	86	84	89
1928-29	63	68	70	56	60	66	66

The variation in mean seasonal precipitation is shown by Plate I, which covers the entire state. On this map, each type of shading represents areas having mean seasonal precipitation within the limits indicated in the legend.

The climate of California is such that the year is divided into two fairly distinct seasons—the winter, or rainy season, and the summer, or dry season. The major portion of the precipitation occurs in the short winter season, from November to April, in the form of rain on the areas of lower elevation and as snow in the high mountain regions.

Run-off.

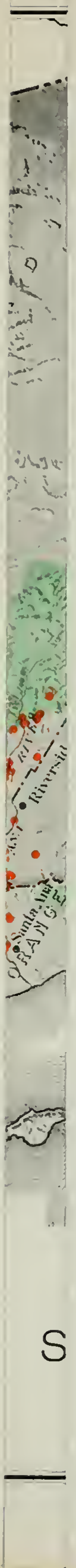
The run-off from the mountainous area of the Sacramento River Basin is 34.8 per cent of the run-off from the total mountainous area of the state. It is exceeded in total amount and in water production in acre-feet per square mile of mountainous drainage area only by the North Pacific Coast Basin.

Knowledge of the run-off in the basin is gained from stream flow measurements. The first records of stream flow in California were those obtained by the State during the time that William Ham. Hall was State Engineer, 1878–1888. The only station maintained in the Sacramento River Basin during that period was at the mouth of the Sacramento River at Collinsville. Since the early nineties, stations have been established throughout the state by the United States Geological Survey. These stations since 1903 have been maintained and operated by the Geological Survey in cooperation with the State.

The first station in the Sacramento River Basin was that established in 1895 at Jellys Ferry on the Sacramento River near Red Bluff. In 1902, it was moved downstream to Iron Canyon at which point it has been maintained since that time. Continuous records of the run-off of the Sacramento River above Red Bluff, therefore, are available for a period of 34 years. Other stations were established throughout the basin from time to time, many of which, however, were discontinued after only a few years of operation. On September 30, 1929, there were 80 stations being maintained on practically all of the main streams and their tributaries. This number had been increased to 81 on September 30, 1930. In addition to these stations maintained by, or from which records are available to, the United States Geological Survey, there are a number which are maintained on canals and streams by private and public agencies, which give valuable data on diversions. The records from those stations which were discontinued are of value in determining the characteristics of the run-off from certain areas. The stations of greatest importance in the studies for this report are those which are maintained at or near the line between the foothills and valley floor and at points near sites for major reservoir units of the State Water Plan. These stations are the ones at Kennett, Jellys Ferry and Red Bluff on the Sacramento River; Oroville on the Feather River; Smartsville on the Yuba River; Van Trent on the Bear River, and more recently Wheatland, which replaces the Van Trent station; Fairoaks on the American River, and East Auburn, Colfax and Camino (formerly Placerville), on the Middle, North and South forks of the American River, respectively; Simpson Bridge near Orland on Stony Creek; Yolo on Cache Creek; and Winters on Putah Creek.

All available data, including the records of the United States Geological Survey and those from other agencies, were used in the water supply studies for this report.

The United States Geological Survey gaging stations for which records are available, their tributary drainage areas where known, and the period of record are shown in Table 4. The locations of the stations are shown on Plate II, "Forested Area and Stream Gaging Stations in California." On this plate the solid red dots indicate stations at which records were being taken on September 30, 1929, and the red open circles those stations which had been discontinued.



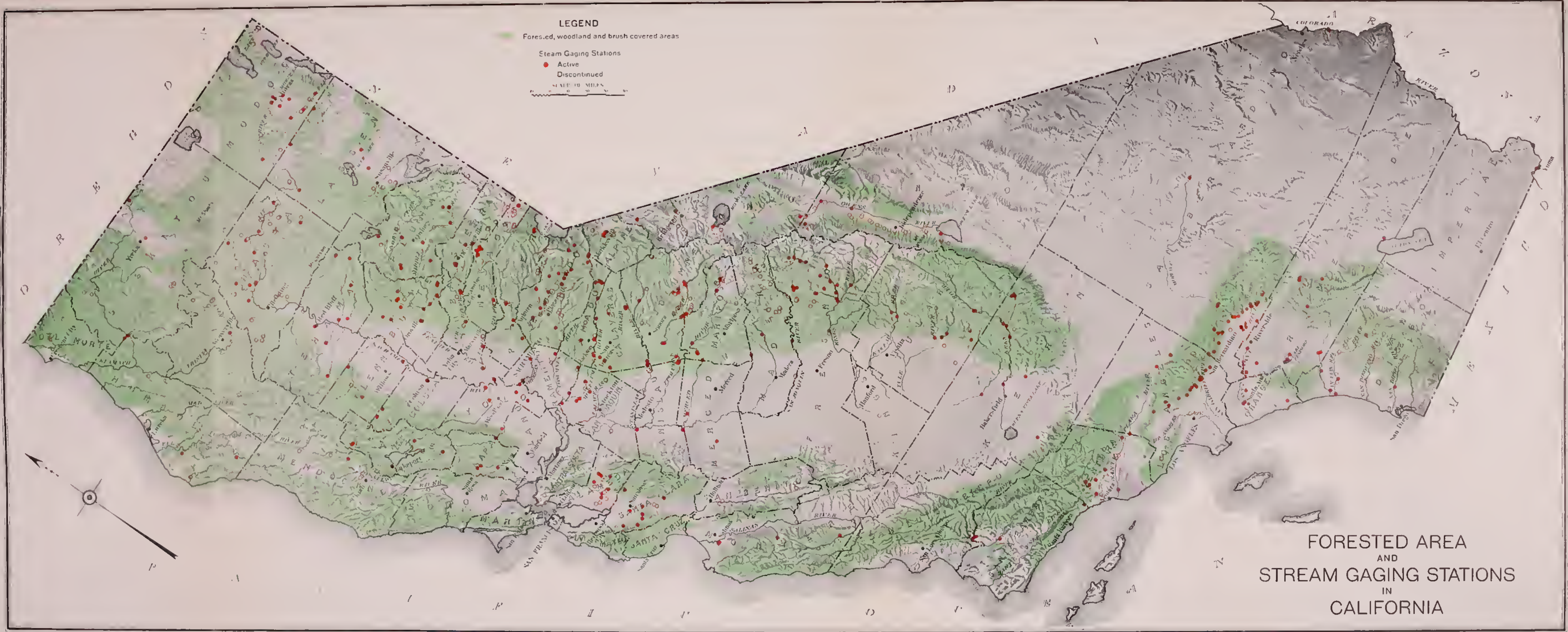

LEGEND
Forested, woodland and brush covered areas
Steam Gaging Stations
Active
Discontinued
FORESTED AREA
AND
STREAM GAGING STATIONS
IN
CALIFORNIA

TABLE 4

UNITED STATES GEOLOGICAL SURVEY STREAM GAGING STATIONS IN SACRAMENTO RIVER BASIN ESTABLISHED PRIOR TO SEPTEMBER 30, 1929

Stream	Station name	Area of drainage basin, in square miles	Period of stream flow record
Pit River, South Fork	Near Ivy	91	Jan. 11, 1904–Nov. 15, 1905
West Valley Creek	Near Likely	140	Jan. 7, 1904–Dec. 31, 1905
Pine Creek	Near Alturas	31	May 27, 1918–Sept. 30, 1929
Pit River	Near Canby	1,460	Dec. 26, 1903–Dec. 31, 1905
Ash Creek	At Adin	252	Mar. 13, 1904–Dec. 31, 1905
Pit River	Near Bieber	3,086	Jan. 22, 1904–Sept. 30, 1908
			Dec. 18, 1913–Aug. 11, 1914
			Sept. 12, 1921–June 30, 1927
Horse Creek	At Little Valley near Pittville	203	Dec. 12, 1928–Sept. 30, 1929
Bear Creek	Near Dana		Mar. 31, 1921–May 31, 1926
McArthur Drainage Canal	At McArthur		May 14, 1921–Sept. 30, 1929
Fall River	At Fall River Mills	600	Jan. 19, 1912–Aug. 10, 1913
Fall River	Near Glenburn		Jan. 4, 1922–Sept. 30, 1922
Pit River	At Fall River Mills	4,152	Mar. 12, 1921–Sept. 30, 1929
Hat Creek	At Hawkins Ranch near Hat Creek	265	Aug. 15, 1911–Aug. 9, 1913
Hat Creek	Near Hat Creek		July 7, 1926–Sept. 30, 1929
Hat Creek	At Hat Creek	326	Sept. 21, 1910–July 2, 1917
Hat Creek	At Wilcox Ranch near Cassel		Aug. 1, 1921–Sept. 30, 1922
Hat Creek	At Browns Ranch near Hat Creek		June 10, 1926–Oct. 16, 1926
Rising River	Near Cassell		Aug. 15, 1911–Mar. 23, 1914
			Mar. 16, 1921–Sept. 30, 1922
Hat Creek	Near Carbon	384	Mar. 7, 1921–Sept. 30, 1922
Pit River	Near Pecks Bridge	4,623	April 24, 1922–Aug. 7, 1924
Burney Creek	Above Burney	44	Oct. 1, 1921–Nov. 7, 1922
Burney Creek	Near Burney	92	Aug. 14, 1911–Aug. 9, 1913
			Mar. 21, 1921–Sept. 30, 1922
Burney Creek	At Burney Falls	25	Mar. 9, 1921–Nov. 30, 1922
Pit River	Below Pit No. 4 Dam		July 20, 1927–Sept. 30, 1929
Pit River	At Lindsay Flat	4,858	Nov. 1, 1922–June 21, 1927
Flow Thru Pit No. 3 Power House	At Lindsay Flat		1925–1927
Kosk Creek	At Big Bend	54	Oct. 1, 1910–Aug. 31, 1916
Pit River	At Big Bend (Henderson)	4,922	Sept. 28, 1910–Sept. 30, 1929
Pit River	Above Hatchet Creek		Oct. 1, 1925–Sept. 30, 1929
Montgomery Creek	At Montgomery Creek	42	Aug. 11, 1911–Aug. 10, 1913
Squaw Creek	Near Ydalpom	112	Oct. 4, 1911–Aug. 10, 1913
Pit River	Near Ydalpom	5,346	Nov. 16, 1910–Sept. 30, 1929
McCloud River	Near Gregory	608	Mar. 23, 1902–June 30, 1908
McCloud River	At Baird	669	Dec. 22, 1910–Sept. 30, 1929
Sacramento River	At Castella	257	Oct. 15, 1910–Sept. 30, 1922
Sacramento River	At Antler	463	Nov. 19, 1910–Dec. 31, 1911
			April 18, 1919–Sept. 30, 1929
Sacramento River	At Kennett	6,603	Nov. 19, 1925–Sept. 30, 1929
Clear Creek	Near Shasta	182	Aug. 31, 1911–Sept. 30, 1913
Little Cow Creek	At Palo Cedro	148	Aug. 9, 1911–Jan. 31, 1914
Clover Creek	At Millville	48	Aug. 10, 1911–Jan. 15, 1914
Cow Creek	At Millville	185	Aug. 10, 1911–Mar. 31, 1914
Bear Creek	Near Millville	106	Aug. 19, 1911–Mar. 31, 1914
Moon Creek	Near Ono	10	Feb. 17, 1919–Dec. 31, 1919
North Fork Cottonwood Creek	Near Ono	12	Feb. 10, 1919–Dec. 31, 1919
North Fork Cottonwood Creek	At Ono	52	Oct. 27, 1907–Dec. 31, 1913
Sacramento River	Jellys Ferry	9,093	April 29, 1895–June 30, 1902
Sacramento River	Near Red Bluff	9,258	Jan. 28, 1902–Sept. 30, 1929
Mill Creek	Near Mineral		Oct. 1, 1928–Sept. 30, 1929
Mill Creek	Near Los Molinos	137	Aug. 9, 1909–Aug. 29, 1913
			Oct. 1, 1928–Sept. 30, 1929
Thomas Creek	At Paskenta	243	Jan. 2, 1921–Sept. 30, 1929
Deer Creek	Deer Creek Meadows		Oct. 1, 1928–Sept. 30, 1929
Deer Creek	Polk Springs		Oct. 1, 1928–Sept. 30, 1929
Deer Creek	Near Vina	206	Oct. 17, 1911–Dec. 31, 1915
			Mar. 9, 1920–Sept. 30, 1929
Little Stony Creek	Near Lodoga	102	Feb. 20, 1907–Sept. 30, 1929
Stony Creek	Near Stonyford	97	April 1, 1913–Dec. 31, 1914
			Nov. 26, 1918–Dec. 19, 1920
			Oct. 1, 1921–Sept. 30, 1929
Stony Creek	Near Elk Creek	298	May 1, 1919–Sept. 30, 1929
Stony Creek	Near Fruto	577	Jan. 30, 1901–June 30, 1912
Stony Creek	Near Orland	636	Jan. 1, 1920–Sept. 30, 1929
Sacramento River	At Butte City*		April 21, 1921–Sept. 30, 1929

*Summer flow records only.

TABLE 4

UNITED STATES GEOLOGICAL SURVEY STREAM GAGING STATIONS IN SACRAMENTO RIVER BASIN ESTABLISHED PRIOR TO SEPTEMBER 30, 1929

Stream	Station name	Area of drainage basin, in square miles	Period of stream flow record
Pit River, South Fork	Near Ivy	91	Jan. 11, 1904–Nov. 15, 1905
West Valley Creek	Near Likely	140	Jan. 7, 1904–Dec. 31, 1905
Pine Creek	Near Alturas	31	May 27, 1918–Sept. 30, 1929
Pit River	Near Canby	1,460	Dec. 26, 1903–Dec. 31, 1905
Ash Creek	At Adin	252	Mar. 13, 1904–Dec. 31, 1905
Pit River	Near Bieber	3,086	Jan. 22, 1904–Sept. 30, 1908
			Dec. 18, 1913–Aug. 11, 1914
			Sept. 12, 1921–June 30, 1927
Horse Creek	At Little Valley near Pittville	203	Dec. 12, 1928–Sept. 30, 1929
Bear Creek	Near Dana		Mar. 31, 1921–May 31, 1926
McArthur Drainage Canal	At McArthur		May 14, 1921–Sept. 30, 1929
Fall River	At Fall River Mills	600	Jan. 19, 1912–Aug. 10, 1913
Fall River	Near Glenburn		Jan. 4, 1922–Sept. 30, 1922
Pit River	At Fall River Mills	4,152	Mar. 12, 1921–Sept. 30, 1929
Hat Creek	At Hawkins Ranch near Hat Creek	265	Aug. 15, 1911–Aug. 9, 1913
Hat Creek	Near Hat Creek		July 7, 1926–Sept. 30, 1929
Hat Creek	At Hat Creek	326	Sept. 21, 1910–July 2, 1917
Hat Creek	At Wilcox Ranch near Cassel		Aug. 1, 1921–Sept. 30, 1922
Hat Creek	At Browns Ranch near Hat Creek		June 10, 1926–Oct. 16, 1926
Rising River	Near Cassell		Aug. 15, 1911–Mar. 23, 1914
			Mar. 16, 1921–Sept. 30, 1922
Hat Creek	Near Carbon	384	Mar. 7, 1921–Sept. 30, 1922
Pit River	Near Pecks Bridge	4,623	April 24, 1922–Aug. 7, 1924
Burney Creek	Above Burney	44	Oct. 1, 1921–Nov. 7, 1922
Burney Creek	Near Burney	92	Aug. 14, 1911–Aug. 9, 1913
			Mar. 21, 1921–Sept. 30, 1922
Burney Creek	At Burney Falls	25	Mar. 9, 1921–Nov. 30, 1922
Pit River	Below Pit No. 4 Dam		July 20, 1927–Sept. 30, 1929
Pit River	At Lindsay Flat	4,858	Nov. 1, 1922–June 21, 1927
Flow Thru Pit No. 3 Power House	At Lindsay Flat		1925–1927
Kosk Creek	At Big Bend	54	Oct. 1, 1910–Aug. 31, 1916
Pit River	At Big Bend (Henderson)	4,922	Sept. 28, 1910–Sept. 30, 1929
Pit River	Above Hatchet Creek		Oct. 1, 1925–Sept. 30, 1929
Montgomery Creek	At Montgomery Creek	42	Aug. 11, 1911–Aug. 10, 1913
Squaw Creek	Near Ydalpom	112	Oct. 4, 1911–Aug. 10, 1913
Pit River	Near Ydalpom	5,346	Nov. 16, 1910–Sept. 30, 1929
McCloud River	Near Gregory	608	Mar. 23, 1902–June 30, 1908
McCloud River	At Baird	669	Dec. 22, 1910–Sept. 30, 1929
Sacramento River	At Castella	257	Oct. 15, 1910–Sept. 30, 1922
Sacramento River	At Antler	463	Nov. 19, 1910–Dec. 31, 1911
			April 18, 1919–Sept. 30, 1929
Sacramento River	At Kennett	6,603	Nov. 19, 1925–Sept. 30, 1929
Clear Creek	Near Shasta	182	Aug. 31, 1911–Sept. 30, 1913
Little Cow Creek	At Palo Cedro	148	Aug. 9, 1911–Jan. 31, 1914
Clover Creek	At Millville	48	Aug. 10, 1911–Jan. 15, 1914
Cow Creek	At Millville	185	Aug. 10, 1911–Mar. 31, 1914
Bear Creek	Near Millville	106	Aug. 19, 1911–Mar. 31, 1914
Moon Creek	Near Ono	10	Feb. 17, 1919–Dec. 31, 1919
North Fork Cottonwood Creek	Near Ono	12	Feb. 10, 1919–Dec. 31, 1919
North Fork Cottonwood Creek	At Ono	52	Oct. 27, 1907–Dec. 31, 1913
Sacramento River	Jellys Ferry	9,093	April 29, 1895–June 30, 1902
Sacramento River	Near Red Bluff	9,258	Jan. 28, 1902–Sept. 30, 1929
Mill Creek	Near Mineral		Oct. 1, 1928–Sept. 30, 1929
Mill Creek	Near Los Molinos	137	Aug. 9, 1909–Aug. 29, 1913
			Oct. 1, 1928–Sept. 30, 1929
Thomas Creek	At Paskenta	243	Jan. 2, 1921–Sept. 30, 1929
Deer Creek	Deer Creek Meadows		Oct. 1, 1928–Sept. 30, 1929
Deer Creek	Polk Springs		Oct. 1, 1928–Sept. 30, 1929
Deer Creek	Near Vina	206	Oct. 17, 1911–Dec. 31, 1915
			Mar. 9, 1920–Sept. 30, 1929
Little Stony Creek	Near Lodoga	102	Feb. 20, 1907–Sept. 30, 1929
Stony Creek	Near Stonyford	97	April 1, 1913–Dec. 31, 1914
			Nov. 26, 1918–Dec. 19, 1920
			Oct. 1, 1921–Sept. 30, 1929
Stony Creek	Near Elk Creek	298	May 1, 1919–Sept. 30, 1929
Stony Creek	Near Fruto	577	Jan. 30, 1901–June 30, 1912
Stony Creek	Near Orland	636	Jan. 1, 1920–Sept. 30, 1929
Sacramento River	At Butte City*		April 21, 1921–Sept. 30, 1929

*Summer flow records only.

TABLE 4—Continued

UNITED STATES GEOLOGICAL SURVEY STREAM GAGING STATIONS IN SACRAMENTO RIVER BASIN ESTABLISHED PRIOR TO SEPTEMBER 30, 1929

Stream	Station name	Area of drainage basin, in square miles	Period of stream flow record
Sacramento River	At Colusa*		April 11, 1921–Sept. 30, 1929
Sacramento River	At Knights Landing*		April 1, 1921–Sept. 30, 1929
Hamilton Branch of Feather River	Near Prattville	230	June 12, 1905–July 1, 1907
Feather River (North Fork)	Above Prattville	245	June 12, 1905–July 1, 1907
Feather River (North Fork)	Near Prattville	506	June 13, 1905–Sept. 30, 1929
Butt Creek	At Butte Valley	73	June 14, 1905–April 30, 1921
Indian Creek	Near Crescent Mills	740	Jan. 1, 1906–Dec. 31, 1909 Sept. 10, 1911–Mar. 31, 1918
Spanish Creek	At Keddie	192	Oct. 22, 1911–Sept. 30, 1929
Grizzly Creek	Near Beckwith	51	Dec. 17, 1905–Sept. 30, 1906
Grizzly Creek	Near Portola	51	Oct. 1, 1925–Sept. 30, 1929
Feather River, North Fork	At Big Bar	1,935	Feb. 24, 1911–Sept. 30, 1929
Feather River, North Fork	At Big Bend	1,956	June 13, 1905–Dec. 31, 1910
Concow Creek	Near Yankee Hill		Oct. 1, 1927–Sept. 30, 1929
Spring Valley Ditch	Near Yankee Hill		Oct. 1, 1927–Sept. 30, 1929
Feather River, Middle Fork	Near Clio	697	Oct. 1, 1925–Sept. 30, 1929
Feather River, Middle Fork	At Sloat (Formerly at Cromberg)	791	Nov. 3, 1910–Feb. 19, 1928
Feather River, Middle Fork	Near Nelson Point	896	Dec. 13, 1923–Sept. 30, 1929
Feather River, South Fork	Near La Porte	24	Oct. 1, 1927–Sept. 30, 1929
Lost Creek	Near Clipper Mills	28	Oct. 1, 1927–Sept. 30, 1929
Forbestown Ditch	Near Clipper Mills		Oct. 1, 1927–Sept. 30, 1929
Feather River, South Fork	At Enterprise	146	Oct. 8, 1911–Sept. 30, 1929
Palermo Land and Water Company's Canal	At Enterprise		Oct. 8, 1911–Sept. 30, 1929
Feather River, Middle Fork	At Bidwell Bar	1,354	Oct. 7, 1911–Sept. 30, 1929
Feather River	At Oroville	3,627	Jan. 1, 1902–Sept. 30, 1929
Yuba River (North Fork)	Near Sierra City		Nov. 1, 1911–1913 Fragmentary Dec. 21, 1923–Sept. 30, 1929
N. Fork of N. Fork of Yuba River	At Downieville	71	Nov. 1, 1910–Sept. 30, 1926
Rock Creek	At Goodyear Bar	11	Oct. 30, 1910–Sept. 30, 1929
Goodyear Creek	At Goodyear Bar	12	Oct. 30, 1910–Sept. 30, 1929
Yuba River (North Fork)	At Goodyear Bar	218	Oct. 31, 1910–Sept. 30, 1929
Yuba River (North Fork)	North San Juan (near)	490	July 1 to Sept. 30, 1900
Yuba River (Middle Fork)	At Milton	41	Dec. 31, 1925–Sept. 30, 1929
Oregon Creek	Near North San Juan		Oct. 28, 1910–Sept. 30, 1929
Yuba River (Middle Fork)	Near North San Juan	206	July 1, 1900–Oct. 20, 1900 Oct. 27, 1910–Sept. 30, 1929
Canyon Creek	Above Jackson Creek		Jan. 1, 1926–Sept. 30, 1929
Jackson Creek	At mouth		Jan. 21, 1926–Sept. 30, 1929
Canyon Creek	Below Bowman Lake		Jan. 5, 1927–Sept. 30, 1929
Bowman-Spaulding Canal	At Intake		Oct. 1, 1927–Sept. 30, 1929
Milton-Bowman Tunnel	At Outlet		May 21, 1928–Sept. 30, 1929
Yuba River	Near Smartsville	1,200	June 2, 1903–Sept. 30, 1929
Yuba River	At Parks Bar Bridge	1,230	June 28, 1900–Oct. 14, 1900
Bear River	Near Colfax		Jan. 1, 1912–June 30, 1917
Bear River Canal	Near Colfax		Jan. 1, 1912–Sept. 30, 1929
Bear River	At Van Trent	262	Oct. 8, 1904–Jan. 22, 1928
Bear River	Near Wheatland		Oct. 23, 1928–Sept. 30, 1929
Feather River	At Nicolaus*		June 13, 1921–Sept. 30, 1929
Sacramento River	At Verona*		Oct. 1, 1926–Sept. 30, 1929
Clear Lake	At Lakeport		Feb. 25, 1913–Sept. 30, 1929
Cache Creek	At Lower Lake	487	Jan. 1, 1901–Nov. 14, 1915
Cache Creek	At Yolo	1,195	Jan. 1, 1903–Sept 30, 1929
American River, North Fork	Near Colfax	308	Aug. 16, 1911–Sept. 30, 1929
Rubicon River	At Rubicon Springs	32	Feb. 1, 1910–Sept. 28, 1914
Rubicon River	Near Quintette	198	Nov. 21, 1909–June 8, 1914
Little Rubicon River	Near Rubicon Springs	7	Nov. 1, 1910–Aug. 31, 1911
Little South Fork Rubicon River	At South Fork Sawmill near Quintette	17	Feb. 1, 1910–July 4, 1914
Gerle Creek	Near Rubicon Springs	9	July 12, 1910–April 2, 1914
Little South Fork Rubicon River	Below Gerle Creek near Quintette	50	Feb. 1, 1910–June 21, 1914
Little South Fork of Rubicon River	At mouth near Quintette	58	Dec. 1, 1909–Dec. 7, 1911
Little South Fork Ditch	At Sawmill near Quintette		June 7, 1910–Nov. 30, 1913
Pilot Creek	Near Quintette	19	Feb. 24, 1910–July 30, 1914
Pilot Creek Ditch	Near Quintette		Feb. 25, 1910–Jan. 31, 1914
American River, Middle Fork	Near East Auburn	619	Oct. 22, 1911–Sept. 30, 1929
Twin Lakes Outlet	Near Kirkwood		Sept. 19, 1922–Sept. 30, 1929

* Summer flow records only.

TABLE 4—Continued

UNITED STATES GEOLOGICAL SURVEY STREAM GAGING STATIONS IN SACRAMENTO RIVER BASIN ESTABLISHED PRIOR TO SEPTEMBER 30, 1929

Stream	Station name	Area of drainage basin, in square miles	Period of stream flow record
Twin Lakes Spillway	Near Kirkwood		June 11, 1925–Sept. 30, 1929
Silver Lake outlet	Near Kirkwood		Sept. 19, 1922–Sept. 30, 1929
Silver Fork of South Fork of American River	Near Kyburz		Aug. 16, 1924–Sept. 30, 1929
American River, South Fork	At Kyburz		April 11, 1906–Nov. 30, 1907 April 19, 1922–Sept. 30, 1929
American River, South Fork	Near Kyburz		Aug. 31, 1907–Dec. 14, 1907 Oct. 1, 1922–Sept. 30, 1929
Medley Lakes Outlet	Near Vade		Sept. 11, 1922–Sept. 30, 1929
Echo Lake Flume	Near Vade		Aug. 23, 1923–Sept. 30, 1929
Eldorado Canal	Near Kyburz		Oct. 1, 1922–Sept. 30, 1929
Alder Creek	Near Whitehall	23	Oct. 1, 1922–Sept. 30, 1929
Plum Creek	Near Riverton	7	Nov. 1, 1922–Sept. 30, 1929
South Fork Silver Creek	At Ice House	28	July 5, 1922–Oct. 15, 1922 Oct. 23, 1924–Sept. 30, 1929
Silver Creek	At Union Valley	83	Oct. 1, 1924–Sept. 30, 1929
American River, South Fork	Below Silver Creek		Aug. 11, 1923–Dec. 16, 1923
Silver Creek	Near Placerville	176	Dec. 23, 1921–Sept. 30, 1929
Finnon Reservoir Outlet	Near Placerville		Oct. 1, 1922–Sept. 30, 1929
Western States Gas and Electric Co's. Flume	Near Camino		Nov. 1, 1922–Sept. 30, 1929
American River, South Fork	Below Silver Fork near Kyburz		Feb. 25, 1906–Aug. 5, 1906 Aug. 11, 1923–Dec. 16, 1923
American River, South Fork	Near Camino	505	Oct. 30, 1922–Sept. 30, 1929
American River, South Fork	Near Placerville	605	Aug. 11 1911–July 31, 1920
American River	At Fairoaks	1919	Nov. 3, 1904–Sep. 30, 1929
American River	At Sacramento*		July 13, 1921–Oct. 27, 1921
Sacramento River	At Sacramento*		June 19, 1921–Nov. 24, 1921
Putah Creek	Near Guenoc	91	Feb. 12, 1904–July 30, 1906
Putah Creek	At Winters	655	Sept. 26, 1905–Sept. 30, 1929
Sacramento River	At Collinsville**		Oct. 1878–Sept. 1885

* Summer flow records only.
**Monthly estimates only.

Full Natural Run-off.—The full natural run-off at any station is the flow as it would be if unimpaired by upstream diversions, uses and storage developments and not increased by importations of water into the watershed. It is the flow that would occur under natural conditions.

The monthly full natural run-offs from each drainage basin during the period of stream discharge measurements were estimated by adding to the measured run-offs at the gaging station the net amounts of water used in the basin for irrigation, by adding the amounts of water stored in and subtracting the amounts of water released from reservoirs in the basin, by adding any water diverted from the basin, and by subtracting the amount of any water diverted into the basin from other basins during the month. For the irrigation correction, the total areas of lands which were estimated to have been irrigated in certain seasons were listed and areas irrigated in other seasons were estimated by interpolation. The unit uses of water on the mountain and foothill lands were taken to be the same as those described for the ultimate uses on these lands in Chapter V. The monthly distribution of the total seasonal uses was taken to be the same as shown in a table in Chapter V. The corrections for storage were made as far as possible from records of actual reservoir operations. Where complete records were not available and water was known to have been stored, estimates were made of the amounts stored in those seasons for which no records could be obtained, by comparison with those for which there were records, and by using the storage capacity known to have been utilized. The monthly distribution of the storage and release was assumed to be the same for years having no records as for those with records.

The above method applies only to the correction of measured run-off records. The monthly full natural run-offs from a basin in the years having no stream flow records were estimated from monthly probable run-off curves for that basin. These curves show the relation between monthly run-off and a monthly factor of wetness and were constructed, one for each of the twelve months, such as January for example, in the following manner: For each January of the period of stream flow record, the monthly full natural run-off from the basin was plotted against the monthly factor of wetness for the basin for the same January and a curve was drawn averaging all of the points so plotted. The monthly factor of wetness for each month of each year is a number representing the average precipitation over the basin during that month in that year divided by the mean precipitation for the month based on records of a number of years, weighted by different percentages of the factors of wetness of preceding months. The full natural run-off for January in a year having no stream flow records was obtained from the January curve by taking from it the run-off corresponding to a factor of wetness computed for that month from precipitation records. In a similar manner, curves were drawn for other months and run-offs for those months in years having no stream flow records were obtained.

This general method was used for all of the stations studied but some variations were necessary for certain gaging stations and dam sites as will be explained in more detail in Chapter IX in the descriptions of the methods of obtaining the water supply for each of the proposed major reservoir units of the State Water Plan in the Sacramento River Basin.

The seasonal full natural run-offs from the minor stream groups were estimated by means of probable run-off curves, most of which are the same as those given for these groups in a previous report.* Very few stream flow records exist on these streams but the few that are available were used in estimating the relation between seasonal run-off and the index of seasonal wetness for the same season. For those streams or stream groups for which no records are available, the curves were drawn by comparison with those for adjacent streams or similar groups. The seasonal run-off for each stream or stream group was obtained by taking from these curves the run-off corresponding to the index of seasonal wetness for that season in the precipitation division in which the stream or stream group lies.

The seasonal full natural run-offs from the mountain and foothill drainage basins of all of the major and minor streams of the Sacramento River Basin, as obtained by the above methods, for the 40-year period 1889–1929, are shown in Table 5. It may be seen from the total mean seasonal run-offs in this table that only about 10 per cent of the total run-off from the entire mountain and foothill drainage area of the Sacramento River Basin is contributed by the minor streams.

* Bulletin No. 5, "Flow in California Streams," Division of Engineering and Irrigation, 1923.

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TABLE 5

SEASONAL FULL NATURAL RUN-OFFS OF SACRAMENTO RIVER BASIN STREAMS

Stream or stream group	Drainage area, in square miles	Run-off, in acre-feet																					
		1889-90	1890-91	1891-92	1892-93	18[illegible]4	1894-95	1895-96	1896-97	1897-98	1898-99	1899-1900	1900-01	1901-02	1902-03	1903-04	1904-05	1905-06	1906-07	1907-08	1908-09	1909-10	1910-11
MAJOR STREAMS—																							
Sacramento River at Kennett dam site*	6,649	12,582,000	4,637,000	5,118,000	7,891,000	5,[illegible],000	7,837,000	7,247,000	6,858,000	3,871,000	4,340,000	5,896,000	6,073,000	7,122,000	6,586,000	9,523,000	7,038,000	7,259,000	8,486,000	5,494,000	8,605,000	6,156,000	6,668,000
Sacramento River at Red Bluff	9,258	22,700,000	6,460,000	7,250,000	12,400,000	8,[illegible],000	12,300,000	11,351,000	10,387,000	5,138,000	5,980,000	8,711,000	9,023,000	11,379,000	9,942,000	16,104,000	10,782,000	11,292,000	13,881,000	7,916,000	14,571,000	9,109,000	10,108,000
Feather River at Oroville	3,627	13,278,000	4,158,000	4,842,000	7,535,000	3,[illegible],000	7,093,000	7,786,000	5,440,000	2,304,000	2,872,000	6,788,000	6,281,000	4,561,000	4,543,000	9,439,000	4,594,000	6,855,000	9,492,000	3,639,000	7,517,000	4,638,000	7,121,000
Yuba River at Smartsville	1,200	6,908,000	1,981,000	1,736,000	3,454,000	2,[illegible],000	3,941,000	2,620,000	3,310,000	1,305,000	2,128,000	3,061,000	2,799,000	2,694,000	2,438,000	4,190,000	2,489,000	3,721,000	4,544,000	1,691,000	3,968,000	2,756,000	3,606,000
Bear River at Van Trent	262	1,212,000	235,000	242,000	553,000	[illegible],000	841,000	560,000	399,000	129,000	251,000	388,000	425,000	351,000	338,000	679,000	375,000	618,000	782,000	246,000	575,000	317,000	567,000
American River at Fairoaks	1,919	8,749,000	1,548,000	2,037,000	4,232,000	2,[illegible]2,000	5,182,000	3,564,000	3,064,000	938,000	1,854,000	3,297,000	3,396,000	2,592,000	2,515,000	5,390,000	2,174,000	4,838,000	5,786,000	1,526,000	4,624,000	3,614,000	5,554,000
Stony Creek at mouth of canyon	710	1,442,000	435,000	209,000	676,000	[illegible]6,000	1,315,000	571,000	408,000	86,900	217,000	348,000	371,000	894,000	726,000	1,032,000	618,000	684,000	1,072,000	350,000	1,316,000	363,000	712,000
Cache Creek at Capay dam site	996	2,125,000	584,000	558,000	1,435,000	[illegible]8,000	1,450,000	903,000	813,000	59,500	398,000	813,000	791,000	787,000	672,000	1,310,000	1,111,000	1,008,000	1,247,000	477,000	1,632,000	492,000	815,000
Putah Creek at Winters	655	1,239,000	346,000	332,000	793,000	[illegible]5,000	908,000	576,000	506,000	17,000	216,000	506,000	489,000	698,000	356,000	663,000	820,000	583,000	691,000	200,000	882,000	228,000	487,000
Totals	18,627	57,653,000	15,747,000	17,206,000	31,078,000	18,[illegible]8,000	33,030,000	27,931,000	24,327,000	9,977,400	13,916,000	23,912,000	23,575,000	23,956,000	21,530,000	38,807,000	22,963,000	29,599,000	37,495,000	16,045,000	35,085,000	21,517,000	28,970,000
MINOR STREAMS—																							
Mill Creek Group	971	2,610,000	787,000	1,170,000	1,543,000	[illegible]3,000	1,543,000	1,647,000	1,212,000	642,000	751,000	1,388,000	1,357,000	1,227,000	1,056,000	1,812,000	1,279,000	1,636,000	2,071,000	746,000	1,720,000	917,000	1,553,000
Butte Creek Group	251	1,178,000	313,000	482,000	652,000	[illegible]5,000	652,000	701,000	499,000	252,000	294,000	584,000	562,000	509,000	424,000	783,000	522,000	695,000	902,000	290,000	744,000	372,000	660,000
Honcut Creek Group	314	522,000	120,000	202,000	281,000	[illegible]7,000	281,000	305,000	212,000	90,000	112,000	251,000	243,000	214,000	176,000	341,000	224,000	301,000	395,000	110,000	325,000	147,000	284,000
Dry Creek	79	137,000	29,600	34,200	66,800	[illegible]3,500	81,500	70,600	57,000	18,200	34,600	55,300	52,800	43,500	42,700	85,300	50,700	79,000	84,500	25,400	75,600	46,900	72,200
Coon Creek Group	210	124,000	14,500	22,400	52,600	[illegible]2,500	59,300	41,400	38,000	6,700	20,100	39,200	40,300	29,100	28,000	70,500	29,100	72,700	90,600	12,300	53,700	25,700	59,300
Red Bank Creek Group	109	202,000	58,000	56,800	128,000	[illegible]2,900	149,000	92,200	80,600	20,300	42,900	80,600	78,300	112,000	59,700	107,000	133,000	116,000	95,700	37,700	107,000	46,400	80,600
Elder Creek Group	414	872,000	256,000	249,000	580,000	[illegible]0,000	658,000	419,000	373,000	33,000	170,000	373,000	364,000	585,000	269,000	486,000	596,000	525,000	437,000	141,000	486,000	190,000	373,000
Willow Creek Group	394	265,000	74,000	71,000	162,000	[illegible]5,000	187,000	116,000	101,000	27,000	55,000	101,000	101,000	141,000	76,000	132,000	166,000	145,000	120,000	48,000	132,000	59,000	101,000
Totals	2,742	5,910,000	1,652,100	2,287,400	3,465,400	1,[illegible]900	3,610,800	3,392,200	2,572,600	1,089,200	1,479,600	2,872,100	2,798,400	2,860,600	2,131,400	3,816,800	2,999,800	3,569,700	4,195,800	1,410,400	3,652,300	1,804,000	3,183,100
Grand totals	21,369	63,563,000	17,399,100	19,493,400	34,543,400	20,[illegible]900	36,640,800	31,323,200	26,899,600	11,066,600	15,395,600	26,784,100	26,373,400	26,816,600	23,661,400	42,623,800	25,962,800	33,168,700	41,690,800	17,455,400	38,737,300	23,321,000	32,153,100

Stream or stream group	Run-off, in acre-feet																		Mean run-off, in acre-feet, for period			
	1911-12	1912-13	1913-14	1914-15	19[illegible]16	1916-17	1917-18	1918-19	1919-20	1920-21	1921-22	1922-23	1923-24	1924-25	1925-26	1926-27	1927-28	1928-29	1889-1929	1909-1929	1919-1929	1924-1929
MAJOR STREAMS—																						
Sacramento River at Kennett dam site*	4,726,000	5,001,000	8,361,000	7,849,000	6,9[illegible]4,000	5,039,000	4,028,000	5,389,000	3,294,000	7,396,000	4,769,000	3,994,000	2,691,000	5,427,000	3,921,000	7,222,000	5,331,000	3,400,000	6,149,000	5,379,000	4,745,000	5,060,000
Sacramento River at Red Bluff	6,574,000	7,044,000	13,716,000	12,568,000	10,[illegible]7,000	7,134,000	5,441,000	7,824,000	4,217,000	11,476,000	6,666,000	5,347,000	3,294,000	8,078,000	5,674,000	10,971,000	7,634,000	4,399,000	9,354,000	7,898,000	6,775,000	7,351,000
Feather River at Oroville	2,244,000	2,823,000	8,110,000	6,067,000	7,[illegible]6,000	5,075,000	2,745,000	3,649,000	2,203,000	6,038,000	5,076,000	3,070,000	1,296,000	3,152,000	3,174,000	5,848,000	4,246,000	1,838,000	5,201,000	4,271,000	3,594,000	3,652,000
Yuba River near Smartsville	1,200,000	1,492,000	3,061,000	2,690,000	3,2[illegible]0,000	2,530,000	1,348,000	1,976,000	1,298,000	3,168,000	2,972,000	2,073,000	603,000	2,123,000	1,606,000	3,542,000	2,435,000	1,007,000	2,653,000	2,240,000	2,083,000	2,143,000
Bear River at Van Trent	152,000	177,000	502,000	430,000	6[illegible]5,000	361,000	147,000	318,000	145,000	486,000	437,000	363,000	66,100	268,000	243,000	523,000	329,000	124,000	402,000	328,000	298,000	298,000
American River at Fairoaks	1,338,000	1,513,000	4,045,000	3,154,000	3,9[illegible]0,000	2,923,000	1,503,000	2,229,000	1,467,000	3,204,000	3,279,000	2,751,000	543,000	2,717,000	1,386,000	3,652,000	2,521,000	1,147,000	3,069,000	2,624,000	2,267,000	2,285,000
Stony Creek at mouth of canyon	65,600	148,000	1,073,000	816,000	5[illegible]8,000	284,000	148,000	266,000	69,400	641,000	259,000	221,000	42,800	509,000	307,000	637,000	377,000	102,000	514,000	379,000	316,000	386,000
Cache Creek at Capay dam site	180,000	302,000	1,487,000	1,254,000	8[illegible]8,000	437,000	193,000	531,000	93,600	959,000	488,000	523,000	76,300	756,000	681,000	914,000	637,000	183,000	762,000	595,000	531,000	634,000
Putah Creek at Winters	57,300	134,000	896,000	711,000	7[illegible]0,000	286,000	90,700	318,000	45,000	513,000	232,000	280,000	41,200	352,000	350,000	547,000	304,000	68,900	442,000	332,000	273,000	324,000
Totals	11,819,900	13,633,000	32,890,000	27,690,000	27,6[illegible]4,000	19,030,000	11,615,700	17,111,000	9,538,000	26,485,000	19,409,000	14,628,000	5,962,400	17,955,000	13,421,000	26,634,000	18,483,000	8,868,900	22,397,000	18,667,000	16,137,000	17,073,000
MINOR STREAMS—																						
Mill Creek Group	570,000	787,000	1,636,000	1,118,000	1,[illegible]8,000	880,000	564,000	834,000	513,000	1,201,000	886,000	751,000	378,000	880,000	839,000	1,217,000	896,000	528,000	1,131,000	903,000	809,000	872,000
Butte Creek Group	214,000	313,000	423,000	478,000	[illegible]1,000	375,000	228,000	297,000	211,000	562,000	414,000	312,000	134,000	302,000	297,000	490,000	396,000	201,000	464,000	357,000	332,000	337,000
Honcut Creek Group	74,000	120,000	301,000	189,000	[illegible]9,000	139,000	70,000	129,000	59,000	209,000	142,000	112,000	33,500	139,000	132,000	211,000	144,000	63,600	194,000	144,000	125,000	138,000
Dry Creek	18,200	26,200	65,900	48,600	[illegible]1,100	36,800	19,000	35,500	20,700	58,300	47,600	34,500	9,300	42,100	27,800	61,100	35,800	18,500	48,600	38,800	35,600	37,100
Coon Creek Group	7,800	10,100	48,100	39,200	[illegible]2,500	21,300	10,100	23,500	11,200	38,000	33,600	31,400	2,200	28,000	14,600	44,800	10,000	10,100	34,700	25,500	23,300	23,300
Red Bank Creek Group	25,500	41,700	182,000	137,000	[illegible]73,600	43,500	29,600	59,100	21,400	119,000	50,000	67,400	20,900	124,000	72,700	105,000	62,200	33,100	79,400	68,700	67,500	78,300
Elder Creek Group	66,000	166,000	711,000	609,000	335,000	177,000	93,000	265,000	44,000	534,000	329,000	249,000	55,000	484,000	246,000	575,000	438,000	95,000	352,000	302,000	305,000	368,000
Willow Creek Group	34,000	53,000	206,000	172,000	[illegible]03,000	55,000	38,000	74,000	29,000	149,000	63,000	86,200	27,300	156,000	92,500	130,000	77,700	42,000	100,000	86,900	85,300	99,600
Totals	1,009,500	1,517,000	3,553,000	2,790,800	2,343,200	1,727,600	1,051,700	1,717,100	909,300	2,870,300	1,965,200	1,643,500	660,200	2,155,100	1,721,600	2,833,000	2,068,700	991,300	2,403,700	1,925,900	1,782,700	1,954,300
Grand totals	12,829,400	15,150,000	36,443,000	30,480,800	30,037,200	20,757,600	12,667,400	18,828,100	10,447,300	29,355,300	21,374,200	16,271,500	6,622,600	20,110,100	15,142,600	29,467,900	20,551,700	9,860,200	24,800,700	20,592,900	17,919,700	19,027,300

*The amounts shown for the drainage area and run-offs for the Sacramento River at Kennett dam site are not used in obtaining the totals since these amounts are included in those for the Sacramento River at Red Bluff.

Stream group	Streams included in group
MILL CREEK GROUP	Mill Creek Deer Creek Antelope Creek Big Chico Creek Little Chico Creek Sycamore Hollow Sheep Hollow Grizzly Hollow Mud Creek Rock Creek Pine Creek Zimmershed Creek Camel Creek Rattlesnake Creek Singer Creek Brush Creek Rio de los Berrendos
BUTTE CREEK GROUP	Butte Creek Little Dry Creek Clear Creek Gold Run Chambers Ravine Coal Canyon
HONCUT CREEK GROUP	North Honcut Creek South Honcut Creek Wyman Creek Wyandotte Creek Dry Creek
COON CREEK GROUP	Coon Creek Auburn Ravine Antelope Creek
RED BANK GROUP	Red Bank Creek Reeds Creek
ELDER CREEK GROUP	Elder Creek Thomas Creek Rice Creek
WILLOW CREEK GROUP	Hambright Creek Willow Creek Logan Creek Hunters Creek Funks Creek Stone Corral Creek Lurline Canal Glenn Valley Slough Freshwater Creek Salt Creek Spring Creek Cortina Creek Sand Creek

The full natural run-offs from each drainage basin for the seasons 1929–30 and 1930–31 are given in Appendix H.

Ultimate Net Run-off.—The monthly full natural run-offs for the 40-year period 1889–1929, at the principal foothill gaging station and dam site or sites for the major reservoir or reservoirs of the State Water Plan on each of the larger streams were reduced to flows that could have been expected under conditions of ultimate development in the drainage basin above these points. These modified flows or "ultimate net run-offs" are the flows as they would have been if impaired by diversions and storage for the ultimate irrigation developments and the present power developments upstream from the point under consideration.

In obtaining these run-offs, estimates were made of the total net irrigable area above the station, the amount of water required to irrigate this area, the area which could be irrigated from natural stream flow without storage and the amount of storage which would be required to complete the irrigation requirements. In estimating the amounts of water which would be necessary for irrigation use, the requirements were obtained as explained in Chapter V under the heading "Ultimate Irrigation Requirements—Mountain Valleys and Foothills." For the Feather, Yuba, Bear and American rivers, allowances were made for diversions to lands outside of the watershed and for return water to the stream from lands irrigated by water from another stream. Corrections for storage in and releases from reservoirs required for the full irrigation of all of the irrigable lands to be supplied by the stream both inside and outside of its watershed were made by months. Corrections also were made by months for water stored in and releases from reservoirs used primarily for power development purposes. The return water from irrigated lands in the watershed above any point was considered as available at that point, except from Sierra Valley on the upper Middle Fork of Feather River, which, it is estimated, would contribute no return water. In making these estimates, it was assumed that some lands now irrigated by diversions from the major streams ultimately would be irrigated by diversions from minor streams so that as much water as possible from the major streams could be made available for regulation at the lowest points of control on those streams.

Present Net Run-off.—The monthly full natural run-offs for the 40-year period 1889–1929, at each dam site for a major reservoir unit of the State Water Plan on the larger streams, were reduced to flows that could have been expected under present conditions of development in the drainage basins above these points. These modified flows or "present net run-offs" are the flows as they would have been if impaired by the uses and storage for the present irrigation and power developments upstream from the dam site.

These flows were estimated in the same manner as the "ultimate net run-offs" except that present instead of ultimate conditions of irrigation development were used.

Variation of Run-off.—The run-offs from the watersheds of both the major and minor streams in the Sacramento River Basin show wide yearly, seasonal, monthly and daily variations.

The full natural run-offs from each drainage basin for the seasons 1929–30 and 1930–31 are given in Appendix H.

Ultimate Net Run-off.—The monthly full natural run-offs for the 40-year period 1889–1929, at the principal foothill gaging station and dam site or sites for the major reservoir or reservoirs of the State Water Plan on each of the larger streams were reduced to flows that could have been expected under conditions of ultimate development in the drainage basin above these points. These modified flows or "ultimate net run-offs" are the flows as they would have been if impaired by diversions and storage for the ultimate irrigation developments and the present power developments upstream from the point under consideration.

In obtaining these run-offs, estimates were made of the total net irrigable area above the station, the amount of water required to irrigate this area, the area which could be irrigated from natural stream flow without storage and the amount of storage which would be required to complete the irrigation requirements. In estimating the amounts of water which would be necessary for irrigation use, the requirements were obtained as explained in Chapter V under the heading "Ultimate Irrigation Requirements—Mountain Valleys and Foothills." For the Feather, Yuba, Bear and American rivers, allowances were made for diversions to lands outside of the watershed and for return water to the stream from lands irrigated by water from another stream. Corrections for storage in and releases from reservoirs required for the full irrigation of all of the irrigable lands to be supplied by the stream both inside and outside of its watershed were made by months. Corrections also were made by months for water stored in and releases from reservoirs used primarily for power development purposes. The return water from irrigated lands in the watershed above any point was considered as available at that point, except from Sierra Valley on the upper Middle Fork of Feather River, which, it is estimated, would contribute no return water. In making these estimates, it was assumed that some lands now irrigated by diversions from the major streams ultimately would be irrigated by diversions from minor streams so that as much water as possible from the major streams could be made available for regulation at the lowest points of control on those streams.

Present Net Run-off.—The monthly full natural run-offs for the 40-year period 1889–1929, at each dam site for a major reservoir unit of the State Water Plan on the larger streams, were reduced to flows that could have been expected under present conditions of development in the drainage basins above these points. These modified flows or "present net run-offs" are the flows as they would have been if impaired by the uses and storage for the present irrigation and power developments upstream from the dam site.

These flows were estimated in the same manner as the "ultimate net run-offs" except that present instead of ultimate conditions of irrigation development were used.

Variation of Run-off.—The run-offs from the watersheds of both the major and minor streams in the Sacramento River Basin show wide yearly, seasonal, monthly and daily variations.

It has been shown previously that there is a wide variation in seasonal precipitation over the Sacramento River Basin. Since run-off is dependent upon precipitation, it will have generally similar variations. Run-off, however, is affected by the intensity and order of occurrence of storms and its seasonal variation from normal, therefore, may not be exactly the same as the variation of the seasonal precipitation from its normal. The variation in seasonal precipitation over the Sacramento River Basin from year to year is shown by the indices of wetness in Table 3, and the variation in run-off from the watersheds of the major streams of the Sacramento River Basin is shown by the seasonal run-offs for these streams given in Table 5. The mean seasonal full natural run-offs for the eight major streams for the 40-year period 1889–1929, and the maximum and minimum seasonal run-offs in the same period, are given in Table 6. These quantities show that the maximum seasonal run-off varies from 243 to 301 per cent and the minimum from 4 to 35 per cent of the mean seasonal for the 40-year period.

TABLE 6

VARIATION IN SEASONAL RUN-OFFS OF MAJOR STREAMS OF THE SACRAMENTO RIVER BASIN, 1889-1929

Stream	Point of measurement	Mean seasonal run-off, in acre-feet	Maximum seasonal run-off in 40-year period			Minimum seasonal run-off in 40-year period		
			In acre-feet	In per cent of mean seasonal run-off	Season	In acre-feet	In per cent of mean seasonal run-off	Season
Sacramento River	Red Bluff	9,354,000	22,700,000	243	1889–90	3,294,000	35	1923–24
Feather River	Orovi le	5,201,000	13,278,000	255	1889–90	1,296,000	25	1923–24
Yuba River	Smartsville	2,653,000	6,908,000	260	1889–90	603,000	23	1923–24
Bear River	Van Trent	402,000	1,212,000	301	1889–90	66,100	16	1923–24
American River	Fair Oaks	3,069,000	8,749,000	285	1889–90	543,000	18	1923–24
Stony Creek	Mouth of canyon	514,000	1,442,000	281	1889–90	42,800	8	1923–24
Cache Creek	Capay dam site	762,000	2,125,000	279	1889–90	59,500	8	1897–98
Putah Creek	Winters	442,000	1,239,000	280	1889–90	17,000	4	1897–98

The wide variation in monthly run-off is due to the occurrence of most of the precipitation in the winter or rainy season, as previously mentioned. Most of the run-off from the rain which falls on the lower areas and valleys finds its way quickly into the stream channels while the snow in the higher mountain regions usually does not melt and appear as run-off until the late spring or early summer. The latter run-off forms the greater part of the stream flows during this period. Since the rainfall runs off quickly, the streams in the Sacramento River Basin reach their highest stages in the winter and early spring months. The run-off from the melting snow varies with the rate of melting and amount of the snow pack. This run-off, therefore, diminishes gradually and the minimum flows occur in the late summer months when practically all of the snow has disappeared. The unequal monthly distribution of the seasonal run-off from the drainage basins of the eight major streams of the Sacramento River Basin is shown in Table 7. The variation in run-off from the minor stream basins is even greater. Most of them lie at relatively low elevations and their run-off is entirely from rainfall. They therefore have fairly large flows for a short time in the winter season and are entirely dry during most of the summer.

TABLE 7

AVERAGE MONTHLY DISTRIBUTION OF SEASONAL RUN-OFFS OF MAJOR STREAMS OF SACRAMENTO RIVER BASIN

Based on full natural run-offs for 40-year period 1889–1929

Month	Mean run-off of Sacramento River at Red Bluff		Mean run-off of Feather River at Oroville		Mean run-off of Yuba River at Smartsville		Mean run-off of Bear River at Van Trent	
	In acre-feet	In per cent of seasonal total	In acre-feet	In per cent of seasonal total	In acre-feet	In per cent of seasonal total	In acre-feet	In per cent of seasonal total
October	304,000	3.25	116,000	2.23	36,800	1.39	8,000	1.99
November	505,000	5.40	226,000	4.35	93,600	3.53	13,000	3.23
December	748,000	8.00	284,000	5.46	153,000	5.77	33,900	8.43
January	1,250,000	13.36	477,000	9.17	285,000	10.74	76,400	19.01
February	1,541,000	16.47	628,000	12.07	331,000	12.48	87,100	21.67
March	1,465,000	15.66	828,000	15.92	412,000	15.53	78,300	19.48
April	1,166,000	12.47	1,001,000	19.25	461,000	17.37	51,100	12.71
May	846,000	9.04	848,000	16.30	484,000	18.24	25,200	6.27
June	540,000	5.77	423,000	8.13	271,000	10.21	13,600	3.38
July	387,000	4.14	173,000	3.33	74,700	2.82	6,000	1.49
August	312,000	3.34	108,000	2.08	26,500	1.00	4,600	1.15
September	290,000	3.10	89,000	1.71	24,400	0.92	4,800	1.19
Totals	9,354,000	100.00	5,201,000	100.00	2,653,000	100.00	402,000	100.00

Month	Mean run-off of American River at Fairoaks		Mean run-off of Stony Creek at mouth of canyon		Mean run-off of Cache Creek at Capay dam site		Mean run-off of Putah Creek at Winters	
	In acre-feet	In per cent of seasonal total	In acre-feet	In per cent of seasonal total	In acre-feet	In per cent of seasonal total	In acre-feet	In per cent of seasonal total
October	31,400	1.02	1,800	.35	11,000	1.44	500	.12
November	68,000	2.21	12,600	2.45	24,000	3.15	12,500	2.83
December	138,000	4.50	36,800	7.16	62,600	8.22	39,000	8.82
January	294,000	9.58	126,000	24.51	163,000	21.39	124,000	28.06
February	349,000	11.37	132,000	25.68	184,000	24.15	128,000	28.96
March	487,000	15.87	110,000	21.40	153,000	20.08	76,700	17.35
April	558,000	18.18	56,400	10.97	87,800	11.52	42,000	9.50
May	607,000	19.78	25,000	4.87	39,800	5.22	12,600	2.85
June	383,000	12.48	8,000	1.56	17,700	2.32	3,900	.88
July	111,000	3.62	2,300	.45	9,900	1.30	1,700	.38
August	25,100	.82	1,700	.33	5,000	.66	700	.16
September	17,500	.57	1,400	.27	4,200	.55	400	.09
Totals	3,069,000	100.00	514,000	100.00	762,000	100.00	442,000	100.00

Due to a short heavy precipitation, a more protracted lighter one, or warm rains on the snow packs in the mountainous regions during the winter or rainy season, a stream's flow may increase rapidly within a period of a few days from a very small amount to one of flood proportions. On the other hand, during the late summer and fall months, flows in all streams become very low and some stream channels are entirely dry. The mean daily flows of the two larger streams, the

Sacramento River at Red Bluff and the Feather River at Oroville, show variations from a few hundred or few thousand second-feet in the late summer months to between two and three hundred thousand second-feet during the winter floods. The maximum and minimum mean daily flows at the foothill gaging stations on the eight major streams in the Sacramento River Basin are shown in Table 8. Some of the low flows have been affected by releases from reservoirs but the maximum flows have been only slightly changed by either storage in or releases from existing reservoirs.

TABLE 8

MAXIMUM AND MINIMUM MEAN DAILY FLOWS IN MAJOR STREAMS OF SACRAMENTO RIVER BASIN

Stream	Gaging station	Mean daily flows			
		Maximum		Minimum	
		In second-feet	Date	In second-feet	Date
Sacramento River	Red Bluff	254,000	Feb. 3, 1909	2,810	[1]1924
Feather River	Oroville	187,000	Mar. 19, 1907	720	June 30, 1924
Yuba River	Smartsville	111,000	Jan. 15, 1909	71	July 30, 1924
Bear River	Van Trent	25,800	Mar. 19, 1907	2	Oct. 2, 1924
American River	Fair Oaks	120,000	Mar. 25, 1928	5	[1]1924
Stony Creek	Near Fruto	29,300	Feb. 2, 1909		[2]
Cache Creek	Yolo	20,100	Feb. 3, 1909	0	[3]
Putah Creek	Winters	40,000	Dec. 31, 1913	0	[4]

[1] Minimum flow occurred on several days in July and August.
[2] Summer flows affected by storage and irrigation diversions for Orland Project.
[3] No flow for periods in nearly every year.
[4] No flow during parts of 1912-1914 and 1918-1929.

Return Water.

In the Sacramento River Basin a large potential water supply is that from water which, once used for irrigation, domestic or other purposes, would return to the streams either as direct drainage or as an inflow from the ground water basin. The return irrigation waters which would constitute a large percentage of all return waters would have their source in the losses from canals or other conduits during conveyance of water from the points of diversion on the streams to points of use, in the surface drainage from the land after irrigation and in seepage to the underground basin. A large portion of the return waters from the mountain and foothill region would be available for storage in the major reservoir units of the State Water Plan, in which they could be regulated to a supply conforming to the irrigation demand for lands on the valley floor. The return waters from the valley floor lands would enter the streams or artificial drains from which they could be again diverted for reuse on lands at lower elevation in the valley. All return waters not used in the valley would flow into the Sacramento-San Joaquin Delta where they would be available for use or for exportation to other areas.

The suitability of this return water for reuse is an important element in the State Water Plan because the return water would constitute a substantial part of the total available water supply. During 1930, the Water Resources Branch of the United States Geological

Survey chemically analyzed samples of water taken during the low water season on many of the principal streams of the state. Among these were analyses of the water in the Sacramento River during the low water season when practically the entire flow was return water from irrigation. These analyses showed that the return water, under present conditions, is entirely satisfactory, chemically, for municipal, irrigation and industrial use and can be classified as ''good.''

The amounts and distribution of the return waters throughout the year also are important elements in making estimates of their reuse for water supply. In order to determine these as accurately as possible, measurements of diversions and return water have been made each year since 1924 by the Sacramento-San Joaquin Water Supervisor. Results of these measurements are given in a bulletin* of the Division of Water Resources. In the Sacramento River Basin, measurements were taken each year of the amounts of water diverted from the Sacramento, Feather, Yuba and American rivers and from borrow pits and canals which intercept drainage water. Measurements also were taken of the flow of the Sacramento River at Kennett, Red Bluff, Butte City, Colusa, Knights Landing, Verona and Sacramento; the Feather River at Oroville and Nicolaus; and the American River at Fairoaks and Sacramento. These stream measurements analyzed in conjunction with the records of diversions show the amounts of water which returned to the river channels between the points of measurement in the months during which the records were taken.

Measurements were taken only during the irrigation season and an attempt was made to avoid any effect on the stream flow of natural run-off from valley floor lands. Since the measurements were taken during the irrigation season only, there is no definite information on the amount of irrigation water which returns slowly to the stream channels during the winter months. The determination of this amount would be difficult as it is combined with run-off from rainfall on the valley floor. The amounts of water which return during the winter season, therefore, must be estimated.

In addition to obtaining the measurements of stream flow and diversions, a survey was made each year to determine the character and acreage of crops grown with the water from each diversion and comprised within the area contributing return water at each point of measurement. The crops were divided into two classes, rice and general, since the unit use of water for the irrigation of rice is considerably greater than for other crops and the rate of return of the unused portion is more rapid.

The measurements covered seasons of both large and small total stream flow and the character of the season probably affected the percentage of return water. There appears to be a tendency to divert large amounts of water in years of ample supply, and since only a definite amount is consumed by the crop, the return flow in these years represents a larger percentage of the total diversions.

The records show that in the period 1924–1929, the return water in the months from April to October, inclusive, in each year, varied from 20 to more than 40 per cent of the water diverted during the

* Bulletin No. 23, "Report of Sacramento-San Joaquin Water Supervisor," Division of Water Resources, 1930.

same period. These data are for areas devoted to the growing of rice and general crops in different proportions and under different conditions of seasonal stream flow. An analysis of these data, therefore, gives a distribution and amounts of return water from areas having different proportions of the total acreage planted to rice. It is estimated, as shown in Chapter V, that when a condition of ultimate development has been reached in the Sacramento Valley, rice will occupy 10 per cent of the total irrigable area each season and all other crops 90 per cent. A study, therefore, was made, using the analysis of the data now available, to estimate the distribution of return water under the condition of ultimate development.

The average requirement of water for rice culture is estimated to be 2.75 times as much as the average for all other crops. It is also believed that practically all the return water from the irrigation of rice reaches the main stream channels during the irrigation months, April to October, inclusive. From a study of the data obtained, it also is concluded that the return from general crops in the same irrigation months is only about 65 per cent of the total annual return and it is believed that the remaining 35 per cent returns at about a uniform rate over the other five months. Therefore, by weighting the amounts and distribution of the return waters from these two types of crops, the average distribution by months for the entire Sacramento Valley under conditions of ultimate development are obtained, as shown in Table 9.

TABLE 9

MONTHLY DISTRIBUTION OF RETURN WATER IN SACRAMENTO VALLEY

Month	Return water in per cent of total annual return	Month	Return water in per cent of total annual return
January	5	July	13
February	5	August	13
March	5	September	11
April	7	October	8
May	10	November	5
June	13	December	5

It was estimated, as shown in Chapter V, that about 42.5 per cent of all water diverted for irrigation under a condition of ultimate development would reach the streams as return water. From Table 9, it may be noted that it is estimated that 75 per cent of this return water would reach the valley streams during the irrigation months of April to October, inclusive, with a regimen that would approximately synchronize with the irrigation demand and that the remainder would return about uniformly throughout the other months of the year. The water returning at such times that it could be reused would be equivalent to additional run-off in so far as water supply for lands on the lower reaches of the streams is concerned.

Ground Water.

Another source of supply is from water collected and stored in the underground basins. These basins are naturally charged by seepage from rainfall and from water applied for irrigation, and by seepage from canals and natural stream channels. Artificial charging or replenishment can be accomplished by spreading water over absorptive areas and holding it on the surface until taken into the underlying basin. Water so introduced to the underground basins is available for use by means of pumping unless it seeps back into the stream channels at lower elevation as return water, as above described.

There are a number of advantages obtained by storing water in underground basins and where suitable storage of this type is available and proper control of draft and replacement is exercised, it is a most flexible, efficient and economical means of conserving and utilizing water over a period of years. With this type of storage, evaporation is reduced to a minimum, the water which percolates underground is accessible for reuse, the water may be obtained by individual pumping plants which makes for flexibility of irrigation operations, and the underground basins may be naturally or artificially charged in periods of plentiful run-off and the waters so stored used in other periods of deficiency in surface supply.

Although there are a number of highly developed tracts in the Sacramento Valley which obtain an irrigation supply by pumping from wells, underground storage is not used in this valley to as great an extent as in the San Joaquin Valley and in some other parts of the state. In proportioning the physical works of a plan for the utilization of the water resources of the Sacramento River Basin, no account was taken of the availability of the underground storage capacity in this basin. If the underground storage were operated in conjunction with surface storage, however, a greater use could be made of the run-offs of the tributary streams since some of the water which would be wasted into the ocean in the winter season could be stored in these underground reservoirs and used in seasons or cycles of low surface run-off.

A very general study of underground basins in the Sacramento Valley was made, in connection with the present investigation of the water resources of the Sacramento River Basin, by Hyde Forbes, engineer-geologist. The study was directed primarily toward determining the locations and capacities of the potential underground reservoirs. No estimates of the yields from these reservoirs were made. Such yields would be dependent upon the replenishment, through natural and artificial means, of the water stored in the underground basins. The report on this study is included in this bulletin as Appendix F. At the end of the report, there is a tabulation of underground basin storage capacities which were estimated from data collected during a brief survey of field conditions, from data on well logs which are available, and from data collected during other investigations in some sections of the valley. The capacities given are necessarily rough approximations, because of the general nature of the study. However, they serve to indicate the possibilities of utilizing underground storage in the irrigation development of the Sacramento Valley.

About 203,000 acres, or 28 per cent, of the irrigated lands in the Sacramento Valley and adjacent foothills in 1929 were served by pumping from ground water. With the future growth and development of irrigation in the valley, the use of ground water may become more extensive and therefore of more importance than at present. Through a greater utilization of underground storage, a more efficient use of the available water supplies could be effected. Because of the importance of this subject, it was deemed advisable to begin a general but systematic collection and compilation of data on ground water conditions in the Sacramento Valley. The depths to the ground water table, therefore, have been measured each year, beginning with 1929, in about 200 wells distributed over the Sacramento Valley floor. These wells are located at approximately five-mile intervals in both north and south and east and west directions. The depth from the ground surface to the water table in each well and the description of the well's location are given in Appendix G.

CHAPTER III

AGRICULTURAL LANDS

The Sacramento River Basin has an area of about 26,150 square miles, which is 16.8 per cent of the total land area of the state. Of this area, about 18 per cent lies in the Sacramento Valley and the remainder is mountains and foothills. There are considerable areas of plateau and valley land distributed throughout the mountains, many of which are suitable for agriculture and some of which are now under cultivation.

Based on the surveys of agricultural lands in the Sacramento and San Joaquin river basins, made during this investigation, and the surveys made during a previous investigation,* it is estimated that the Sacramento River Basin contains 26.8 per cent of the agricultural lands of the state. These are distributed over the Sacramento Valley floor, in the foothills, and in the mountain valleys. The relation of the Sacramento River Basin to the remainder of the state in total area and the area of agricultural land is shown on the frontispiece. The locations of the agricultural lands in the basin are shown on Plate III, "Agricultural Lands and Areas Under Irrigation in the Sacramento Valley and Adjacent Foothills."

Geology and Soils.

The Sacramento Valley is a great plain, extending approximately 150 miles from Red Bluff to Suisun Bay and having a maximum width of about 40 miles, which has been built up with sediments brought down from the surrounding mountain ranges as the valley subsided and the mountain ranges rose. These changes have been gradual and have been taking place since early geologic time so that the depositions have been varied in time and character. Although the present configuration of the valley is due largely to the manner in which these sediments were deposited, some parts have been raised by faulting and folding and this uplift afforded opportunity for the streams to erode these parts and form hilly or rolling country.

The valley comprises five divisions which are described in some detail in Appendix F of this report. These divisions are the uplands of older alluvium, the low plains, the modern flood plain ridges, the flood basins, and the delta region. The uplands of older alluvium lie along the rim of the valley and in places extend well out into it. They have become indurated through age, drainage patterns have been developed through run-off erosion, and depressions and border lands have been filled or covered with a thin veneer of modern sediments reworked from the older alluvium. The low plains or modern alluvial fans of the major streams and combinations of fans of the minor streams extend from the uplands and mountainous borders on both the east and west

* Bulletin No. 6, "Irrigation Requirements of California Lands," Division of Engineering and Irrigation, 1923.

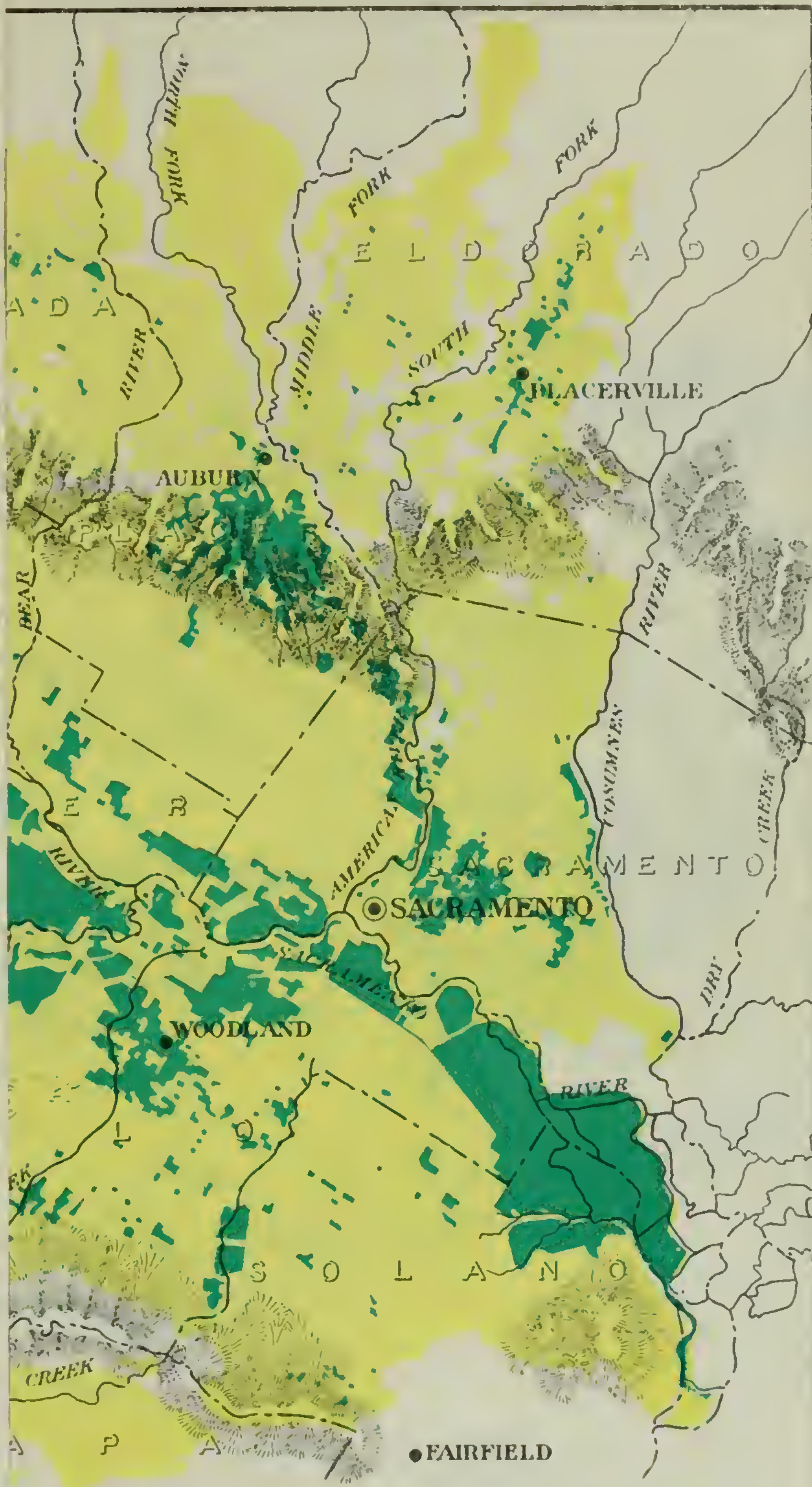
sides of valley toward its trough. The modern flood plain ridges are broad alluvial deposits that have been built up along the Sacramento and Feather rivers through recurrent overflows. The overflow or flood basins are broad shallow troughs lying between the flood plain ridges or between these ridges and the low plains or upland areas. Their soils are the result of the processes of deposition but are heavier than those in the adjacent flood plain ridges and plains lands. The fifth division is the delta region, much of which originally existed as a tule covered swamp. The soil on many islands is a peat formation and where not of this nature is light silts.

The accumulated sediments in the valley are of great depth, several borings of over 2000 feet having failed to penetrate to consolidated materials. The soils, as just pointed out, are mostly the old valley-filling material and the recent alluvial-fan and alluvial material. In the foothills along the border of the valley, the soils are residual materials from the disintegration and weathering in place of consolidated rocks. There is also a small amount of wind deposited material but this is relatively unimportant. Within these broader classifications of soils, there are a number of soil series in each of which the soils have similar characteristics of color, of subsoil, or substratum, of parent material, and of mode of formation, but differences of texture or the proportions of the particles of differing sizes of which each type is composed. The soils in the valley and a considerable area of the adjacent foothills have been classified by the Bureau of Soils of the United States Department of Agriculture and the data from these surveys were a great help in classifying the lands.

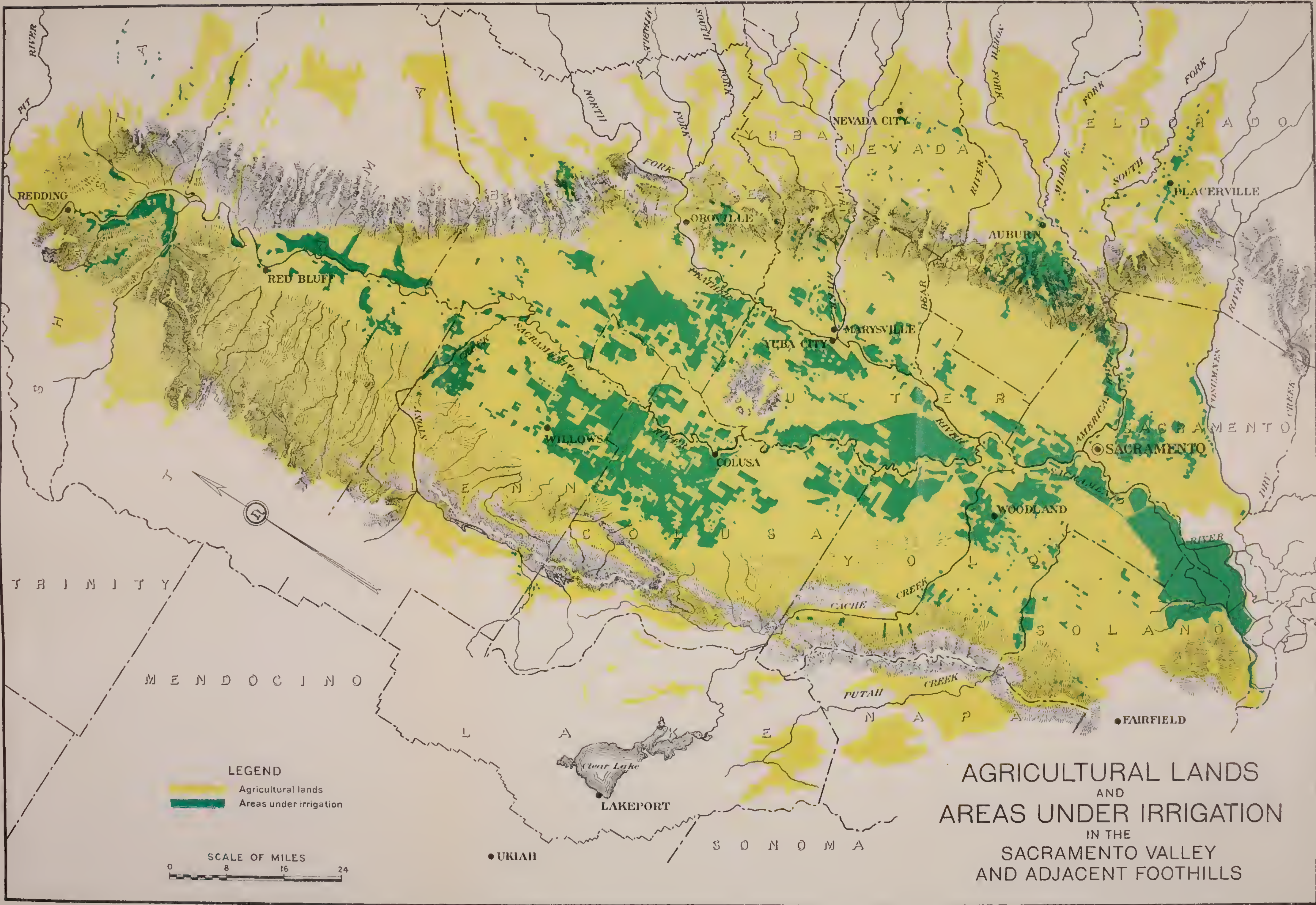
Land Classification.

The lands in the Sacramento Valley and the agricultural areas in the adjacent foothills were classified on the basis of their adaptability for irrigation. No attempt was made to classify the mountain valleys or the foothills and mountains in the Sierra Nevada at elevations in excess of about 3000 feet. Lands in the Coast Range foothills were completely classified with the exception of those in the drainage basin tributary to Cache Creek above the outlet of Clear Lake.

An area of 8,750,000 acres of land was classified. Of this total, about 7,750,000 acres were classified from a field survey and about 1,000,000 acres from data used in making assessments for the Sacramento and San Joaquin Drainage District. In making the field survey, each area was visited and the detail classification of the land as actually obtained from inspection was plotted on a map. The maps of the Sacramento Valley published by the United States Geological Survey on a scale of two inches to one mile were used for the area which they cover. For other areas, enlargements of county maps, United States War Department maps, and other United States Geological Survey maps were used. Use also was made as far as possible of soil surveys published by the United States Department of Agriculture. All data obtainable, such as character of soil, kind and quality of crops grown on the land, topography, presence of alkali and hardpan were given weight in determining the class in which each tract of land was placed.



AGRICULTURAL LANDS
AND
AREAS UNDER IRRIGATION
IN THE
SACRAMENTO VALLEY
AND ADJACENT FOOTHILLS


AGRICULTURAL LANDS
AND
AREAS UNDER IRRIGATION
IN THE
SACRAMENTO VALLEY
AND ADJACENT FOOTHILLS
LEGEND
Agricultural lands
Areas under irrigation
SCALE OF MILES
0
8
16
24
REDDING
RED BLUFF
OROVILLE
NEVADA CITY
AUBURN
PLACERVILLE
MARYSVILLE
YUBA CITY
WILLOWS
COLUSA
SACRAMENTO
WOODLAND
FAIRFIELD
LAKEPORT
UKIAH
Clear Lake
TRINITY
MENDOCINO
LAKE
SONOMA
NAPA
SOLANO
YOLO
COLUSA
GLENN
SUTTER
YUBA
NEVADA
PLACER
ELDORADO
SACRAMENTO
TEHAMA
SHASTA
BUTTE
PIT
RIVER
FEATHER
SACRAMENTO
RIVER
AMERICAN
BEAR
CACHE
CREEK
PUTAH
CREEK
COSUMNES
DRY
CREEK
STONY
CREEK
NORTH
FORK
SOUTH
FORK
MIDDLE
FORK

Valley Floor Lands.—The Sacramento Valley lands were divided into five classes. The character of the land and the features which influenced in placing different tracts in each class are described as follows:

Class 1. All lands were included in this class where soil texture, alkali or topography do not materially limit the feasibility of irrigation or crop yield. They are lands capable of good crop yields at low cost of preparation. They include lands of all soil textures except those affecting crop yields on account of being too heavy or very coarse. Alkali is absent or too small in amount to be a factor. Level hardpan lands where hardpan is at sufficient depth, as evidenced by local observations other than borings, to allow of general cropping were included, as well as hardpan lands where development by blasting and leveling has removed the original deficiency of the land. All lands now successfully growing alfalfa, vines and trees were included. It was the endeavor to place in this group all lands which will be first in their demand for water and in progressive development. The continuance of the use of water on these lands over successive irrigation periods would likewise remain most nearly constant once an irrigation supply were available. Considerable rolling land of good soil depth and free of heavy brush and timber growth was placed in this group where all of it was of such topography as to be readily farmed. All lands were placed in Class 1 that anyone of fair-minded judgment could contend should fall in such grouping. These lands are now generally settled in progressively farmed areas.

Class 2. These lands are a deferred type both as to use of irrigation waters (where outside of present organized areas) and as to future settlement and development. The presence of alkali and hardpan, roughness, deficient soil texture, and heavy expense of removal of brush and timber, each and all, were contributing factors in the placing of lands in this grouping. Overflow lands which would otherwise be in Class 1 were included in Class 2 where such overflow is a constant factor limiting the adaptability of the land for permanent cropping and lessening the length of the period of irrigation upon the land. Reclamation of lands subject to inundation is well advanced in the Sacramento Valley and large bodies of land now used for flood channels and subject to periodical overflow will probably remain permanently in this condition. For this reason, all lands permanently subject to overflow were classed one grouping lower than their physical characteristics would place them if they were in an area capable of reclamation against floods. Lands in Class 2 whether in present organized and developed areas or not, can be expected to have a less continuous and uniform use of water than lands in Class 1. On account of their deficiencies, greater portions of these lands are likely to remain out of crop production in periods of depression of prices of farm products. Also, periods of lying fallow will be more extended than in Class 1. Lands in this grouping are more generally used for pasture at the present time and, being less developed, are held in larger holdings than the better lands.

Class 3. Extremely hummocky and hogwallow lands, lands with shallow soils, rough channel cut lands and lands of steeply rolling topography (usually covered with timber and brush) were placed in this class. Alkali and hardpan and deficient soil texture to a greater

Valley Floor Lands.—The Sacramento Valley lands were divided into five classes. The character of the land and the features which influenced in placing different tracts in each class are described as follows:

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Class 2. These lands are a deferred type both as to use of irrigation waters (where outside of present organized areas) and as to future settlement and development. The presence of alkali and hardpan, roughness, deficient soil texture, and heavy expense of removal of brush and timber, each and all, were contributing factors in the placing of lands in this grouping. Overflow lands which would otherwise be in Class 1 were included in Class 2 where such overflow is a constant factor limiting the adaptability of the land for permanent cropping and lessening the length of the period of irrigation upon the land. Reclamation of lands subject to inundation is well advanced in the Sacramento Valley and large bodies of land now used for flood channels and subject to periodical overflow will probably remain permanently in this condition. For this reason, all lands permanently subject to overflow were classed one grouping lower than their physical characteristics would place them if they were in an area capable of reclamation against floods. Lands in Class 2 whether in present organized and developed areas or not, can be expected to have a less continuous and uniform use of water than lands in Class 1. On account of their deficiencies, greater portions of these lands are likely to remain out of crop production in periods of depression of prices of farm products. Also, periods of lying fallow will be more extended than in Class 1. Lands in this grouping are more generally used for pasture at the present time and, being less developed, are held in larger holdings than the better lands.

Class 3. Extremely hummocky and hogwallow lands, lands with shallow soils, rough channel cut lands and lands of steeply rolling topography (usually covered with timber and brush) were placed in this class. Alkali and hardpan and deficient soil texture to a greater extent than for Class 2 lands also were contributing factors for placing lands in this class. Under present conditions, where not now included in organized irrigation projects, these lands are likely to be long deferred in development and use of irrigation water unless included in the development of larger tracts containing mainly lands of better classification. These lands where in organized irrigation projects are largely devoted to rice culture and gun clubs. Except for this use, practically all of the Class 3 land is now used as pasture and range land in large undeveloped holdings. Any orchard or vine plantings previously made have been abandoned. This class of land is not adapted to grain production and if grain were grown, crop returns would be small.

Class 4. Lands have been included in this classification which are of extremely dubious agricultural worth because of alkili or deficient soil conditions. They are now almost entirely used for pasture and gun clubs, although rice has been grown on some portions of flat alkali lands which are included in organized irrigation projects. Rice growing has not been very successful on such heavily alkali lands and is not likely to continue except in periods of high prices. Gun clubs are established on a considerable area of land of this class where water is available.

Class 5. These are lands of no present or potential agricultural value. Outside of the Sutter Buttes and river channels, the only areas on the valley floor which were placed in this class are those made permanently nonusable by large drainage canals, levees and borrow pits.

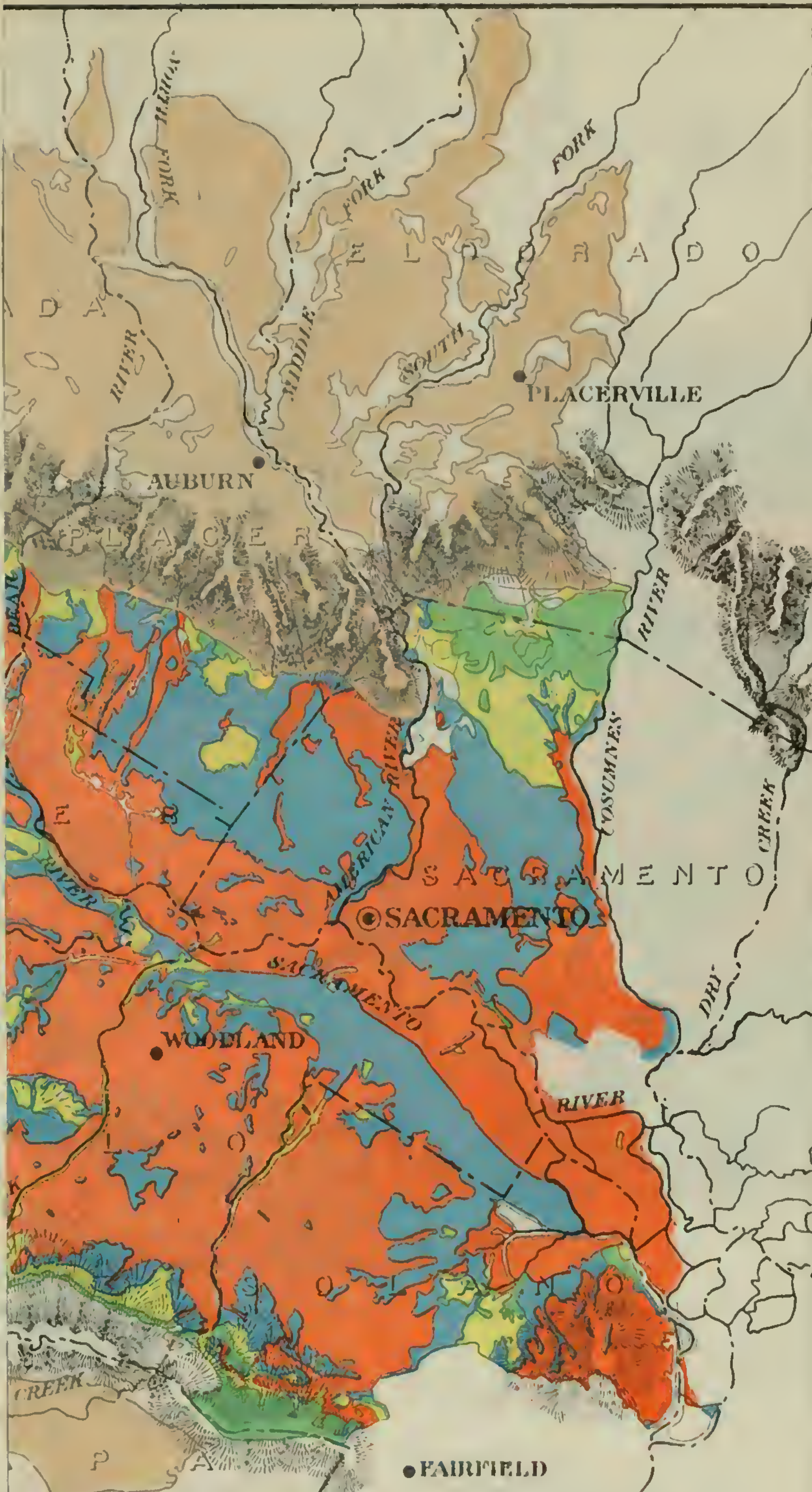
The locations of the lands in Classes 1 to 4 on the valley floor are shown on Plate IV, "Classification of Agricultural Lands in the Sacramento Valley." Class 5 land is not considered as agricultural and is not shown on the map.

TABLE 10

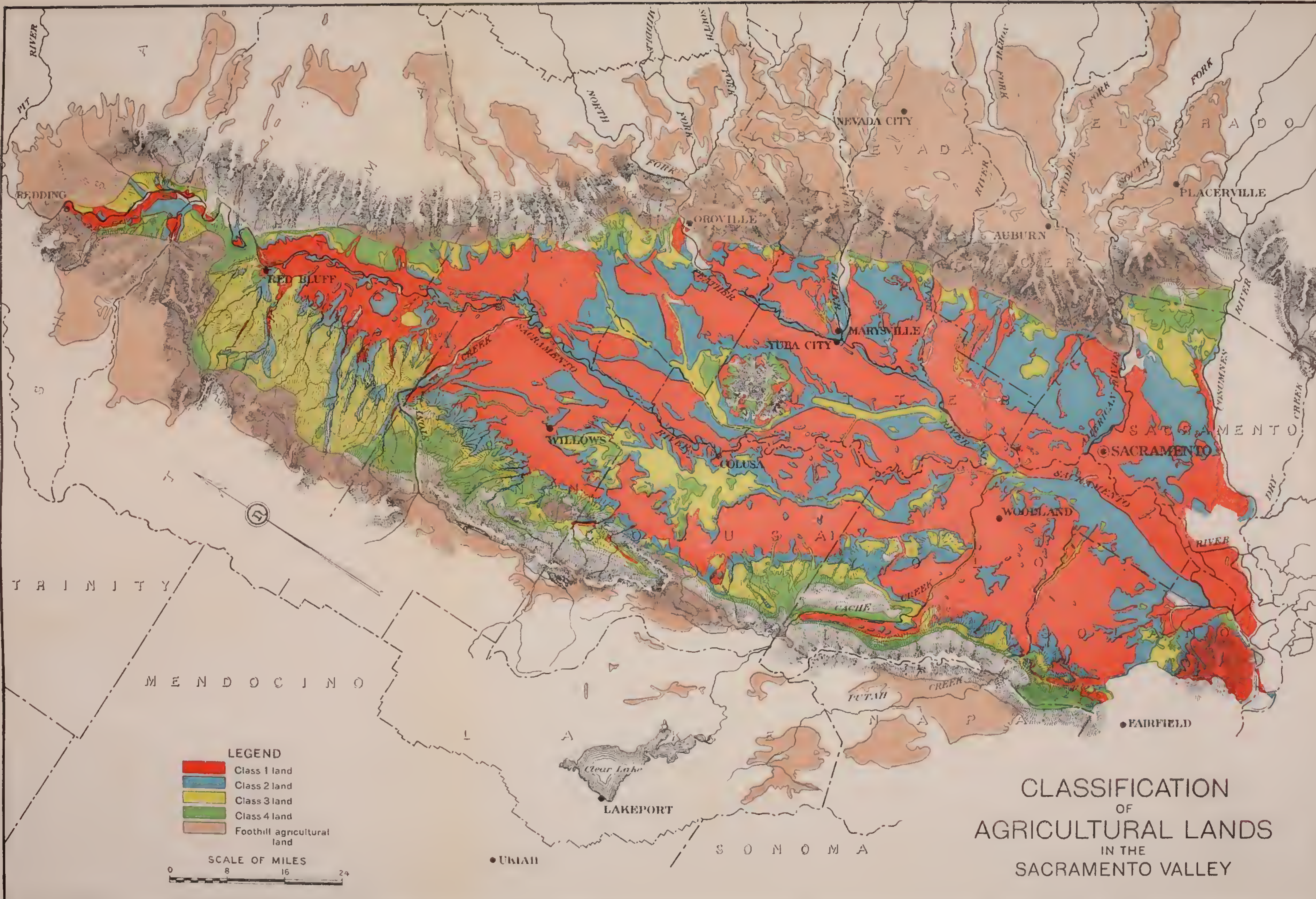
CLASSIFICATION OF LANDS ON THE SACRAMENTO VALLEY FLOOR

Class	Sacramento Valley floor excluding Sacramento Delta		Sacramento Delta		Total Sacramento Valley floor	
	Gross area		Gross area		Gross area	
	In acres	In per cent of total	In acres	In per cent of total	In acres	In per cent of total
1	1,735,000	47.1	124,000	87.3	1,859,000	48.6
2	943,000	25.6	15,000	10.6	958,000	25.0
3	573,000	15.6	2,000	1.4	575,000	15.0
4	248,000	6.7	1,000	.7	249,000	6.5
5	185,000	5.0			185,000	4.9
Totals	3,684,000	100.0	142,000	100.0	3,826,000	100.0

The areas of each of the five classes of land, on the Sacramento Valley floor, are shown in Table 10. In this table, the area of each class of land in that portion of the valley lying outside of the Sacramento Delta is shown separately from the area of each class in that delta. The southern boundary line of the Sacramento Valley, used in obtaining these areas, is shown by the lower end of the colors representing the different classes of land on Plate IV. From this map, it may be seen that the classification was carried to the Cosumnes River



CLASSIFICATION
OF
AGRICULTURAL LANDS
IN THE
SACRAMENTO VALLEY


CLASSIFICATION
OF
AGRICULTURAL LANDS
IN THE
SACRAMENTO VALLEY
LEGEND
Class 1 land
Class 2 land
Class 3 land
Class 4 land
Foothill agricultural land
SCALE OF MILES
0
8
16
24
REDDING
RED BLUFF
OROVILLE
NEVADA CITY
PLACERVILLE
AUBURN
MARYSVILLE
YUBA CITY
WILLOWS
COLUSA
SACRAMENTO
WOODLAND
FAIRFIELD
LAKEPORT
UKIAH
Clear Lake
TRINITY
MENDOCINO
SONOMA
NAPA
EL DORADO
NEVADA
PLACER
YUBA
SACRAMENTO
PIT RIVER
FEATHER
SACRAMENTO
CREEK
RIVER
AMERICAN RIVER
COSUMNES
DRY CREEK
CACHE
CREEK
PUTAH
CREEK
NORTH
FORK
SOUTH
MIDDLE
FORK

on the east side of the valley. The boundary line separating the Sacramento Delta from the San Joaquin Delta is a line which approximately divides lands which use water from, or drain to, the Sacramento River and the San Joaquin River or its tributaries, respectively. Its location is shown in detail in another report.* The other boundaries of the Sacramento Valley floor are the same as the outside boundaries of the "water service areas" as these areas are shown on Plate VI in Chapter V.

Foothill Lands.—The foothill lands also were divided into five classes but these were not determined on strictly the same bases as those for the valley floor classes. For these lands, the classes were determined largely by the amount or percentage of land which might come under irrigation at some future time. This percentage, in turn, was governed by topography; soil depths, quality and areas; and the feasibility of irrigation. Without regard to economics, it was determined before classifying any of these lands as agricultural, that it would be physically possible to furnish them a water supply. No attempt was made to determine the area of Class 5 lands.

In classifying the foothill lands they were divided into two general groups: The first group includes all of the Sierra Nevada foothills, all of the valley floor and foothill lands north of Red Bluff and south of Redding, and the Coast Range foothills north of the Tehama-Glenn county line. This area is characterized by continuous commanding ridges which affect the feasibility of irrigation. The percentage of irrigable land in each class in this group is estimated to be as follows:

Class 1	90 per cent
Class 2	75 per cent
Class 3	60 per cent
Class 4	20 and 40 per cent

The Class 4 land is mainly pasture land but it varies in type and therefore has been estimated to have different percentages of irrigable area according to its characteristics. One of the two values given above was used for each individual tract in this class.

The other group includes the Coast Range foothills south of Tehama County, except those in the drainage basin tributary to Clear Lake on Cache Creek. This area is characterized by rounded knolls and disconnected ridges and the Class 3 and 4 lands will have smaller percentages of their areas susceptible of irrigation. The percentage of irrigable land in each class in this group is estimated to be as follows:

Class 1	90 per cent
Class 2	75 per cent
Class 3	50 per cent
Class 4	20 per cent

The results of the classification of the foothill lands on the above bases are shown in Table 11.

Classification by Counties.—Although the same numbers are used for the classes of land in the foothills as are used for valley floor lands, it should be kept in mind in combining areas of lands under these classifications that they are on a somewhat different basis.

* Bulletin No. 27, "Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay," Division of Water Resources, 1931—Plate III.

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* Bulletin No. 27, "Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay," Division of Water Resources, 1931—Plate III.

TABLE 11

CLASSIFICATION OF AGRICULTURAL LANDS IN FOOTHILLS ADJACENT TO SACRAMENTO VALLEY FLOOR

Class	Gross area	
	In acres	In per cent of total
1	104,000	5.0
2	280,000	13.3
3	789,000	37.6
4	926,000	44.1
Totals	2,099,000	100.0

Such a combination was made for Table 12 in which the total area of land in each of the first four classes is shown for each county. Since no attempt was made to measure the Class 5 lands in the foothills, this classification was omitted from the table and the total area shown for each county, therefore, is not the gross area of that county.

TABLE 12

CLASSIFICATION OF AGRICULTURAL LANDS IN SACRAMENTO VALLEY AND ADJACENT FOOTHILLS, BY COUNTIES

County	Gross area, in acres				
	Class				Total agricultural lands
	1	2	3		
Butte	218,000	154,600	136,600	90,200	599,400
Colusa	228,300	105,400	124,500	58,200	516,400
El Dorado*	6,600	9,400	99,600	205,000	320,600
Glenn	231,200	96,400	82,100	102,000	511,700
Nevada	1,300	68,700	88,500	68,600	227,100
Lake	1,700	7,400	11,100	20,600	40,800
Napa	12;600	9,900	18,500	37,000	78,000
Placer	62,400	108,000	89,100	89,700	349,200
Sacramento**	199,200	139,400	39,400	19,700	397,700
Shasta	21,500	44,100	144,600	106,800	317,000
Sierra	----------	----------	----------	2,600	2,600
Solano	203,900	64,600	21,200	14,400	304,100
Sutter	243,700	78,900	27,300	9,700	359,600
Tehama	129,200	124,400	352,300	234,100	840,000
Yolo	318,800	149,500	56,200	27,000	551,500
Yuba	84,600	77,300	73,000	89,400	324,300
Totals	1,963,000	1,238,000	1,364,000	1,175,000	5,740,000

Lands in Sacramento Delta included in above totals

Sacramento	50,000	1,700	1,700	----------	53,400
Solano	29,000	9,600	200	1,000	39,800
Yolo	45,000	3,700	100	----------	48,800
Totals	124,000	15,000	2,000	1,000	142,000

* Including 97,900 acres in San Joaquin River Basin.
** Excluding lands in San Joaquin Delta and south of Cosumnes River.

Gross Agricultural Areas.—In Table 13, the gross areas of agricultural lands in the Sacramento River Basin and in the entire Sacramento-San Joaquin Delta are presented by sections. All of the delta lands are included since, although only about one-third of the delta lies in the Sacramento River Basin, a large part of the water supply for the entire delta naturally comes from this basin. Class 5 lands are not included in the areas shown in the table since this class is considered as having no portion which will ever be suitable for agriculture.

TABLE 13

GROSS AGRICULTURAL AREAS IN THE SACRAMENTO RIVER BASIN AND THE ENTIRE SACRAMENTO-SAN JOAQUIN DELTA

Section	Gross agricultural area	
	In acres	In per cent of total
Valley floor	3,499,000	54.4
Foothill area	2,099,000	32.6
Mountain valleys	416,000	6.5
Sacramento Delta	142,000	2.2
San Joaquin Delta	[1]279,000	4.3
Totals	6,435,000	100 0

[1]Includes 9000 acres of land formerly reclaimed, flooded at time of survey of 1929, but subject to reclamation.

Present Development in Sacramento Valley and Adjacent Foothills.

During the investigations, surveys were made to determine the present agricultural development of the Sacramento Valley and adjacent foothills. These surveys were made to ascertain both the use which was made of the land and the amount of land which was under irrigation.

Cropped Areas.—The survey to determine the crops which were grown was carried on coincidently with the classification of the agricultural lands. This survey was made for the purpose of finding the locations in which crops of different kinds were grown, the approximate number of acres planted to each of these crops, and the adaptability of certain areas to the growing of crops of different types. In making this survey, the crops were divided into groups, each of which was designated by a number. The numbers used and the crops represented by them are shown in the following tabulation:

Number *Crop or use of land represented by number*

1. Citrus and olive orchards.
2. Deciduous orchards, including figs and nuts.
3. Grape and hop vines.
4. Grain and grain land.
5. Alfalfa and sudan grass and land checked for alfalfa.
6. Field crops—under this classification there were included only such crops as are not used for human consumption such as field corn, maize, etc.
7. Cotton.
8. Pasture and uncultivated land.
9. Truck crops—including truck gardening, root and bush vegetables and fruits, such as beans, potatoes, sugar beets, melons, strawberries, etc.
10. Rice and land prepared for rice culture.

The crop survey covered the entire area of land classification, including the area classified from data obtained from previous surveys. No effort was made in the crop survey to grade the crops but the quality of the crop was used as an aid in classifying the land.

Practically every crop grown in California can be found in some part of the Sacramento Valley and its adjacent foothills. Citrus fruits are grown on the west side of the valley in the region west of Maxwell and in the vicinity of Corning and Orland. They also are grown on the east side of the valley in the vicinity of Oroville, near Lincoln, and near Fairoaks and Orangevale. Other scattering small groves may be found in other parts of the valley but the sections above mentioned are the most important for citrus culture.

Deciduous orchards, including those of fig and nut trees, are quite generally distributed over the entire valley. There are, however, certain sections where the land is more generally devoted to these orchards than to other crops. On the west side of the valley, the largest area of orchards is located in the section extending from Vacaville to Winters along the foothills of the Coast Range, and up the Capay Valley. In the vicinity of Arbuckle, there is a large area of almond groves. Orchards are also found along the Sacramento River north of Colusa and in the vicinity of Orland and Corning. On the east side of the valley, there are considerable areas of orchard around Chico and Paradise. The largest orchard section in the valley is the so-called "peach bowl" in Sutter, Butte and Yuba counties. This section extends from the vicinity of Nicolaus to Biggs and is devoted mainly to the growing of canning peaches. Shipping fruits are grown in large quantities in the foothill fruit belt extending from Rocklin to Auburn and in scattering areas throughout the foothills from Auburn to Nevada City. Pears are now being planted over a considerable area in the foothills in the vicinity of Placerville and Camino. Shipping fruits are also grown in large quantities along the American River from Sacramento to Folsom and along the banks of most of the channels in the Sacramento Delta.

Hops were formerly grown on large areas of the bottom lands of the American and Bear rivers and along the Sacramento River in Yolo County. In recent years, however, the hop vines have been removed from a large part of these areas and the land planted to other crops.

Grapes of nearly all varieties are grown on scattering areas throughout most of the valley but the largest single area planted mainly to vines is in Sacramento County between the American and Cosumnes rivers. In this section a considerable acreage also is planted to small fruits, principally strawberries.

Alfalfa plantings are widely scattered throughout the valley and no single area can be said to be planted mainly to this crop, except possibly the Orland Project. There are also a number of scattering large tracts planted to alfalfa in Yolo County.

Field crops, which include corn and maize, are grown mostly in the Sacramento Delta and in the trough of the valley along the Sacramento River and the borrow pits in the Yolo Basin, where water is available.

The largest areas devoted to the growing of truck crops such as celery, asparagus, potatoes, beets and beans are found in the Sacramento Delta. Beans of the small varieties also are extensively grown in the flood basins of the Sacramento Valley and sugar beets are grown on several large tracts in the Yolo, Colusa and Sutter basins.

During the past two decades, rice has become one of the principal crops grown in the Sacramento Valley. The area planted to this crop in any season varies considerably with the price and the amount of water available for irrigation. Practically no rice is grown south of the latitude of the city of Sacramento. The two largest rice growing areas are in the upper Colusa Basin from the vicinity of Colusa and Williams to Willows and in the upper Butte Basin from the Sutter Buttes to Durham. Other large areas, however, are found in the lower Colusa Basin, Sutter Basin, upper Yolo Basin, and the area along the Sacramento River between the American and Feather rivers.

A few small tracts have been planted to cotton during the last few years but it has not become an important crop in the Sacramento Valley.

In the early days of agriculture in the Sacramento Valley, grain was the principal crop. As the valley has developed and land has come under irrigation, grain lands have become more valuable for other crops and the areas of grain plantings have been greatly reduced. Grain is still grown, however, in practically all sections of the valley and will probably always be one of the principal crops of the Sacramento River Basin.

The areas of crops and land used for other purposes, under each of the ten classifications shown in the foregoing list, in that portion of each county covered by the land classification and crop survey, are shown in Table 14.

The yields and values of agricultural and live stock products from the Sacramento River Basin and an inventory value of farms, equipment and live stock in the basin are shown in Table 15, by counties. These data were taken mainly from the Fifteenth Census of the United States and no means are available for determining what portion of the products and their values from counties lying only partially within the basin can be credited to it. For this reason, no data are included for Lassen, Siskiyou and Napa counties, the larger part of whose agricultural lands lie outside the Sacramento River Basin. To offset the losses on products and values from the portions of these counties lying in the basin, the products and values from portions of Modoc, El Dorado, Sacramento and Solano counties which lie outside of the basin are included with those for lands in these counties lying within the basin. It is believed, therefore, that the totals shown for the seventeen counties in Table 15 are not greatly different from those which would be obtained for the Sacramento River Basin area only.

For comparison of the agricultural industry in the Sacramento River Basin with that of the entire state, totals are given in the last column of Table 15 for the yields and values of agricultural and live stock products and the inventory values from farms, equipment and live stock, for the state.

Areas Under Irrigation in 1929.—Owing to the fact that part of the land classification and crop survey was made in the late fall and winter months, it was impossible to determine in connection with that survey the areas of some of the lands which were irrigated. An independent investigation was conducted, therefore, to ascertain as accurately as possible the total acreage of irrigated lands in the Sacramento Valley and foothills in 1929 in the same areas covered by the land classification and crop survey of that year. The method of conducting this investigation is described in Chapter IV, in which it is shown that the

TABLE 14

CLASSIFICATION OF CROPS IN THE SACRAMENTO VALLEY AND ADJACENT FOOTHILLS BY COUNTIES, 1929

County	Area in acres										
	1	2	3	4	5	6	7	8	9	10	
	Citrus and olives	Deciduous orchard	Vines	Grain	Alfalfa and Sudan grass	Field crops	Cotton	Uncultivated and pasture	Truck	Rice	Totals
Butte	7,400	37,400	2,400	110,200	7,700	14,100	2,500	345,600	3,900	68,200	599,400
Colusa	1,000	18,500	3,300	193,000	16,900	11,600	200	216,400	2,300	53,200	516,400
El Dorado*	0	6,600	1,100	4,100	0	0	0	308,800	0	0	320,600
Glenn	1,200	16,500	1,000	153,400	23,900	10,200	3,400	251,500	200	50,400	511,700
Nevada	0	3,900	400	400	100	100	0	222,100	100	0	227,100
Lake	0	1,000	200	1,800	500	0	0	37,300	0	0	40,800
Napa	0	2,500	700	8,500	500	0	0	65,800	0	0	78,000
Placer	200	37,500	5,300	43,600	200	300	0	262,000	100	0	349,200
Sacramento**	3,900	38,900	33,400	128,400	11,400	12,600	0	314,400	57,000	4,100	694,100
Shasta	1,000	2,900	500	3,700	3,300	2,800	0	302,600	200	0	317,000
Sierra	0	0	0	0	0	0	0	2,600	0	0	2,600
Solano	0	28,800	1,400	102,800	7,600	3,500	0	135,200	24,300	500	304,100
Sutter	100	42,000	10,000	150,400	10,300	31,700	2,600	85,900	10,800	15,800	359,600
Tehama	400	25,000	1,600	54,600	9,200	6,100	1,400	740,800	900	0	840,000
Yolo	0	27,500	4,500	227,500	28,000	27,500	200	190,000	28,200	18,100	551,500
Yuba	1,300	13,900	4,000	39,600	1,900	2,300	400	243,400	2,500	15,000	324,300
Totals	16,500	302,900	69,800	1,222,000	121,500	122,800	10,700	3,724,400	130,500	225,300	5,946,400

* Entire county including portion lying in the Cosumnes River watershed which is in the San Joaquin River Basin.
** Entire county including portion lying in the San Joaquin Delta and south of the Cosumnes River.

TABLE 15

AGRICULTURAL STATISTICS OF SACRAMENTO RIVER BASIN BY COUNTIES

Item	Unit	Butte	Colusa	El Dorado	Glenn	Lake	Modoc	Nevada	Placer	Plumas	Sacramento	Shasta	Sierra	Solano	Sutter	Tehama	Yolo	Yuba	Total for 17 counties	Total for state
Yield of agricultural products in 1929—																				
Citrus[1]	Boxes	159,200	2,500	0	62,000	0	0	200	10,500	0	101,200	100	0	2,100	1,100	3,100	2,700	2,200	346,900	53,803,000
Olives	Tons	3,540	0	3	250	2	0	1	190	0	1,500	20	0	2	30	810	130	560	7.038	20,800
Orchard fruits[2]	Tons	15,020	4,890	15,520	6,800	19,290	420	3,140	48,190	39	32,330	1,840	1	30,750	31,060	3,740	10,120	13,410	236,560	1,139,000
Nuts	Tons	1,560	220	14	180	190	0	15	23	0	190	4	0	120	530	57	420	21	3,544	42,500
Grapes (fresh basis)	Tons	2,410	2,200	460	280	660	0	380	6,200	2	41,000	780	0	5,000	11,500	440	6,390	2,510	80,212	1,691,000
Hops	Tons	0	0	0	0	100	0	0	0	0	810	0	0	0	81	26	400	440	1 857	3,953
Grain[3]	Bushels	1,937,000	3,081,000	1,300	2,616.000	102,000	288,000	400	203,000	64,000	1,363.000	161,000	2,000	1,808,000	2,964,000	737,000	4,115,000	357,000	19,799,700	42,367,00
Alfalfa	Tons	30,100	35,100	800	50,300	12,300	27,200	1,800	1,700	1,600	55,100	21,300	800	30,400	25,800	28,800	74,400	4,900	402,400	2,793,800
Hay and forage crops[4]	Tons	13,000	5,600	5,300	8,500	6,700	84,100	4.700	5,000	18,800	27,100	27,000	11,800	22,600	8,400	11,200	15,200	6,300	281,300	1,494,300
Field crops[5]	Bushels	121,500	19,400	0	121,100	9,400	100	1,700	4,700	0	133,400	28,100	0	30,800	33,300	79,700	29,600	19,700	632,500	3,171,400
Seed[6]	Bushels	5,290	7,130	0	20,210	570	10,500	0	10	0	14,930	250	0	560	5,280	380	13,310	0	78,420	5,186,000
Beans and peas (dry)	Bushels	107,100	30,400	0	400	1,800	20	0	0	0	241,900	1,300	0	1,000	232,400	6,700	175,600	55,200	853,820	5,589,200
Cotton	Bales	85	0	0	1,018	0	0	0	0	0	0	0	0	0	188	18	88	3	1,400	253,900
Small fruits[7]	Quarts	111,400	26,400	21,500	9,800	10,600	16,000	18,300	188,000	4,100	1,903,200	78,500	600	8,900	22,600	55,800	4,700	30,700	2,511,100	21,736,000
Sugar beets	Tons	0	0	0	100	0	45	0	0	0	10,200	40	0	32,000	67,300	0	55,300	0	164,985	452,800
Potatoes	Bushels	15,510	50	3,280	420	4,410	15,000	8,820	110	7,280	25,720	19,750	2,640	1,050	3,450	2,630	98,030	1,320	209,470	6,489,000
Asparagus	Value in dollars	800	300	0	200	0	0	400	0	0	3,269,000	100	0	1,863,000	170,000	900	276,000	0	5,580,700	7,786,000
Celery	Value in dollars	400	0	0	0	0	0	0	0	0	529,000	0	0	13,900	0	0	16,000	0	559,300	5,753,000
Rice	Bushels	1,669,000	447,000	0	590,000	0	0	0	0	0	43,000	0	0	0	818,000	9,000	578,000	82,000	4,241,000	4,968,000
Yield of livestock products in 1929—																				
Milk produced	Gallons	3,342,000	2,982,000	1,114,000	5,143,000	1,192,000	2,375,000	1,145,000	1,290,000	1,477,000	7,434,000	2,294,000	641,000	4,196,000	3,559,000	2,651,000	6,246,000	1,405,000	48,486,000	445,530,000
Wool shorn (unwashed)	Pounds	517,000	779,000	94,000	1,517,000	162,000	492,000	81,000	227,000	33,000	208,000	182,000	7,000	1,202,000	491,000	1,619,000	985,000	426,000	9,022,000	18,747,000
Honey	Pounds	330,000	16,100	8,900	210,000	2,700	18,900	4,200	4,900	100	132,000	83,000	100	3,400	31,800	188,000	70,000	5,600	1,109,700	5,476,000
Chicken eggs produced	Dozens	1,310,000	475,000	282,000	910,000	328,000	187,000	259,000	917,000	57,000	5,658,000	428,000	33,000	1,125,000	828,000	1,036,000	923,000	285,000	15,041,000	159,422,000
Chickens sold	Number	116,000	23.300	14,000	71,300	22,400	12,300	19,900	71,000	5,000	477,000	49,900	2,400	66,900	59,800	119,000	52,200	24,300	1,206,700	13,861,000
Value of crops and live stock products in 1929—																				
Fruits and nuts		$2,423,000	$306,000	$1,135,000	$674,000	$1,293,000	$30,000	$246,000	$3,773,000	$4,000	$4,413,000	$108,000	0	$2,364,000	$2,147,000	$297,000	$1,041,000	$887,000	$21,141,000	$296,242,000
Cereals		3,518,000	2,679,000	1,000	2,674 000	101 000	276 000	2,000	193,000	58,000	1,317,000	197,000	$2,000	1,439,000	3,437,000	637,000	3,637,000	397,000	20,565,000	43,040,000
Other grains and seeds		435,000	176,000	0	3,000	14,000	128,000	0	0	0	1,108,000	6,000	0	10,000	894,000	27,000	730,000	232,000	3,763,000	28,779,000
Hay and forage		661,000	600,000	86,000	897,000	319,000	1,411,000	94,000	104,000	259,000	1,186,000	695,000	159,000	764,000	503,000	605,000	1,316,000	161,000	9,820,000	66,863,000
All other field crops		18,000	0	0	99,000	37,000	0	0	0	0	250,000	0	0	224,000	509,000	8,000	483,000	97,000	1,725,000	30,629,000
Vegetables		164,000	82,000	41,000	18,000	121,000	54,000	38,000	43,000	16,000	4,914,000	163,000	6,000	2,123,000	235,000	84,000	1,071,000	37,000	9,210,000	71,926,000
Dairy products		550,000	493,000	173,000	818,000	175,000	349,000	186,000	210,000	239,000	1,504,000	332,000	104,000	771,000	615,000	360,000	1,132,000	242,000	8,253,000	96,357,000
Wool shorn		139,000	210,000	26,000	410,000	45,000	143,000	23,000	64,000	10,000	56,000	51,000	2,000	325,000	133,000	437,000	266,000	115,000	2,455,000	5,192,000
Chicken eggs produced		393,000	142,000	93,000	273,000	105,000	64,000	85,000	303,000	19,000	1,698,000	145,000	11,000	338,000	249,000	311,000	277,000	86,000	4,592,000	51,519,000
Chickens sold		116,000	23,000	66,000	71,000	80,000	12,000	20,000	71,000	5,000	477,000	50,000	2,000	67,000	60,000	119,000	52,000	24,000	1,315,000	14,699,000
Honey		30,000	1,000	1,000	19,000	0	2,000	0	0	0	12,000	10,000	0	0	3,000	19,000	6,000	1,000	104,000	523,000
Cattle sold		495,000	350,000	324,000	451,000	158,000	1,178,000	202,000	162,000	223,000	556,000	780,000	136,000	438,000	245,000	780,000	469,000	289,000	7,236,000	43,808,000
Sheep and lambs sold		513,000	912,000	96,000	1,595,000	159,000	483,000	75,000	216,000	28,000	139,000	189,000	12,000	1,082,000	399,000	1,395,000	923,000	369,000	8,585,000	19,646,000
Hogs sold		371,000	530,000	29,000	342,000	54,000	117,000	28,000	52,000	29,000	236,000	343,000	10,000	140,000	230,000	375,000	543,000	81,000	3,510,000	14,475,000
Total value of crops and livestock products in 1929		$9,826,000	$6,504,000	$2,071,000	$8,344,000	$2,661,000	$4,247,000	$999,000	$5,191,000	$890,000	$17,866,000	$3,069,000	$444,000	$10,085,000	$9,659,000	$5,454,000	$11,946,000	$3,018,000	$102,274,000	$783,698,000
Inventory value of farms, implements and machinery, and livestock in 1930—																				
Land and buildings		$48,303 000	$33,798,000	$10,608,000	$38,230,000	$18,084,000	$11,443,000	$5,006,000	$25,088,000	$3,738,000	$76,560,000	$14,734,000	$1,445,000	$45,107,000	$57,300,000	$30,078,000	$67,574,000	$16,710,000	$503,806,000	$3,419,471,000
Implements and machinery		2,804,000	1.778,000	551,000	2,350,000	773,000	729,000	263,000	1,142,000	167,000	4,070,000	699,000	81,000	2,544,000	3,608,000	1,368,000	3,671,000	900,000	27,498,000	135,741,000
Domestic animals, chickens and bees		2,917,000	2,758,000	1,197,000	4,453,000	837,000	4,205,000	790.000	1,197,000	703,000	3,447,000	2,736.000	354,000	3,506,000	1,888,000	5,189,000	3,455,000	1,615,000	41,247,000	200,288,000
Total inventory value in 1930		$54,024,000	$38,334,000	$12,356,000	$45,033,000	$19,694,000	$16,377,000	$6,059,000	$27,427,000	$4,608,000	$84,077,000	$18,169,000	$1,880,000	$51,157,000	$62,796,000	$36,635,000	$74,700,000	$19,225,000	$572,551,000	$3,755,500,000

NOTE: Data compiled from Fifteenth Census of the United States, 1930, except value of cattle, sheep and hogs sold. The value of live stock sold was computed from the live stock inventory and estimate of value of live stock production by California Cooperative Crop Reporting Service.

[1] Grapefruit, lemons, oranges and limes.
[2] Apples, apricots, cherries, figs, nectarines, peaches, pears, plums and prunes, and quinces.
[3] Wheat, oats, barley, rye and mixed grains not separated in harvesting.
[4] Corn silage, timothy, clovers, tame and wild grasses, small grains for hay, legumes for hay and sorghum fodder.
[5] Corn and sorghums harvested for grain.
[6] Grass seeds, clover, alfalfa, sunflower, vetch, cottonseed, flower and vegetable seeds.
[7] Blackberries, loganberries, blueberries, gooseberries, strawberries, raspberries, currants and other fruits.

estimated area of irrigated lands in the Sacramento Valley and adjacent foothills was 719,000 acres. Of this area, 515,600 acres were irrigated from surface supplies and 203,400 acres by pumping from ground water.

In addition to the area given above, it is estimated that 138,000 acres of land were irrigated in the mountain valleys.

Future Development of Sacramento River Basin.

A study was made to estimate the ultimate water requirements in the Sacramento River Basin, as explained in Chapter V. In order to estimate these ultimate water requirements, it was necessary to make an estimate first of the amounts of land that would be irrigated under the condition of ultimate development. It was assumed that all of the arable land in the Sacramento River Basin ultimately will be brought into use and that all of the lands which are of sufficiently good quality and for which it is physically possible to furnish a water supply will be irrigated. It is not expected that this condition will be reached until a very distant date but allowances were made in all studies for water requirements for an ultimate development in the mountains and foothills and on the Sacramento Valley floor.

For estimating the number of acres of the valley floor and foothill lands which are irrigable, the entire area was divided into eight zones which are shown on Plate V, "Zones Used for Estimating Net Irrigable Areas in the Sacramento Valley and Adjacent Foothills." These zones are briefly described below. In each zone, varying characteristics of topography, soil conditions and artificial works so affect the different classes of land that only certain percentages of each class are estimated to be irrigable within that zone. These percentages may vary for the same class of land in different zones. Class 5 land is considered as having no portion which will ever be suitable for irrigation.

The zones are briefly described as follows:

Zone A. This zone includes all of the Sierra Nevada foothills and a portion of the valley floor lying along the base of these foothills, all of the valleys and foothills north of Red Bluff and south of Redding, and the Coast Range foothills and plains lands along their base north of the Tehama-Glenn County line except the area designated as refractory Corning gravelly loams just north of the county line. In this zone, the percentage of the class of land which it is estimated will be irrigable is the same whether the land was classified under the foothill or valley method of classification. These percentages are estimated to be as follows:

Class 1	90 per cent
Class 2	75 per cent
Class 3	60 per cent
Class 4	20 and 40 per cent

Class 4 land in this zone, as previously stated, is mainly pasture land, but it varies in type and therefore is estimated to have different percentages of irrigable areas according to its characteristics. The Class 4 land from Honcut Creek northerly on the east side of the Sacramento River is mainly lava overlain with shallow soil and is rock strewn. The Class 4 land west of the Sacramento River in this zone, while not overlying lava, is similar in type to that north of Honcut

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Future Development of Sacramento River Basin.

A study was made to estimate the ultimate water requirements in the Sacramento River Basin, as explained in Chapter V. In order to estimate these ultimate water requirements, it was necessary to make an estimate first of the amounts of land that would be irrigated under the condition of ultimate development. It was assumed that all of the arable land in the Sacramento River Basin ultimately will be brought into use and that all of the lands which are of sufficiently good quality and for which it is physically possible to furnish a water supply will be irrigated. It is not expected that this condition will be reached until a very distant date but allowances were made in all studies for water requirements for an ultimate development in the mountains and foothills and on the Sacramento Valley floor.

For estimating the number of acres of the valley floor and foothill lands which are irrigable, the entire area was divided into eight zones which are shown on Plate V, "Zones Used for Estimating Net Irrigable Areas in the Sacramento Valley and Adjacent Foothills." These zones are briefly described below. In each zone, varying characteristics of topography, soil conditions and artificial works so affect the different classes of land that only certain percentages of each class are estimated to be irrigable within that zone. These percentages may vary for the same class of land in different zones. Class 5 land is considered as having no portion which will ever be suitable for irrigation.

The zones are briefly described as follows:

Zone A. This zone includes all of the Sierra Nevada foothills and a portion of the valley floor lying along the base of these foothills, all of the valleys and foothills north of Red Bluff and south of Redding, and the Coast Range foothills and plains lands along their base north of the Tehama-Glenn County line except the area designated as refractory Corning gravelly loams just north of the county line. In this zone, the percentage of the class of land which it is estimated will be irrigable is the same whether the land was classified under the foothill or valley method of classification. These percentages are estimated to be as follows:

Class 1	90 per cent
Class 2	75 per cent
Class 3	60 per cent
Class 4	20 and 40 per cent

Class 4 land in this zone, as previously stated, is mainly pasture land, but it varies in type and therefore is estimated to have different percentages of irrigable areas according to its characteristics. The Class 4 land from Honcut Creek northerly on the east side of the Sacramento River is mainly lava overlain with shallow soil and is rock strewn. The Class 4 land west of the Sacramento River in this zone, while not overlying lava, is similar in type to that north of Honcut

Creek on the east side. The Class 4 land on the lower foothills from Lincoln southerly to the American River is classified as "scab land" and is similar to that in the northern end of the east side of the valley. In all of the above areas, the Class 4 land is estimated to be 20 per cent irrigable. In the remainder of this zone, the Class 4 land is mainly classed as Aiken stony loam, which is a better type of soil than the scab land, and where this soil is of a superior type it is estimated to be 40 per cent irrigable.

Zone B. The Corning Plains. This area is all Class 3 land. In it the Corning gravelly loam is of a particularly refractory type, and because of this fact the Class 3 land is considered as only 50 per cent irrigable.

Zone C. Coast Range Foothills and West Side Plains Lands South of Tehama County. This zone includes the west side foothill lands previously described and also a considerable area of the higher valley floor lands along the base of the Coast Range. In this zone, also, the percentage of each class of land which it is estimated will be irrigible is the same whether the land is classified under the foothill or the valley method of classification. These percentages are estimated to be as follows:

Class 1	90 per cent
Class 2	75 per cent
Class 3	50 per cent
Class 4	20 per cent

Zone D. The Montezuma Hills. While the soils in this zone are of a good type, the topography is such that it is estimated that only 75 per cent of the agricultural land will ever be irrigated.

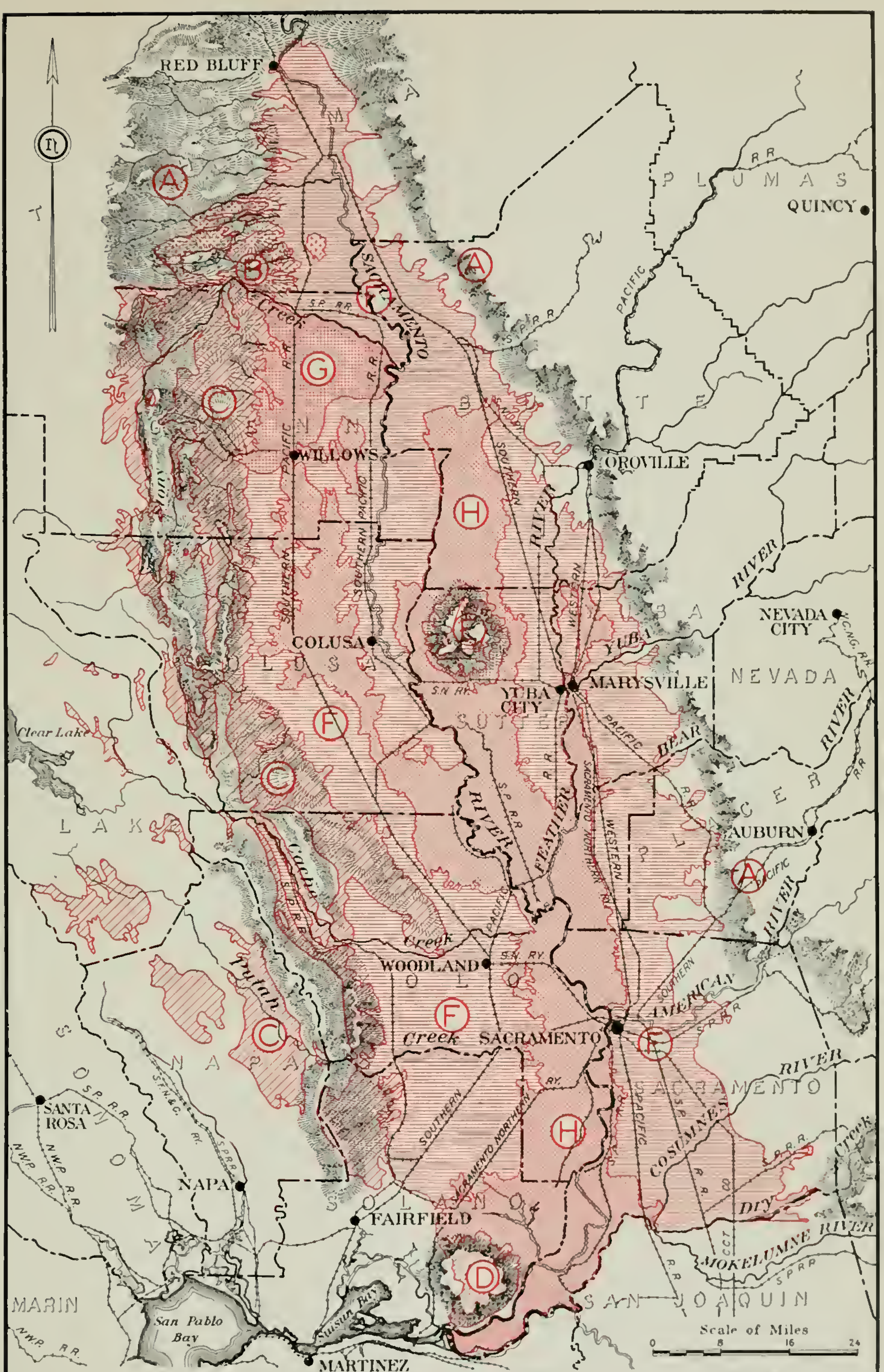
Zone E. The Sutter Buttes. Due to the isolated character of these buttes and the necessity of pumping water for an irrigation supply, it is assumed that the Class 4 lands in this zone will never be irrigated. The percentage of irrigable land in each of the other classes is estimated to be as follows:

Class 1	90 per cent
Class 2	80 per cent
Class 3	70 per cent

Zone F. The Valley Floor. Except where special conditions noted in Zones G and H exist, the percentages of irrigable land in each class in this zone is estimated to be as follows:

Class 1	90 per cent
Class 2	80 per cent
Class 3	70 per cent
Class 4	20 per cent

Zone G. Orland-Willows Area (Valley floor citrus area). The Class 1 land in this zone is estimated to be 90 per cent and the Class 3 land 70 per cent irrigable. The Class 2 land in this zone is so rated on account of an excessive gravel content. It is estimated to be 90 per cent irrigable and probably will require more water than Class 1 land to produce a crop. The Class 4 land is a gravel wash area along Willow Creek. It is estimated to be only 20 per cent irrigable as the larger portion of its area probably will never be used for anything but a stream channel.



ZONES USED FOR ESTIMATING NET IRRIGABLE AREAS

IN THE

SACRAMENTO VALLEY AND ADJACENT FOOTHILLS

Zone H. Rice and Gun Club Area. Lands in this zone were graded mainly with reference to their alkali content. Large canals and drains will be necessary for the irrigation of these lands and the areas deducted from the better grades of land for rights of way for these structures will reduce their irrigable areas. The percentage of land irrigable in each class, therefore, will be more nearly uniform in this zone. The percentage of irrigable land in each class is estimated to be as follows:

Class 1	80 per cent
Class 2	75 per cent
Classes 3 and 4	70 per cent

Reclaimed Area.—Where reclamation from inundation is necessary, the drain ditches and levees with their spoil banks and borrow pits will reduce the irrigable areas of the better lands. In this zone, the percentage of each class of land estimated to be irrigable is as follows:

Class 1	80 per cent
Class 2	75 per cent
Classes 3 and 4	70 per cent

By applying the foregoing percentages to the gross areas of lands of each class in the different zones, the net irrigable areas on the valley floor and in the foothills were computed. The net irrigable areas in the mountain valleys were estimated to be about 75 per cent of the gross agricultural lands.

The net irrigable areas are presented in Table 16 by the same sections as were used in showing the gross agricultural areas in the Sacramento River Basin in Table 13.

TABLE 16

NET IRRIGABLE AREAS IN THE SACRAMENTO RIVER BASIN AND THE ENTIRE SACRAMENTO-SAN JOAQUIN DELTA

Section	Net irrgable area	
	In acres	In per cent of total
Valley floor	2,640,000	61.9
Foothill area	922,000	21.6
Mountain valleys	312,000	7.3
Sacramento Delta	135,000	3.2
San Joaquin Delta	257,000	6.0
Totals	4,266,000	100.0

CHAPTER IV

IRRIGATION DEVELOPMENT

On account of climatological conditions in the Sacramento River Basin, dry farming has been more successfully carried on than in the San Joaquin Valley and southern California. Irrigation, therefore, has not developed as rapidly as in these latter sections. Nevertheless, during the last two decades the area irrigated has increased more than 500,000 acres, principally due to the increase in orchard and rice plantings.

It is pointed out in Chapter V that although water is used in the Sacramento River Basin for practically all of the purposes for which it is required, the use for irrigation does and probably will continue to predominate. In this chapter, therefore, a brief history of irrigation development in the basin, a description of the agencies furnishing irrigation water, and the present status of irrigation are given.

History of Irrigation Development.

One of the first areas in the Sacramento Valley to receive a supply of water dedicated principally to irrigation use is that lying in Yolo County west of the city of Woodland. A supply from Cache Creek was delivered to this area through a ditch constructed by James Moore in 1856. Nine years later a small ditch was constructed on Stony Creek by the Stony Creek Improvement Company. The paucity of authentic records on other streams makes it difficult to say with any degree of certainty when irrigation was first practiced on the larger streams. In the foothills of the Mother Lode counties, there was extensive construction of canals and reservoirs dating back as far as 1851. These were constructed mainly for mining purposes, both for hydraulic placer washing and to supply water for water-wheel operated mills which were in common use in the quartz mines, and also for domestic water supplies for the towns and mining camps. Doubtless water was available for irrigation in the early fifties and in all probability some irrigated farming was carried on in Nevada, Placer, Yuba and El Dorado counties. The early agriculture on the valley floor was the growing of grain by dry farming methods and stock raising. It is probable that in areas adjacent to settled communities, there were some irrigated truck gardens even in the fifties but the small amount of data available indicate that there was little interest in irrigated farming until 1864, which was a year of drought of unprecedented severity. In the mountain valleys of the Pit and upper Feather rivers it is probable that the flooding of meadows for pasturage was practiced in the fifties.

Early State interest in irrigation is evidenced by the passage of "An act to promote irrigation by the formation of irrigation districts," by the California Legislature of 1872. This act so far as accomplishment is concerned was of no importance and is only mentioned to show that there was a state-wide interest in the subject. However, interest was probably keener in the southern part of the state and in the San Joaquin Valley than it was in the Sacramento Valley which was at that time being successfully dry farmed.

Interest in the subject of irrigation in the state is also evidenced by an act of Congress in 1873 which authorized a commission composed of two engineer officers of the United States Army and one officer of the Coast Survey to examine and report "on a system of irrigation in the San Joaquin, Tulare and Sacramento valleys of the State of California." The report,* which was transmitted to Congress on March 23, 1874, contains no statistical information as to the area irrigated at that time in the Sacramento River Basin. Mention is made, however, of the fact that ditches in the foothills that were built originally for mining had become "more or less abandoned for mining and their water is now diverted to the irrigation of gardens, orchards and vineyards which betoken the permanent settlement and cultivation of these foothills."

The State Engineer in his report to the Legislature of 1880 gave data on the areas irrigated in certain sections of the state. Complete statistics were evidently not available at that time as is shown by the following quotation from the report: "It will be seen that the total area of lands cultivated by irrigation prior to the present season of 1880, in the districts spoken of, is 292,885 acres, viz, San Bernardino and Los Angeles, 82,485 acres; San Joaquin Valley plains, 188,000 acres; Sacramento Valley (Cache Creek), 13,400 acres; in the foothill counties east of the Sacramento and San Joaquin Valley, 9000 acres. I have no means of estimating the extent of irrigation in other quarters." Also, "The fact has not been overlooked that there are other large and important districts in the State, where irrigation is practiced, having equal claim to consideration by this department but the means and time have, as yet, been inadequate to the extension of the investigation beyond its present limits." Among the areas then listed are "the mountain valleys of Plumas, Lassen and Shasta counties, where no small amount of progress has already been made in the artificial use of water." Elsewhere in the same report there appears "In Shasta and Plumas, as well as in other counties, there are ditches constructed * * * expressly for irrigation purposes." From all information obtained, it appears that in 1880 there were probably considerably less than 100,000 acres of irrigated land in the whole Sacramento River Basin.

During the period of the seventies and eighties, there was great interest throughout the state in irrigation and much controversy over this subject. There appears to have been a great desire for development but the large land owners and owners of riparian rights were not in sympathy with the agitation for community endeavor.

During the latter half of 1880, the State Engineer made a further study of the subject of water rights and irrigation and drew up proposed measures for ascertaining the extent and nature of valid claims to water, for providing for the control of streams and the regulation

* House Document No. 290, 43d Congress, 1st session.

of the diversions therefrom, and for the promotion of irrigation, which were presented in his report to the Legislature of 1881. In the act for the promotion of irrigation, he outlined a plan for the formation and government of irrigation districts. No action on any of the proposed measures was taken by the Legislature.

From 1881 to 1887, attempts were made to enact some general irrigation law and to legislate against riparian owners. In 1887, an irrigation act known as the "Wright Irrigation District Act" was passed by the Legislature and remained on the books for 10 years with important amendments, drafted in the light of experience, adopted in 1889, 1891, 1893 and 1895. Under this act the following districts in the Sacramento River Basin were formed: Orland and Central in 1887; Browns Valley, Colusa, Orland Southside and Kraft in 1888; and Happy Valley in 1891. Of these older districts only the Browns Valley is now active. The Central Irrigation District constructed about 40 miles of canal but ceased work on account of financial and legal difficulties and in 1903 leased its works to a private company. These works are now a part of those of the Glenn-Colusa Irrigation District. The original Happy Valley district accomplished nothing and was soon abandoned. It was reorganized in 1916 and constructed an irrigation system. The district defaulted and was dissolved in 1925 and the water system is now operated by a public utility water company. The other districts constructed no works and were either dissolved or abandoned.

In 1897 the Wright Act was rewritten, considerably enlarged, and reenacted as an entirely new law, variously known as the "Bridgeford Act," the "Irrigation Act of 1897" and the "California Irrigation District Act." The latter name was definitely adopted by the Legislature of 1917. Many further amendments have been made from time to time, and numerous supplemental acts have been passed, most of which deal with financial aspects or State control.

In 1901, the Office of Experiment Stations, United States Department of Agriculture, published a report* on irrigation investigations in California. In the Sacramento River Basin, the Yuba River and Cache Creek areas are described in considerable detail. Stony Creek is mentioned but no report on that stream is included. In the discussion of the use of water for irrigation, the statement is made that the irrigated lands in the drainage basin of the Yuba River are located principally in the Browns Valley Irrigation District and near Smartsville, elsewhere being confined to small gardens and orchards in and adjacent to the small towns in the foothills and mountains. The areas in the watershed, however, were insignificant when compared with the large area served with Yuba River water in the watersheds of the Bear and American rivers in the fruit belt between Colfax and Roseville. Only about 600 acres were irrigated in the Browns Valley district but the irrigable area was estimated at 5000 to 8000 acres. Irrigation was reported as almost at a standstill due to reconstruction and litigation. The report does not state the total area that was irrigated in 1900, only certain small farms being mentioned as examples of economic or usage conditions.

* Bulletin No. 100, "Irrigation Investigations in California," 1901.

A special census taken by the United States in 1902 reports the area irrigated in the Sacramento River Basin as 206,300 acres. Another census was taken in 1909 but in the data given in the report, the areas of irrigated lands are given by counties and as some counties lie only partially in the Sacramento River Basin, it would be difficult to determine from the census data the area irrigated in the basin in that year. Data on areas of irrigated lands also were secured by the Conservation Commission of California in 1911 and published in their report* of January, 1913. These data indicate that 312,000 acres were irrigated in the Sacramento River Basin at that time.

The United States Census taken in 1919 reports an area of 641,000 acres irrigated in the Sacramento River Basin. This figure compared with the one published for the year 1902—206,300 acres—shows an increase of 210 per cent in the irrigated area from 1902 to 1919.

Estimates made during the present investigation indicate that there were about 857,000 acres of irrigated lands in the Sacramento River Basin counties in 1929. These lands were distributed as follows: 550,000 acres on the valley floor‡ outside of the delta, 103,000 acres in the Sacramento Delta,‡ 66,000 acres in the Sierra Nevada foothills adjacent to the valley, and 138,000 acres in the mountain valleys.

The increase in the area irrigated between 1880 and 1929 is shown by the figures given in Table 17.

TABLE 17

AREAS IRRIGATED IN SACRAMENTO RIVER BASIN, 1880-1929

Year	Irrigated area, in acres	Authority
1880	Less than 100,000	Approximation based on State Engineer's report of 1880.
1902	206,300	United States Census.
1911	312,000	Conservation Commission of California.*
1919	641,000	United States Census.
1929	857,000	Estimate by State Engineer's office.

*"Report of the Conservation Commission of California," January 1, 1913.

Agencies Furnishing Irrigation Service.

In California, the following types of enterprises furnish irrigation water: irrigation districts, public utilities, mutual water companies, contract companies, individuals, partnerships, associations, private companies, United States Bureau of Reclamation, United States Indian Service, water works districts, municipal improvement districts, water conservation districts and reclamation districts. Consideration will be given only to those which are most in use in the Sacramento River Basin, viz—the irrigation district, the public utility, the mutual water company, the United States Bureau of Reclamation, the reclamation district, the individual, and private companies.

The Irrigation District.—The irrigation district is probably the most important agency or form of organization in California for the construction of irrigation works and the delivery of irrigation water. These districts are formed under the "California Irrigation District

* "Report of the Conservation Commission of California," January 1, 1913.
‡ For descriptions of boundaries of Sacramento Valley and Sacramento Delta, see pages 86 and 87 in Chapter III.

Act,'' the history and adoption of which has previously been described. The districts have power to issue bonds to pay for their works and to levy and collect taxes, assessments and water tolls to amortize the cost of, operate and maintain their water systems. California irrigation districts are political subdivisions of the State and are organized under the jurisdiction of the county or counties in which they are located. While it is possible to organize an irrigation district and issue bonds with the consent of the board of supervisors of the county in which the district is located even if the district is not approved by the State Engineer, the bonds are not legal security for savings banks unless the plans and organization of the district are approved by the State Engineer and the bonds approved by the California District Securities Commission. The affairs of the district are administered by a board of directors, assessor, tax collector, treasurer and secretary, all of whom are elected except the secretary, who is appointed by the board, and the plans for the district must be prepared by a competent engineer.

There are now 23 active irrigation districts in the Sacramento River Basin and eight inactive ones. Their histories and statistics are given in detail in other publications.* Of the active districts only one, the Browns Valley Irrigation District, was in existence prior to 1914. The period of greatest activity in the formation of these districts was between the years 1915 and 1925. The year in which the greatest number of districts throughout the state were organized was 1920. A tabulation of the districts in the basin, their sources of water supply, the county or counties in which they are located, the years of their organization and their total and irrigated areas in 1929, is given in Table 18.

The Public Utility Water Company.—The public utility water company has been defined by California statutes as any firm or private corporation, or its representatives, which sells, leases, rents or delivers water, except when such private corporation or association is organized to deliver water at cost to its members only. Whenever any corporation or association organized to deliver water solely to its members or stockholders at cost delivers water for compensation to other than its members or stockholders, it also becomes a public utility. All public utility water companies are subject to the jurisdiction and control of the Railroad Commission of California which has power not only to fix the rates charged by these companies, but also to regulate their manner of service and the general conduct of their business.

A tabulation of the principal public utility water companies supplying irrigation water in the Sacramento River Basin, their sources of water supply, the county or counties in which they operate and the areas irrigated in 1929, are given in Table 19.

The Mutual Irrigation Company.—According to California statutes, whenever any private corporation or association is organized for the purpose solely of delivering water to its stockholders or members at cost, and delivers water to no one except its stockholders or members, such private corporation or association is not a public utility and is not subject to the jurisdiction, control or regulation of the Railroad Commission of California. The methods of organizing such mutual

* Bulletins No. 21, 21-A, and 21-B, "Irrigation Districts in California," Division of Engineering and Irrigation, and Division of Water Resources.

TABLE 18

IRRIGATION DISTRICTS IN SACRAMENTO RIVER BASIN

Active Districts

District	Source of supply	County	Year organized	Area within district boundary, in acres	Area irrigated in 1929, in acres
Anderson-Cottonwood	Sacramento River	Shasta-Tehama	1914	32,000	16,295
Browns Valley	North Fork Yuba River	Yuba	1888	40,000	6,992
Camp Far West	Bear River	Placer-Yuba	1924	4,089	2,446
Carmichael	American River	Sacramento	1916	3,138	1,950
Citrus Heights	North Fork Ditch Company	Sacramento-Placer	1920	3,077	2,850
Compton-Delevan	Sacramento River	Colusa	1920	12,652	1,092
Cordua	Yuba River	Yuba	1919	5,461	1,500
Deer Creek	Deer Creek	Tehama	1926	1,907	1,907
El Camino	Wells	Tehama	1921	7,549	4,000
El Dorado	South Fork American River and Webber Creek	El Dorado	1925	30,000	6,000
Fairoaks	North Fork Ditch Company	Sacramento	1917	3,900	2,553
Glenn-Colusa	Sacramento River	Glenn-Colusa	1920	121,592	40,590
Hot Spring Valley	Pit River	Modoc	1919	9,497	9,497
Jacinto	Sacramento River	Glenn	1917	11,554	4,155
Maxwell	Sacramento River	Colusa	1918	8,820	5,720
Nevada	Yuba and Bear rivers	Nevada-Placer	1921	263,500	4,200
Oroville-Wyandotte	South Fork Feather River	Butte	1919	24,100	2,068
Paradise	Little Butte Creek	Butte	1916	11,260	3,300
Princeton-Cordora-Glenn	Sacramento River	Glenn-Colusa	1916	13,656	4,171
Provident	Sacramento River	Glenn-Colusa	1918	22,805	4,399
Richvale	Feather River	Butte	1930	17,170	6,500
Table Mountain	Feather River	Butte	1922	1,955	261
Thermalito	Feather River	Butte	1922	3,110	1,967
Totals				652,792	134,413

Inactive Districts

District	County	Year organized
Baker	Glenn	1922
Big Valley	Modoc and Lassen	1925
Crooks Canyon	Modoc	1919
Dry Creek	Yuba	1926
Fall River Valley	Shasta	1922
Feather River	Sutter	1920
Juniper	Modoc	1925
South Capay	Glenn	1921

TABLE 19

PUBLIC UTILITY WATER COMPANIES IN SACRAMENTO RIVER BASIN, 1929

Name of company	Source of supply	County in which water is served	Approximate area irrigated, in acres
Happy Valley Water Company	Clear and Cottonwood creeks	Shasta	1,500
Coneland Water Company	Mill and Antelope creeks	Tehama	10,000
Clear Lake Water Company	Cache Creek	Yolo	11,260
Sutter-Butte Canal Company	Feather River	Butte and Sutter	27,410
Western Canal Company	Feather River	Butte and Glenn	9,650
Los Verjeles Land and Water Company	Dry Creek	Yuba	600
Pacific Gas and Electric Company	Yuba, Bear and American rivers	Placer	27,000
North Fork Ditch Company	North Fork of American River	Sacramento	1,980
Natomas Water Company	South Fork of American River	Sacramento	1,800
Diamond Ridge Water Company	Cosumnes River	El Dorado	600

companies include incorporation and ordinary contract between the members. Their distinctive feature is their mutual or nonprofit character. The stock of such companies represents their capital and is divided into shares distributed among the members. Such shares represent the right to receive water. Such stock may or may not be appurtenant to the land and represent its water rights. In Table 20 there are listed several of the larger mutual water companies in the Sacramento River Basin, their sources of supply, the approximate areas irrigated in 1929 and the counties wherein their service areas lie.

TABLE 20

MUTUAL WATER COMPANIES IN SACRAMENTO RIVER BASIN, 1929

Name of company	Source of supply	County in which water is served	Approximate area irrigated, in acres
Alicia Mutual Water Company	Feather River	Yuba	1,400
Colusa Irrigation Company	Sacramento River	Colusa	850
Durham State Land Settlement Water Users Association	Butte Creek	Butte	2,750
Elkhorn Mutual Water Company	Sacramento River	Sacramento	2,730
Feather River Mutual Water Company	Feather River	Sutter	240
Garden Highway Mutual Water Company	Feather River	Sutter	2,210
Hallwood Irrigation Company	Yuba River	Yuba	5,400
Improvement Mutual Water Company	Sacramento River	Sutter	560
Loam Ridge Mutual Water Company	Wells	Glenn	1,000
Natomas Central Mutual Water Company	Sacramento River	Sacramento and Sutter	2,650
Natomas Northern Mutual Water Company	Sacramento River	Sutter and Sacramento	2,400
Natomas Riverside Mutual Water Company	Sacramento River	Sacramento	1,150
Meridian Farms Water Company	Sacramento River	Sutter	5,380
Orangevale Water Company	North Fork Ditch Company	Sacramento	----------
Plumas Mutual Water Company	Feather River	Yuba	1,500
Roberts Ditch Irrigation Company	Sacramento River	Colusa	800
Stanford Vina Ranch and Irrigation Company	Deer Creek	Tehama	3,020
Sutter Mutual Water Company	Sacramento River	Sutter	31,970
Swinford Tract Irrigation Company	Sacramento River	Colusa	140

The United States Bureau of Reclamation.—The Orland Project, located in Glenn County in the Sacramento Valley, is the only development by the United States Bureau of Reclamation in the Sacramento River Basin. It has a total area of about 20,750 acres, of which about 13,500 acres were irrigated in 1929.

Reclamation Districts.—Although reclamation districts in California generally have been formed for the unwatering and protection from floods of swamp and overflow lands, some of these districts also have constructed irrigation works. Section 3455 of the Political Code of California includes the provision that "the term 'works of reclamation' as used in this chapter shall include not only such public works and equipment as are necessary for the unwatering of lands in reclamation districts, but shall also include such like works as may be necessary to water or irrigate the same lands in such districts." Furthermore, section 3467 of the Political Code provides that "In all reclamation districts where plans have been adopted by the trustees of the district for the irrigation of the lands in said district, the trustees of the district shall have power to adopt rules and regulations for the distribution of said water, and adopt a schedule of rates * * *, and shall have the right to collect the same * * *." Three of the more important districts that operate irrigation works under these laws are Reclamation District No. 108 in Colusa and Yolo counties, Reclamation District No. 2068 in Solano and Yolo counties, and Reclamation District No. 2035 (Conaway Ranch) in Yolo County. Lands in many other districts also are being irrigated but not by systems operated by the district organization.

Individuals and Private Companies.—In many cases, individuals, or companies, who farm land outside of an organized area, or who have an adequate water supply independent of organized agencies, divert irrigation water from streams by gravity or by pumping, or pump ground water where the depth to the water table is favorable, for the irrigation of their own lands.

Present Irrigation Development.

The area irrigated in the Sacramento River Basin each year varies considerably on account of climatological conditions and the market for irrigated crops, especially rice. Most of the irrigated lands receive their supplies from unregulated streams, or from streams on which the regulation is primarily for power development purposes in the mountains. A relatively small acreage of irrigated lands has storage works for the regulation of its water supply, and as a consequence there is insufficient water for the full demands of all irrigated lands in dry years.

A survey of the lands irrigated or under irrigation was made in 1929 in connection with this investigation. This survey covered only the valley floor and adjacent foothills but other data on the lands irrigated in the mountain valleys were available. The present irrigation developments are described herein by mountain valleys, foothills and the valley floor. The method of estimating the area irrigated in 1929 also is given.

Mountain Valleys.—The irrigable mountain valleys of the Sacramento River Basin lie principally within the drainage basins of the Pit River and its tributaries and the forks and tributaries of the upper Feather River. There are also a few small tracts on the upper Sacramento River. It is estimated that the area irrigated in these valleys in 1929 was about 138,000 acres, of which about 37,000 acres were within the Feather River watershed and the remainder in the Pit and upper Sacramento river watersheds.

There is only one active irrigation district, the Hot Spring Valley District near Alturas, in these mountain valleys. This district stores water in the Big Sage Reservoir, which has a capacity of 77,000 acre-feet. There are also a number of other storage reservoirs in the Pit River area owned by individuals or companies but a large part of the irrigation in all of the valleys is accomplished by the diversion of the natural stream flow or return flow from irrigation of lands on the upper part of the stream. A large portion of the irrigated land is used for pasture and is irrigated by wild flooding.

Foothills East of Sacramento Valley.—It is estimated that there were 66,000 acres of land irrigated in the foothills of the Sierra Nevada in 1929. This foothill area includes the Paradise, Oroville-Wyandotte, Browns Valley, Nevada and El Dorado irrigation districts with a combined area of about 370,000 acres, of which only about 6 per cent was irrigated in 1929.

In addition to the area in these districts, a large body of land is irrigated in the Placer County deciduous fruit belt by water delivered by the Pacific Gas and Electric Company and some small areas are irrigated with water obtained by purchase from irrigation districts and water companies. Also, a small area in El Dorado County is served by the Diamond Ridge Water Company.

The Paradise Irrigation District obtains its water supply from Little Butte Creek and the West Branch of North Fork of Feather River and has one storage reservoir. The Oroville-Wyandotte district obtains its supply from the South Fork of Feather River on which it has constructed the Lost Creek Reservoir. The Browns Valley district obtains its water supply by direct diversion from the North Fork of Yuba River. The Nevada district obtains its water supply from the Middle and South forks of Yuba River, Bear River and Deer Creek. The principal storage reservoir is Bowman Reservoir on Canyon Creek, a tributary of the South Fork of Yuba River. The El Dorado district receives its supply from the South Fork of American River and Webber Creek, a tributary of that fork, on which the district has a storage reservoir.

The water served by the Pacific Gas and Electric Company to the Placer County area is obtained from the Yuba, Bear and American rivers and most of it is used en route for the generation of hydroelectric energy. The Diamond Ridge Water Company obtains its supply from the Cosumnes River.

Valley and Foothills—Redding to Red Bluff.—The most important body of irrigated land in this division of the Sacramento River Basin is the Anderson-Cottonwood Irrigation District. The district has an area of 32,000 acres, most of which is in Shasta County. The water supply for the district is obtained by direct diversion from the Sacramento River at Redding. There is also an area of about 1500 acres in Happy Valley, lying west of Anderson, which obtains a water supply from several small creeks through the Happy Valley Water Company. Several small tracts on Cow, Bear, Ash and Battle creeks receive irrigation supplies by direct diversion from these streams.

Sacramento Valley—West Side.—Irrigation water for the lands west of the Sacramento River is obtained principally from that river, although some lands are irrigated from tributary streams and some scattering tracts receive their supply from pumped ground water.

The irrigation districts lying west of the river are the El Camino, Jacinto, Provident, Compton-Delevan, Princeton-Codora-Glenn, Maxwell and Glenn-Colusa. All of these districts, except the El Camino, receive their water supply from the Sacramento River. The El Camino district pumps its supply from ground water. The aggregate area of these districts is almost 200,000 acres, of which only about 32 per cent was irrigated in 1929.

The Orland Project of the United States Bureau of Reclamation lies along Stony Creek, near the town of Orland. It has a total area of 20,750 acres, of which about 65 per cent is irrigated. The project obtains its water supply from Stony Creek, on which it has constructed two storage reservoirs, East Park and Stony Gorge, with an aggregate capacity of about 100,000 acre-feet.

Other public or semipublic organizations supplying irrigation water are Reclamation District No. 108, Colusa Irrigation Company, Roberts Ditch Irrigation Company, Swinford Tract Irrigation Company and Reclamation District No. 2035 (Conaway Ranch), which take water from the Sacramento River; the Clear Lake Water Company, which supplies an area around Woodland with water from Cache Creek; Reclamation District No. 2068, which takes water from sloughs in the lower Yolo Basin; and land colonies around Richfield and Corning, which obtain supplies from small tributaries of the Sacramento River or by pumping from ground water.

Large diversions are also made from the Sacramento River and drains flowing into the river by individuals and companies for use on their own lands. These diversions are nearly all made by pumping and extend along the entire river from Sacramento to Redding and along drains in the Colusa and Yolo basins.

Sacramento Valley—East Side.—The valley lands, east of the Sacramento River are irrigated from the Sacramento, Feather, Yuba, Bear and American rivers, small tributary streams and ground water.

The irrigation districts supplying water in this area are Deer Creek, Richvale, Table Mountain, Thermalito, Cordua, Camp Far West, Citrus Heights, Fairoaks and Carmichael. These districts have a total area of 43,800 acres of which 50 per cent was irrigated in 1929. The Deer Creek district in Tehama County receives its water supply from the creek of the same name which is a tributary of the Sacramento River, the Richvale district uses Feather River water supplied by the Sutter-Butte Canal Company, the Thermalito and Table Mountain districts obtain their water from the West Branch of Feather River and have a storage reservoir, Lake Wilenor, with a capacity of 8000 acre-feet, on Concow Creek, the Cordua district obtains water from the Yuba River, the Camp Far West district's supply is obtained from the Bear River, and the other three districts obtain water from the American River.

The largest public utility water company is the Sutter-Butte Canal Company which supplies lands in Butte and Sutter counties with water diverted from the Feather River. The Western Canal Company also diverts water from the Feather River for the irrigation of between 10,000 and 13,000 acres in upper Butte Basin. The Natomas Water Company and North Fork Ditch Company divert water from the American River to irrigate small areas in Sacramento County. Lands in the Los Molinos Colony in Tehama County are served with water from Mill and Antelope creeks by the Coneland Water Company and lands in the Los Verjeles Colony in Yuba County are served by the Los Verjeles Land and Water Company with water from Dry Creek on which it has a storage reservoir.

A considerable area is irrigated with water supplied by mutual water companies. Water is diverted from the Sacramento River by the Elkhorn, Natomas Central, Natomas Northern and Natomas Riverside mutual water companies for irrigation in Reclamation District No. 1000; and by the Sutter and Improvement mutual water companies for irrigation in Reclamation Districts Nos. 1500 and 1660. Several mutual water companies furnish water from the Feather and Yuba rivers for irrigation in Reclamation District No. 784, in the Hallwood tract near Marysville, and in Sutter Basin. Water also is diverted from two of the smaller streams by mutual water companies. The Stanford Vina Ranch and Irrigation Company diverts water from Deer Creek for the irrigation of the Stanford Vina Ranch in Tehama County and the settlers on the former Durham State Land Settlement have a mutual water company which diverts water from Butte Creek for the irrigation of their lands.

In this area, as in that west of the river, large tracts are irrigated by individuals and private companies. The water is obtained by pumping from river channels, drains and borrow pits and to a large extent by pumping from underground water. This latter method of obtaining water is extensively used in Sutter County near Yuba City and in the territory east and south of the city of Sacramento.

Sacramento Delta.—Irrigation in this area is fully covered in another report.* The entire area is reclaimed swamp and overflow land. Irrigation water is obtained from the channels surrounding or adjacent to the various tracts either by pumping or syphoning and a large part of the area is naturally subirrigated. There were 103,000 acres irrigated in the Sacramento Delta in 1929.

Areas Irrigated in 1929.—An investigation was made in connection with the studies for this report to ascertain as accurately as possible the area of the lands irrigated in the Sacramento River Basin in 1929. The areas irrigated from surface supplies were determined from data collected from the reports of the Sacramento Water Supervisor of the Department of Public Works, from irrigation districts and from companies furnishing irrigation water. All areas irrigated from surface supplies were accounted for and the data concerning them are considered reliable.

In addition to the lands irrigated from surface supplies, there are a number of areas which obtain their water supply by pumping from ground water. Very little direct information on these lands was available, so their areas were estimated from the horse power of electric motors connected to pumps. A study of a number of areas obtaining supplies from ground water showed that probably less than five per cent of the total pumping was done with power other than electric. An estimate of the total area irrigated from ground water, therefore, based on connected electric motor ratings and neglecting other power is believed to be reasonably correct since the horsepower of electric motors operating pumps on wells for domestic supply and for other farm uses will about balance the power of other kinds used for pumping irrigation water. The horsepower ratings of connected electric motors were obtained from the power companies and were segregated into local districts in which the crops, soils, and pumping lifts are similar. A field canvass in each local district determined the average number of acres irrigated per horsepower of connected load. This factor was applied to the total connected load in the district to estimate

* Bulletin No. 27, "Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay," Division of Water Resources, 1931

the number of acres irrigated. In some districts, the area irrigated from ground water has been determined by the power company and these data where available were used.

The total acreage of lands irrigated in 1929 in the area included in the survey, segregated by counties where the data would permit, is shown in Table 21.

TABLE 21

AREAS OF IRRIGATED LANDS IN THE SACRAMENTO VALLEY AND ADJACENT FOOTHILLS, BY COUNTIES, 1929

County	Area in acres		
	Surface supply	Ground water	Total
Sacramento*	47,150	46,850	94,000
El Dorado	11,300	270	11,570
Nevada and Placer	31,340	870	32,210
Yuba	22,690	12,430	35,120
Butte	68,160	20,750	88,910
Tehama and Shasta	66,360	12,720	79,080
Glenn and Colusa	86,000	35,790	121,790
Sutter	62,840	41,910	104,750
Yolo and Solano	119,770	31,800	151,570
Totals	515,610	203,390	719,000

*Excluding portion in San Joaquin Valley.

In addition to these areas on the valley floor and in the foothills, it is estimated that there were 138,000 acres irrigated in the mountain valleys, or a total for the whole Sacramento River Basin of 857,000 acres.

The areas under irrigation in the Sacramento Valley and adjacent foothills are shown on Plate III.

CHAPTER V

WATER REQUIREMENTS

The variety of uses of water in California probably exceeds that in any other state in the Union. These uses include domestic, municipal, irrigation, salinity control, industrial, navigation, power development, hydraulic mining and recreational. The Sacramento River and San Joaquin River basins are the only ones in the state in which the uses of water comprise all of those given above. The use of water for irrigation, however, does and probably will continue to predominate in the Sacramento River Basin.

In this report, use is made of certain terms relating to the use of water which are defined as follows:

"Irrigation requirement" is the amount of water in addition to rainfall that is required to bring a crop to maturity. This amount varies with the crop to be supplied and the point at which the water is measured. As related to the point of measurement, it is the "gross allowance," "net allowance," or "net use." These terms together with the term "consumptive use," are defined as follows:

"Gross allowance" designates the amount of water diverted at the source of supply.

"Net allowance" designates the amount of water actually delivered to the area served.

"Consumptive use" designates the amount of water actually consumed through evaporation, and transpiration by plant growth.

"Net use" designates the sum of the consumptive use from artificial supplies and irrecoverable losses.

A study of the irrigation requirements of California lands was made several years ago by the Division of Engineering and Irrigation, Department of Public Works, and the results of the investigation were published in a previous report.* The study was made for the purpose of determining the monthly distribution of the need for irrigation water as well as the total amount of water required. Studies have been continued by the Division of Water Resources and other branches of the State government since the publication of this report and much information has been obtained on the water requirements of various crops. These studies have yielded information on the amount of water actually consumed by the crop, the amount of water which it is necessary to deliver to the field to care for evaporation, transpiration, return water and deep percolation to ground water, and the probable losses in conveyance of the water from the point of supply to the fields where it is to be used.

Records of the actual diversions of water from the main streams for use on the valley floor, the classes of crops using water from each diversion, and the amounts of water returned to the streams have been

* Bulletin No. 6, "Irrigation Requirements of California Lands," Division of Engineering and Irrigation, 1923.

obtained each year since 1924 by the Sacramento-San Joaquin Water Supervisor and were published for the period 1924 to 1928 in his report.*

The uses of water for power and hydraulic mining may cause some alteration in the regimen of flow and some losses in the amounts of water reaching the valley floor, due to evaporation during storage, but will otherwise have very little effect on the total run-off from a stream basin. The uses of water for municipal, industrial and domestic purposes are similar, as they are confined largely to the more thickly populated areas and have a more uniform distribution throughout the year than the use for irrigation. It has been found that for cities the size of those in the Sacramento River Basin, the unit use of water for domestic service alone is practically the same as for irrigation. For industries, the unit use would be somewhat larger but, since the industrial use in this basin is small, no serious error results from also assuming this unit use the same as for irrigation. Uses for navigation and salinity control result in no actual consumption of water but, if they are to be maintained, certain amounts of flow in the streams will be required throughout the year. The use of water for irrigation, therefore, was adopted as the basis for estimating the water requirements of the Sacramento River Basin. Allowances also were made for the additional amounts of water required to maintain flows sufficient for salinity control and navigation.

Present Use of Water for Irrigation.

There are in the Sacramento River Basin at the present time only a few irrigated areas which have storage works from which they obtain a regulated water supply. Some other areas use water supplies which are available from water released from mountain reservoirs operated primarily for power development purposes but most of the present use is from natural stream flow unregulated by any storage. The present use, therefore, varies to a large extent with the amount of stream flow. In years of plentiful water supply, there is a tendency to divert large amounts of water, much of which is in excess of the actual requirements for irrigation and returns to the streams. In years of small run-off, on the other hand, irrigators either take, or are allowed, as small amounts as will serve their needs. Present uses of water, therefore, must be carefully analysed in obtaining irrigation requirements.

During the investigation covered by a previous report,** data were collected on the monthly distribution of the use of water as well as the total seasonal use. Since there is so little regulated flow, present monthly distributions of uses also are affected by the amounts of stream flow and the character of the season. In years of small precipitation, irrigation starts earlier and more water is used in the spring months to increase the moisture content of the soil, both on account of the deficiency caused by short rainfall and in anticipation of a shortage in irrigation supply in later months. It was found, however, that under ordinary conditions the irrigation season in the Sacramento River Basin opens about the first of April and closes in October. The

* Bulletin No. 23, "Report of Sacramento-San Joaquin Water Supervisor for the Period 1924–1928," Division of Water Resources, 1930.

** Bulletin No, 6, "Irrigation Requirements of California Lands," Division of Engineering and Irrigation, 1923.

present monthly distribution is not ideal, except in the few sections where regulated surface supplies are available or the supplies are obtained by pumping from ground water, so that data obtained from present uses must be adjusted by careful analysis to estimate the desirable monthly distribution of the seasonal supply.

Mountain Valleys.—The irrigable areas on the upper Feather River, the Pit River and the Sacramento River above the Pit have been considered in this investigation as the mountain valleys. These lands lie at elevations from 2000 to 5000 feet and the areas now under irrigation are planted almost entirely to hay, grain or forage crops or are used for pasture. Much irrigation is done by wild flooding and the water is used again after returning to the streams. Information collected during the previous investigation shows net uses ranging from 1.25 to two feet, with an average of 1.3 feet. Under present conditions, however, there is a shortage of water in the latter part of the irrigation season over much of these areas and the use is probably not as large as it would be with better regulated supplies.

Foothills Adjacent to Sacramento Valley Floor.—All agricultural lands between the Sacramento Valley floor and an elevation of about 3000 to 4000 feet on both the Sierra Nevada and Coast Range sides of the Sacramento River Basin, except the mountain valleys, are included in the foothill group. Irrigation in this section is briefly described in Chapter IV.

This group of lands is well adapted to the growing of deciduous fruit and at present is planted largely to this crop. There are also some plantings of alfalfa and citrus fruits and some pasture lands are irrigated.

In a previous investigation, quite complete data were collected, and are shown in the report,* on the use of water for irrigation in these foothill areas. The water supply in practically all areas is now ample for all requirements throughout the season so that present uses are very nearly, if not exactly, equivalent to crop needs. These data show net uses ranging from one to 2.5 acre-feet per acre per season with an average for all data obtained of 1.47 acre-feet.

Data for recent years were obtained during the present investigation and are shown in Table 22.

Sacramento Valley Floor.—The Sacramento Valley floor comprises the lands lying between the Sierra Nevada and Coast Range foothills south of Red Bluff and north of the Sacramento-San Joaquin Delta. It actually includes the Sacramento Delta, but since irrigation conditions are considerably different in the delta than in other parts of the valley, the delta area is considered as a separate unit. Irrigation on the valley floor is described in Chapter IV.

In a previous investigation, data were obtained from irrigation districts and individuals on the use of water for irrigation in the Sacramento Valley and these are tabulated in the report.* In only a few instances, however, are the uses given for individual crops, the others being for all crops collectively.

* Bulletin No. 6, "Irrigation Requirements of California Lands," Division of Engineering and Irrigation, 1923.

TABLE 22

PRESENT USE OF WATER FOR IRRIGATION IN FOOTHILL DISTRICTS OF SACRAMENTO RIVER BASIN

Unit	Year	Crop	Area irrigated, in acres	Length of irrigation season, in days	Seasonal allowance in acre-feet per acre		Conveyance loss, in per cent	Method of obtaining water supply	Authority
					Gross	Net			
Browns Valley Irrigation District.	[1]1928	Olives	645	------	------	2.00			L. B. Guerney[2]
		Citrus	82	------	--------	2.00			
		Grapes	470	------	--------	1.50			
		Deciduous fruits	770	------	--------	1.50			
		Field crops	1,980	------	--------	2.00			
		Pasture	3,060	------	--------	2.30			
		Total	7,007	------	--------	2.00	23	(3)	
El Dorado Irrigation District	1929	Deciduous fruits	5,180	120	--------	[4]1.67	------	(3)	R. W. Browne[2]
Oroville-Wyandotte Irrigation District	1929	Olives	381	------	--------	1.86	------	(3)	R. C. Tyler[2]
	1925	Mostly citrus and olives.	4,407	------	--------	1.62	------		
	1926		4,432	------	--------	1.45	------		
	1927		4,507	------	--------	1.70	------		
	1928		4,582	------	--------	1.52	------		
	1929		4,825	------	--------	1.43	------		
Placer County fruit belt.	1921	Practically all in deciduous fruits and vines.	23,940	150	2.16	1.50	31	(3)	Pacific Gas and Electric Company
	1922		26,260	150	2.16	1.50	31		
	1923		26,960	150	2.16	1.50	31		
	1924		26,200	150	2.16	1.50	31		
	1925		25,490	150	2.14	1.50	30		
	1926		26,560	150	2.08	1.50	28		
	1927		26,920	150	2.08	1.50	28		
	1928		27,110	150	2.06	1.50	27		
	1929		27,130	150	2.02	1.50	26		
Francis orchard near Auburn.	1924	Deciduous fruit	65	------	--------	1.30	-----	(6)	(7)
	1925		65	------	--------	[5]1.30	-----		
Taylor orchard near Loomis.	1924	Deciduous fruit	65	------	--------	[8]1.30	------	(6)	(7)
	1925		65	------	--------	[8]1.12	------		

[1] Amounts were about the same for 1925, 1926, 1927 and 1929.
[2] District manager.
[3] By gravity diversion from a stream and canal conveyance.
[4] Measurements of water not very accurate and in some places there are considerable transportation losses beyond the points of measurement.
[5] 13 acre-inches applied, 25 per cent drained off, net application 9.75 acre-inches. Soil moisture deficit of six inches. Net use equal to 9.75 plus 6.0 or about 16 acre-inches or 1.33 acre-feet.
[6] By gravity diversion from a supply canal.
[7] "Some Studies of the Irrigation Requirements of Sacramento Valley Lands," by M. R. Huberty, Assistant Professor of Irrigation Investigations and Practice, University of California. (Not yet published.)
[8] About one-tenth of water applied ran off. Soil moisture deficit amounted to six inches. In 1924, net use equal to .9 of 1.30 plus 0.5 or 1.67 acre-feet. In 1925, net use equal to .9 of 1.12 plus 0.5 or 1.51 acre-feet.

Since 1924, records of the water diverted by gravity and pumped from the main channels in the valley have been obtained each year, during the irrigation season, by the Sacramento-San Joaquin Water Supervisor of the Division of Water Resources. A survey also was made each year to determine the character and acreage of crops grown with the water from each diversion. The crops, however, were divided into only two classes, rice and general, and in only a few instances can the use of water for an individual crop be determined. The data for the years 1924–1928 are given in a report * of the Sacramento-San Joaquin Water Supervisor and data for years since 1928 are available from his office. Uses of water obtained from these data are shown in Table 23.

* Bulletin No. 23, "Report of Sacramento-San Joaquin Water Supervisor for the Period 1924–1928," Division of Water Resources, 1930.

During recent years, experiments were made and data collected for the determination of the irrigation requirements of certain individual crops or types of crops in the Sacramento Valley. The experiments were carried on cooperatively by the Agricultural Experiment Station of the University of California; the Division of Agricultural Engineering, United States Department of Agriculture; and the Division of Water Resources, California Department of Public Works. The uses of water by rice, alfalfa and other crops are given in published bulletins.[1, 2, 3, 4] The results of a five year, 1924–1928, inclusive, study[5] of the use of water by orchards, vineyards and field crops are not yet published but were available for estimating water requirements during this investigation. The conclusions on the water requirements for different crops, drawn from all of the experiments and studies, are presented in the bulletins referred to above. A summary of these conclusions is as follows:

Rice.—The following quotations with reference to the use of water for rice are taken from the bulletin[1] giving the report on the studies of 1914–1919. In these quotations, the term "total depth of water applied" and "net depth" are believed to correspond to the terms "net allowance" and "net use," respectively, as used in this report.

> "In 43 full-season measurements of the amount of water used in rice irrigation in Sacramento Valley, 1914 to 1918, the total depth of water applied ranged from 3.91 to 18.70 feet, and the net depth, after deducting measured or estimated waste, ranged from 3.91 to 13.43 feet."
>
> "In 32 full-season observations on clay and clay adobes of the Willows, Sacramento, Stockton, and Capay series the total depth of water applied ranged from 3.91 to 10.09 feet, the net depth from 3.91 to 9.11 feet, and the average depth from 3.94 to 5.72 feet."
>
> "The average net depth of water applied to 22,404 acres embraced in the 43 full-season observations mentioned, was 4.89 feet. Of this area 21,419 acres was clay or clay adobe of the Willows, Sacramento, Stockton, or Capay series."
>
> "A four-year record of use on 39.5 acres of Stockton clay adobe near Biggs, well prepared and well irrigated, showed a range in depth of water applied of 4.27 to 4.87 feet and an average of 4.53 feet."
>
> "An annual depth of 5 feet of irrigation water for rice is sufficient for the principal rice soils of Sacramento Valley, viz: for the clays and clay adobes of the Willows, Stockton, Sacramento, Capay and Yolo series. Pervious loam soils require an excessive amount of irrigation water, and from a water standpoint are not suitable for rice growing."
>
> "About one-third of the water applied to rice fields is lost by evaporation from the surface of the standing water during submergence. This factor in the duty of water can not be controlled."

The following quotation is taken from the report[3] on later experiments. The term "net duty" in this quotation is believed to correspond to the term "net use" in this report.

> "Studies carried on in 1924 and 1925 show that under the method of continuous submergence the net duty of water for rice should not amount to more than 5 acre-feet to the acre on the clay, clay adobe or adobe soils. On the loam soils the net duty may amount to as much as 8 acre-feet to the acre."

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[1] Bulletin 325, "Rice Irrigation Measurements and Experiments in Sacramento Valley, 1914–1919," Agricultural Experiment Station, University of California, 1920.

[2] Bulletin No. 3, "Investigations of the Economical Duty of Water for Alfalfa in Sacramento Valley, California, 1910–1915," State Department of Engineering, 1917.

[3] Bulletin 454, "Rice Experiments in Sacramento Valley, 1922–1927," Agricultural Experiment Station, University of California, 1928.

[4] Bulletin 450, "Irrigation Investigations With Field Crops at Davis and at Delhi, California, 1909–1925," Agricultural Experiment Station, University of California, 1928.

[5] "Some Studies of the Irrigation Requirements of Sacramento Valley Lands," by M. R. Huberty, Assistant Professor of Irrigation Investigations and Practice and Associate Irrigation Engineer in the Experiment Station, University of California. (Not yet published.)

Grain.—Investigations of the irrigation of wheat, oats and barley were carried on at Davis over a period of eleven years, 1910 to 1921, and some of the conclusions from the report [1] on these investigations are as follows:

"Under Sacramento Valley conditions, with a seasonal rainfall of 17 inches or more, normally distributed, the increases in grain yields do not warrant irrigation."

"Under conditions of extreme rainfall deficiency, such as 1910, 1912, and 1913, two irrigations of four to six acre-inches to the acre should be sufficient to produce normal yields. Under conditions of partial drought, especially where a deficiency of rainfall occurs in the late winter and early spring (March and April), satisfactory yields may be obtained through one irrigation."

Corn and grain sorghum.—Investigations of the irrigation of these crops were started in 1910 and carried through 1915 at Davis. Another experiment was made in 1922. The following conclusions as to the amounts of water required for these crops are taken from the report.[1] In these conclusions, the term "net irrigation requirement" is believed to correspond to the term "net use" in this report.

"On medium soil types and in years of normal rainfall in the Sacramento Valley, the net irrigation requirement for full crop production should not exceed 12 acre-inches per acre, applied in not more than three irrigations."

"In years of deficient rainfall the net seasonal irrigation requirement for these crops should not exceed 18 acre-inches, applied in not more than four irrigations."

Alfalfa.—Investigations of the use of water for the irrigation of alfalfa were made at the University Farm at Davis from 1910 to 1915, inclusive; on 54 Sacramento Valley alfalfa farms near Gridley, Los Molinos, Orland, Willows, Woodland, and Dixon, during 1913 and 1914; and on an experimental tract near Willows in 1915. The following quotations are taken from the report [2] on these investigations. It is believed that the term "water applied" in these quotations corresponds to the term "net allowance" as used in this report.

"Average annual depths of water applied were found to vary from 1.83 feet in the Willows area to 5.15 feet in the Los Molinos area, and on a single field the smallest annual application was 1.04 feet on a clay loam, as compared to 9.59 feet, on a gravelly loam, both of which were at Orland."

"With the exception of the highly permeable Elder gravelly loams at Orland and the very impervious Tehama clays and clay loams at Willows, the results of the work, as a whole, are in agreement with the results of the six-year duty of water study at Davis. These have indicated that a depth of from 30 to 36 inches of water annually is the most desirable quantity of irrigation water to apply under general Sacramento Valley conditions. Total depths of less than 24 inches annually, exclusive of rainfall, are insufficient for satisfactory yields as indicated by the Willows work, while application of depths of 48 or more inches per year do not produce corresponding increases in alfalfa yields."

"Irrigation of alfalfa in Sacramento Valley is confined to the months March to October, inclusive, and in 1913 and 1914 it was confined to the months May to September, inclusive, at Gridley and Willows, and May to October, inclusive, at Los Molinos. Considering the entire six districts in which the investigations were made, the average percentage of the total annual use that was applied in each month of the irrigation seasons of 1913 and 1914 was as follows: March, 5.18; April, 1.75; May, 20.21; June, 18.76; July, 23.40; August, 15.34; September, 13.61; October, 1.75."

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[1] Bulletin 450, "Irrigation Investigations with Field Crops at Davis and at Delhi, California, 1909–1925," Agricultural Experiment Station, University of California, 1928.

[2] Bulletin No. 3, "Investigations of the Economical Duty of Water for Alfalfa in Sacramento Valley, California, 1910–1915," State Department of Engineering, 1917.

The investigations were continued at Davis from 1918 to 1925, inclusive, and the following conclusions are taken from the report[1] covering both these investigations and those of 1910–1915.

"At Davis, the average maximum yield and the average maximum profit were produced with total seasonal application of 36 acre-inches to the acre, but the difference between the yields produced by 30 inches and those produced by 36 inches is so slight that it is not significant; 30 acre-inches per acre, therefore, can be considered an economic seasonal application under the conditions present."

"Total depths of less than 24 inches annually, exclusive of rainfall, are insufficient for satisfactory yields. Application of depths of 48 inches or more annually produce smaller yields than were obtained by applying 36 inches."

"Variation in the number of irrigations (three to twelve), when a total seasonal depth of 30 inches was applied, caused only small differences in yield. The lighter applications given at more frequent intervals tended to produce the higher yields, but the increases in yields did not warrant the extra labor cost and the inconvenience of applying frequent light irrigations. In loam soils, under Sacramento Valley conditions, a total seasonal application of 30 inches applied in four irrigations represents good irrigation practice for alfalfa. Observations in other localities have shown that the very open or very impervious soils should be irrigated more than once between cuttings."

Deciduous orchards.—Investigations for the determination of the use of water for the irrigation of deciduous orchards were made during the seasons 1924 to 1928 in orchards located near Woodland, Winters, Los Molinos, Vina, Chico, Red Bluff and at the University Farm at Davis. The following conclusions are taken from the report[2] covering these investigations.

"Including water stored by rainfall and applied in irrigation, the seasonal use by an orchard of large size and vigor would not be more than 36 acre-inches per acre."

"On the deep soils of light texture three irrigations, totaling 18 inches in depth, will provide available moisture for the average orchard of the valley. Irrigations totaling 24 inches in depth would meet the demands of the large vigorous growing orchards."

"The average mature orchard, growing on deep silt loam soil with the water table at a depth greater than 15 feet below the ground surface, will require a total depth of irrigation of about 18 inches, applied in two irrigations."

Vineyards.—A few investigations of the use of water by grapevines were made at the same time as those for orchards. On two vineyards of four-year-old Thompson seedless grapes, the net use in 1925 on one was 1.08 acre-feet per acre and the net use on the other in 1926 was 1.5 acre-feet per acre.

Data were collected during the investigations covered by this report on the use of water in certain irrigation districts and in areas served by some of the water companies. A summary of these data and those taken from the reports of the Sacramento-San Joaquin Water Supervisor, previously referred to, is presented in Table 23.

Sacramento-San Joaquin Delta.—The consumptive use of water by growing crops and natural vegetation in the Sacramento-San Joaquin Delta is based chiefly upon experiments with growing vegetation in tanks in the area. These experiments were conducted by the United States Department of Agriculture in cooperation with State agencies over a period of six years. The complete report of the uses determined in this way has not been prepared but a summary of the results of the measurements was made especially for this investigation. This sum-

[1] Bulletin 450, "Irrigation Investigations with Field Crops at Davis and at Delhi, California, 1909–1925," Agricultural Experiment Station, University of California, 1928.

[2] "Some Studies on the Irrigation Requirements of Sacramento Valley Lands" by M. R. Huberty, Assistant Professor of Irrigation Investigations and Practice and Associate Irrigation Engineer in the Experiment Station, University of California. (Not yet published.)

mary furnishes what may be considered reasonably close figures on the estimated water consumption by crops, vegetation, and evaporation in the delta. The unit consumptive uses over the entire Sacramento-San Joaquin Delta, as obtained from the summary, are shown in Table 24. These uses represent amounts of water consumed, irrespective of the source, and therefore include amounts consumed from rainfall. However, the greater part of both annual and seasonal consumption occurs in the dry months and hence the source of supply is chiefly from the delta channels. In estimating consumptive uses it was assumed that all vegetation on lands which lie below an elevation of five feet above mean sea level would consume water from the delta channels even though no artificial diversion of water were made for irrigation. This assumption was based upon the fact that the average water level in the delta is about 1.5 feet above mean sea level, reaching higher levels each day, and that the high water table in the islands resulting therefrom affords an opportunity for the vegetation to obtain moisture without artificial diversions.

Ultimate Irrigation Requirements.

In estimating the amounts of water that would be required for irrigation in different parts of the Sacramento River Basin under a condition of ultimate development, estimates were made of the net area of land which could be irrigated in each division, the kinds of crops and the acreage of each that would be grown, and the unit uses of water for each crop.

In making these estimates, the mountain valleys and the foothill areas were considered as one division of the Sacramento River Basin, since the use of water in both of these sections would affect the water supply that would ultimately be available for irrigation use on the valley floor by regulation in the reservoirs of the State Water Plan. The Sacramento Valley floor outside of the delta, was considered as another division since the water for its irrigation would be that regulated by the reservoirs of the State Water Plan. The third division would necessarily be the Sacramento Delta, the only remaining part of the basin. The San Joaquin Delta has been included in this last division also, since the whole Sacramento-San Joaquin Delta would be dependent largely upon the Sacramento River Basin for its water supply under the condition of ultimate development of the Great Central Valley.

In estimating the ultimate irrigation requirements in the Sacramento River Basin, it was assumed that all irrigable land would be furnished eventually with a water supply.

Mountain Valleys and Foothills.—The estimated net irrigable areas in the mountain valleys and foothills are shown in Chapter III to be 312,000 acres and 922,000 acres, respectively.

In the mountain valleys, the land now under irrigation is cropped almost entirely to hay and grain or is used for pasture and, on account of climatic and transportation conditions, it is believed that this character of use will not change materially. The present seasonal net use of water averages about 1.3 acre-feet per acre but, taking into account that there is at present a shortage of water in the latter part of the

TABLE 23

PRESENT USE OF WATER FOR IRRIGATION ON SACRAMENTO VALLEY FLOOR

Unit	Year	Area irrigated, in acres	Seasonal allowance[1], in acre-feet per acre		Conveyance loss, in per cent	Method of obtaining water supply	Authority
			Gross	Net			
Olive Groves							
Berkeley Olive Association	1922 to 1925	500		1.80		(9)	A. L. Chaffin, Superintendent
	1926	500		2.00		(9)	A. L. Chaffin, Superintendent
	1927	500		2.00		(9)	A. L. Chaffin, Superintendent
	1928	500		2.10		(9)	A. L. Chaffin, Superintendent
	1929	500		2.60		(9)	A. L. Chaffin, Superintendent
Average for olive groves				1.99			
Deciduous orchards—							
Clear Lake Water Company	1927	1,159		0.82	50	(8)	Clear Lake Water Company
	1928	1,490		1.02	50	(8)	Clear Lake Water Company
Elkhorn Mutual Water Company	1927	354		1.74	47	(7)	L. E. Spangler, Superintendent
	1928	384		1.54	55	(7)	L. E. Spangler, Superintendent
	1929	287		1.26	53	(7)	L. E. Spangler, Superintendent
Sutter Mutual Water Company	1928	3,204		1.10		(7)	Rex Lundberg, Superintendent
North Fork Ditch Company	1929	[2]1,980		1.21		(8)	L. K. Jordan, Manager
Hearst Estate	1927	400		1.50		(7)	Sacramento-San Joaquin Water Supervisor
	1928	400		1.80		(7)	Sacramento-San Joaquin Water Supervisor
	1929	400		1.95		(7)	Sacramento-San Joaquin Water Supervisor
Hayward Reed	1927	[3]290		2.43		(7)	Sacramento-San Joaquin Water Supervisor
	1928	[3]335		1.83		(7)	Sacramento-San Joaquin Water Supervisor
	1929	[3]325		5.19		(7)	Sacramento-San Joaquin Water Supervisor
El Dorado Ranch	1927	[4]621		3.33		(7)	Sacramento-San Joaquin Water Supervisor
	1928	[4]572		3.39		(7)	Sacramento-San Joaquin Water Supervisor
	1929	[4]555		3.81		(7)	Sacramento-San Joaquin Water Supervisor
I. G. Zumwalt	1927	[4]285		0.71		(7)	Sacramento-San Joaquin Water Supervisor
	1928	[4]250		1.60		(7)	Sacramento-San Joaquin Water Supervisor
	1929	[4]250		2.14		(7)	Sacramento-San Joaquin Water Supervisor
A. F. and R. C. Wohlfrom	1927	[4]147		2.29		(7)	Sacramento-San Joaquin Water Supervisor
	1928	[4]147		3.15		(7)	Sacramento-San Joaquin Water Supervisor
	1929	[4]147		2.09		(7)	Sacramento-San Joaquin Water Supervisor
St. Johns Park Company	1927	[4]166		2.48		(7)	Sacramento-San Joaquin Water Supervisor
	1928	[4]166		2.07		(7)	Sacramento-San Joaquin Water Supervisor
	1929	[4]166		3.29		(7)	Sacramento-San Joaquin Water Supervisor
G. C. Shannon	1927	66		1.65		(7)	Sacramento-San Joaquin Water Supervisor
	1928	80		1.88		(7)	Sacramento-San Joaquin Water Supervisor
	1929	84		1.38		(7)	Sacramento-San Joaquin Water Supervisor
Average for deciduous orchards				1.71			

Alfalfa and Sudan grass—							
Clear Lake Water Company	1927	8,346		2.36	About50	(8)	Clear Lake Water Company
	1928	8,104		2.73	About 50	(8)	Clear Lake Water Company
Sutter Mutual Water Company	1926	(6)		2.5	About 34	(7)	Rex Lundberg, Superintendent
	1927	(6)		3.6	About 31	(7)	Rex Lundberg, Superintendent
	1928	381		2.6	About 33	(7)	Rex Lundberg, Superintendent
A. and M. Marty	1927	400		2.27		(7)	Sacramento-San Joaquin Water Supervisor
	1928	400		2.55		(7)	Sacramento-San Joaquin Water Supervisor
	1929	385		3.49		(7)	Sacramento-San Joaquin Water Supervisor
A. A. Sousa	1927	280		1.91		(7)	Sacramento-San Joaquin Water Supervisor
	1928	300		2.46		(7)	Sacramento-San Joaquin Water Supervisor
	1929	340		3.82		(7)	Sacramento-San Joaquin Water Supervisor
J. L. Browning	1927	240		3.50		(7)	Sacramento-San Joaquin Water Supervisor
	1928	240		2.63		(7)	Sacramento-San Joaquin Water Supervisor
	1929	520		2.86		(7)	Sacramento-San Joaquin Water Supervisor
California Joint Stock Land Bank	1927	273		3.89		(7)	Sacramento-San Joaquin Water Supervisor
	1928	359		3.10		(7)	Sacramento-San Joaquin Water Supervisor
	1929	370		3.52		(7)	Sacramento-San Joaquin Water Supervisor
Average for alfalfa and Sudan grass				2.57			
Truck crops—							
Elkhorn Mutual Water Company	1927	919		1.47	47	(7)	L. E. Spangler, Superintendent
	1928	915		1.20	55	(7)	L. E. Spangler, Superintendent
	1929	827		1.85	53	(7)	L. E. Spangler, Superintendent
Natomas Central Mutual Water Company	1927	102		1.25	26	(7)	L. E. Spangler, Superintendent
	1928	127		1.46	29	(7)	L. E. Spangler, Superintendent
	1929	257		1.90	39	(7)	L. E. Spangler, Superintendent
Natomas Riverside Mutual Water Company	1928	440		1.15	59	(7)	L. E. Spangler, Superintendent
	1929	205		1.52	63	(7)	L. E. Spangler, Superintendent
Sutter Mutual Water Company	1929	4,307		2.12	33	(7)	Company records.
Stanford-Vina Ranch	1926	200		1.97		(8)	H. V. Burnett, Superintendent
Reese and Greer	1927	[6]275		1.83		(7)	Sacramento-San Joaquin Water Supervisor
	1928	[6]275		1.96		(7)	Sacramento-San Joaquin Water Supervisor
	1929	[6]265		3.05		(7)	Sacramento-San Joaquin Water Supervisor
Pollock Ranch	1929	921		2.52		(7)	Sacramento-San Joaquin Water Supervisor
Average for truck crops				1.92			
Rice—							
Northern Mutual Water Company	1926	1,990	7.33	6.03	17.8	(7)	L. E. Spangler, Superintendent
	1927	1,613	8.71	7.23	17.0	(7)	L. E. Spangler, Superintendent
	1928	1,693	8.55	6.77	21.0	(7)	L. E. Spangler, Superintendent
	1929	2,101	7.87	6.15	21.8	(7)	L. E. Spangler, Superintendent
Western Canal Company	1924	7,251	9.10	5.65	37.8	(8)	H. F. Cauthard, Manager
	1925	9,153	8.10	5.46	32.4	(8)	H. F. Cauthard, Manager
	1926	11,635	9.20	6.80	25.7	(8)	H. F. Cauthard, Manager
	1927	11,902	7.65	6.67	12.8	(8)	H. F. Cauthard, Manager
	1928	9,821	8.00	6.10	24.1	(8)	H. F. Cauthard, Manager
	1929	6,862		6.56		(8)	Sacramento-San Joaquin Water Supervisor
Sebia Davis	1927	1,570		4.50		(7)	Sacramento-San Joaquin Water Supervisor
	1928	1,180		4.99		(7)	Sacramento-San Joaquin Water Supervisor

TABLE 23—Continued

PRESENT USE OF WATER FOR IRRIGATION ON SACRAMENTO VALLEY FLOOR

Unit	Year	Area irrigated, in acres	Seasonal allowance[1], in acre-feet per acre		Conveyance loss, in per cent	Method of obtaining water supply	Authority
			Gross	Net			
Rice—Continued							
River Farms Company	1928	2,945	----	10.14	----	(7)	Sacramento-San Joaquin Water Supervisor
Jameson and Rosenfelds	1927	260	----	9.47	----	(7)	Sacramento-San Joaquin Water Supervisor
Helphenstine and Rush	1927	290	----	8.70	----	(7)	Sacramento-San Joaquin Water Supervisor
Hattie O'Hair	1927	110	----	8.20	----	(7)	Sacramento-San Joaquin Water Suprevisor
Tuttle Land Company	1927	240	----	5.67	----	(7)	Sacramento-San Joaquin Water Supervisor
Conaway Ranch	1929	1,959	8.30	----	----	(7)	Sacramento-San Joaquin Water Supervisor
Sutter Mutual Water Company	1928	8,441	----	9.50	----	(7)	Company records
	1929	5,660	----	9.70	----	(7)	Company records
Average for rice	----	----	----	6.94	----	----	----

[1] "Allowance" refers to use of this term as defined at beginning of chapter. Amounts shown in these columns are actual diversions and applications.
[2] Some citrus area included; does not include area served by districts which buy water wholesale.
[3] All in pears.
[4] All in prunes.
[5] Acreage not available; assumed same as in 1928 for calculation of average.
[6] All in beets.
[7] Diversion by pumping from stream channel or borrow pit.
[8] Diversion by gravity from stream channel.
Diversion by gravity from canal.

TABLE 24

PRESENT UNIT CONSUMPTIVE USES OF WATER IN SACRAMENTO-SAN JOAQUIN DELTA

Crop or water-using agency	Consumption in acre-feet per acre													
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total seasonal, April-Oct.	Total annual
Alfalfa[3]	[1](.06)	(.08)	.10	.30	.40	.50	.65	.55	.50	.20	(.10)	(.07)	3.10	3.51
Asparagus[4]	.05	.05	.05	.05	.08	.14	.40	.68	.55	.42	.12	.10	2.32	2.69
Beans[4]	(.06)	(.08)	(.08)	(.16)	(.20)	.14	.24	.58	.37	(.09)	(.07)	(.05)	1.78	2.12
Beets[4]	(.06)	(.08)	(.08)	.13	.32	.51	[2].61	[2].53	[2].20	(.13)	(.10)	(.07)	2.43	2.82
Celery[4]	(.04)	(.04)	(.04)	(.08)	(.10)	.10	.10	.20	.25	.30	.20	.05	1.13	1.50
Corn[4]	(.04)	(.04)	(.04	(.08)	(.10)	.24	.85	[2].84	[2].40	.10	(.10)	(.07)	2.61	2.90
Orchard[3]	(.04)	(.04)	(.04)	.18	.32	.50	.57	.40	.23	.07	(.07)	(.05)	2.27	2.51
Grain and hay[4]	(.04)	(.04)	.07	.60	.83	.20	(.14)	(.23)	(.21)	(.14)	(.07)	(.05)	2.35	2.62
Onions[4]	(.04)	(.04)	.08	.13	.27	.49	.43	.20	(.16)	(.13)	(.10)	(.07)	1.81	2.14
Pasture[5]	.08	.10	.20	.25	.25	.25	.25	.25	.20	.15	.10	.08	1.60	2.16
Potatoes[4]	(.06)	(.08)	(.08)	(.16)	.15	.38	.52	.30	.15	(.09)	(.07)	(.05)	1.75	2.09
Seed[6]	(.06)	(.08)	(.08)	.10	.25	.50	.50	.50	.35	.10	(.10)	(.07)	2.30	2.69
Other vegetables[6]	(.06)	(.08)	.10	.10	.25	.50	.45	.45	.30	.15	.10	(.07)	2.20	2.61
Average for irrigated crops	.05	.06	.07	.23	.33	.27	.42	.50	.34	.19	.09	.07	2.28	2.62
Willows[7]	.05	.03	.09	.22	.33	.38	.46	.40	.35	.29	.18	.10	2.43	2.88
Tules[6]	.16	.09	.30	.74	1.10	1.28	1.53	1.32	1.18	.98	.59	.36	8.13	9.63
Average idle land with weeds, below elevation 5.0 feet, U.S.G.S. datum[5]	.06	.08	.08	.16	.20	.26	.28	.24	.16	.13	.10	.07	1.43	1.82
Idle land above elevation 5.0 feet, U. S. G. S. datum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Open water surfaces[6]	.08	.13	.23	.34	.60	.76	.84	.78	.60	.33	.14	.08	4.25	4.91

[1] Figures in parentheses represent consumptive use on cropped areas before planting and after harvest, or during the dormant season.
[2] Includes additional use of water by weeds during these months.
[3] From experiments in adjacent areas.
[4] From recent cooperative experiments in Sacramento-San Joaquin Delta by Division of Water Resources and United States Department of Agriculture.
[5] Estimated by United States Department of Agriculture by comparison with similar crops.
[6] From data of recent cooperative experiments and other agencies, modified by Charles H. Lee.
[7] From data of recent cooperative experiments and other agencies, modified by Charles H. Lee. Use based upon willows in large groves with an additional 10 per cent for isolated trees.

season over much of the area and that the net use would increase with regulated supplies, it was estimated that the average ultimate seasonal net use over the entire area would be 1.8 acre-feet per acre.

The foothill areas, as previously stated, are well adapted to the growing of deciduous fruits and are now largely planted to these crops. The data previously presented show that the net use of water for all irrigation in the foothills, for several years prior to 1922, averaged 1.47 acre-feet per acre. More recent data show that the net use of water for the irrigation of deciduous orchards ranged from about 1.3 to 1.5 acre-feet per acre. It is believed that as the area is further developed, there will not be much change in the relative proportion of crops now grown and that deciduous fruits will predominate. It therefore was estimated that a water supply for a net use of 1.5 acre-feet per acre over the entire net irrigable area will be ample.

Although conveyance channels in the mountain valleys and foothills would not be excessively long they would be, in general, on side hills and would have relatively high percolation losses. Also, the tracts irrigated would have considerable slope and much of the water applied would run off. In estimating the gross allowances in these areas, therefore, it was assumed that the net uses would be 60 per cent of the gross allowances or diversions and that 40 per cent of the gross allowances would be return water.

The estimated monthly distributions of the seasonal uses of irrigation water in the mountain valleys and foothill areas, respectively, in per cents of the seasonal totals, are as follows:

Month	*Upper Sacramento River, Pit River and upper Feather River mountain valleys*	*Other mountain and foothill areas*
January	0	0
February	0	0
March	0	2
April	3	2
May	14	15
June	24	20
July	26	22
August	21	20
September	12	13
October	0	5
November	0	1
December	0	0

Based on the above methods of estimating, the ultimate seasonal gross allowances and net uses of water for the net irrigable areas in the mountain and foothill portions of the drainage basin of each of the major streams of the Sacramento River Basin, and in the lower foothill areas lying between these watersheds but above the valley floor, would be as shown in Table 25. This table also shows the estimated gross area of agricultural land and the net irrigable area in each watershed.

Sacramento Valley Floor Outside of Sacramento Delta.—This portion of the basin includes all lands lying south of Red Bluff and between the foothills of the Sierra Nevada and Coast Range, except the delta area, which it would be possible to serve with water regulated by the major reservoir units of the State Water Plan in the Sacramento River Basin, including the Trinity River diversion, described in Chapter IX.

TABLE 25

ULTIMATE SEASONAL WATER REQUIREMENTS OF IRRIGABLE LANDS IN MOUNTAIN AND FOOTHILL AREAS OF SACRAMENTO RIVER BASIN

Watershed	Gross agricultural area, in acres	Net irrigable area, in acres	Gross allowance, in acre-feet	Net use, in acre-feet
Sacramento River above Red Bluff	883,000	525,000	1,443,000	866,000
Between Sacramento and Feather rivers	112,000	46,000	115,000	69,000
Feather River above Oroville	225,000	90,000	250,000	150,000
Between Feather and Yuba rivers	164,000	82,500	206,000	124,000
Yuba River above The Narrows	157,000	82,000	205,000	123,000
Between Yuba and Bear rivers	62,000	24,000	60,000	36,000
Bear River above Camp Far West Dam	128,000	72,500	182,000	109,000
Between Bear and American rivers	147,000	91,000	227,000	136,000
American River above Folsom	316,000	119,000	298,000	179,000
Between Sacramento River and Stony Creek	140,000	58,000	145,000	87,000
Stony Creek above Millsite dam site	42,000	13,500	33,000	20,000
Putah Creek above Yolo County line	139,000	30,500	77,000	46,000
Totals	2,515,000	1,234,000	3,241,000	1,945,000

Since only about 21 per cent of the irrigable lands on the valley floor are now under irrigation, and since the proportion of the total area of the valley that would be planted to each crop under a condition of ultimate development would be considerably different than under present conditions, an estimate was made of the kinds of crops and the percentage of the total area that would be planted to each kind, in different sections of the valley. To do this, the valley floor was divided into fifteen "crop groups" in each of which it is estimated that a certain percentage of the area would be used for each of the crops or uses shown in Table 26, under conditions of ultimate development. The area to be included in each group was determined by some predominating characteristics of soils, climatological conditions and present use for crops. The soil conditions and present use for crops were determined by the field surveys previously described in Chapter III. The percentage and area of the total irrigable lands which it was estimated, from a combination of the areas from all the crop groups, would be used ultimately, each year, for each class of crops or other use requiring water, are shown in Table 26.

TABLE 26

AREAS OF CROPS AND GUN CLUBS EACH YEAR IN THE SACRAMENTO VALLEY UNDER CONDITIONS OF ULTIMATE DEVELOPMENT

Crop or use	Ultimate area	
	In per cent of total irrigable area	In acres
Citrus orchards	2.0	52,800
Olive orchards	1.0	26,400
Deciduous orchards	20.0	528,000
Vines	7.5	198,000
Grain	10.0	264,000
Alfalfa and sudan grass	20.0	528,000
Field crops	9.5	250,800
Pasture	6.5	171,600
Truck crops	10.5	277,200
Rice	10.0	264,000
Gun clubs	3.0	79,200
Totals	100.0	2,640,000

The unit net allowance and net use of water for the irrigation of each of the crops shown in Table 26 were estimated from the data on present uses previously referred to or given in this chapter. In fixing these unit uses, the opinions of consultants having considerable experience in irrigation matters in the Sacramento Valley also were obtained. The aim was to allow a liberal but not an excessive use for each crop.

In the ultimate irrigation of the Sacramento Valley, the water for the irrigation of most of the lands will have to be conveyed relatively long distances, whether the conveyance be by natural or artificial channels. Conveyance losses, therefore, will be large and these were taken into consideration in fixing the gross allowances, or amounts of water to be drawn from the major reservoir units of the State Water Plan. For all crops or uses, a conveyance loss of one-third was allowed as this corresponds very well with present loses on large irrigation systems. This percentage of loss is probably liberal as, under conditions of ultimate irrigation development, most artificial channels probably will be lined.

The use of water for flooding ponds for gun clubs was obtained from consultants having experience with furnishing water for this purpose.

The unit gross and net allowances and net uses of water for the different crops and for gun clubs are shown in Table 27.

TABLE 27

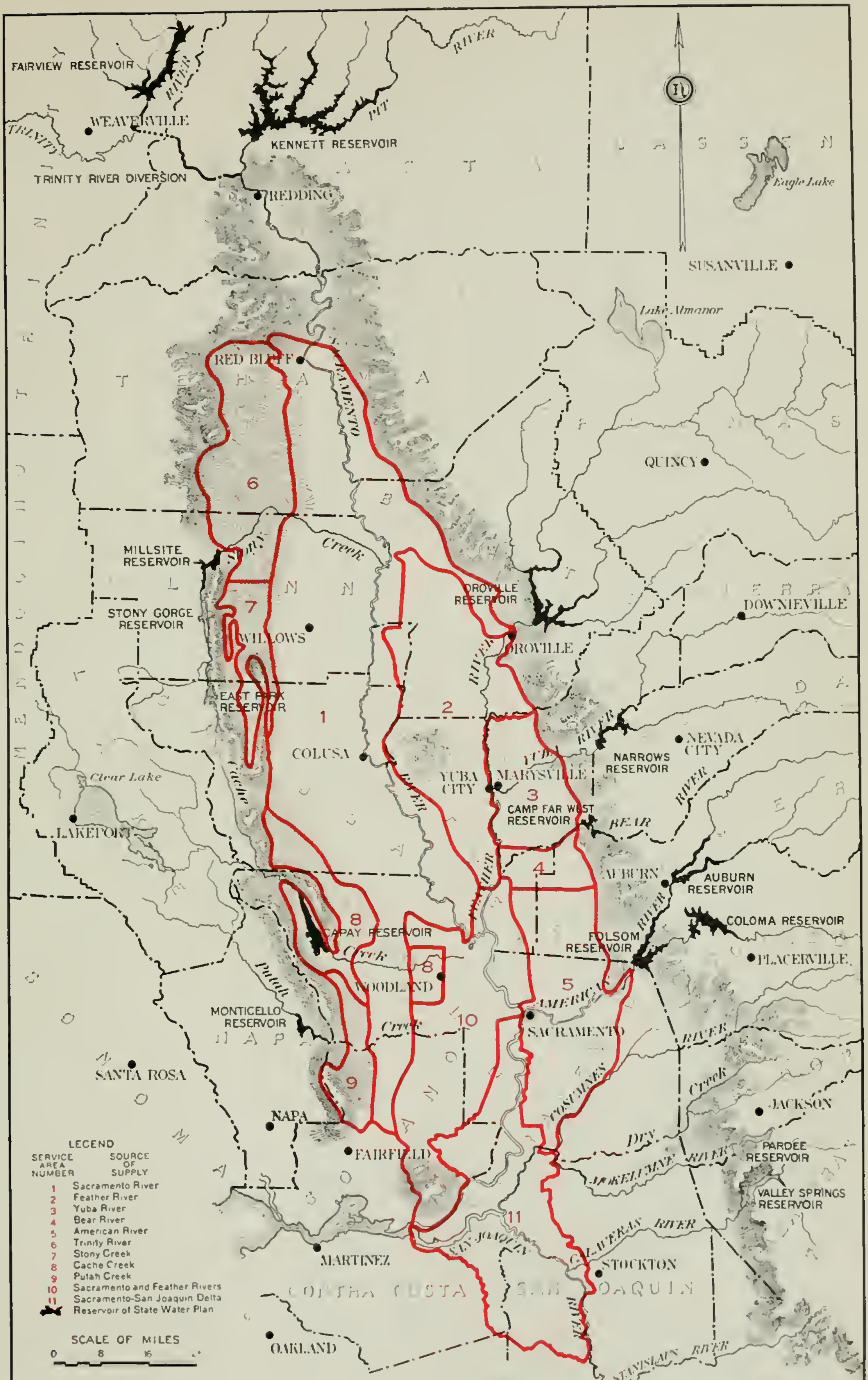
UNIT ALLOWANCES AND USES OF WATER IN SACRAMENTO VALLEY UNDER CONDITIONS OF ULTIMATE DEVELOPMENT

Water used for	Acre-feet per acre per season		
	Allowance		Net use
	Gross	Net	
Citrus orchards	3.75	2.50	2.12
Olive orchards	3.00	2.00	1.60
Deciduous orchards	2.63	1.75	1.59
Vines, general	2.25	1.50	1.32
Vines, on shallow soils	2.63	1.75	1.34
Grain	1.50	1.00	0.80
Alfalfa and sudan grass—general	4.50	3.00	2.65
Alfalfa and sudan grass—on gravelly soil	7.50	5.00	2.75
Field crops	2.63	1.75	1.59
Pasture	1.88	1.25	0.82
Truck crops	3.00	2.00	1.85
Rice	9.00	6.00	5.05
Gun clubs	2.25	1.50	1.07

The estimated monthly distribution of the seasonal uses of irrigation water on the Sacramento Valley floor, in per cents of the seasonal total, is as follows:

January	0	May	16	September	12
February	0	June	20	October	4
March	1	July	22	November	0
April	5	August	20	December	0

For purposes of estimating the amount of water required on the Sacramento Valley floor, from each stream, and the possibility of obtaining an adequate supply from the stream, the entire valley floor area was divided into "water service areas." The land in each area



WATER SERVICE AREAS IN THE SACRAMENTO VALLEY

is physically feasible of irrigation from the stream to which it was allotted. To supply water to all of the land in these areas by gravity, canals, constructed at elevations as high as water could be diverted below the major reservoir units of the State Water Plan on the streams, would be necessary for conveying water along the rims of the valley. Some lands would be irrigated by direct diversion and pumping from the streams and artificial channels as at present. These "water service areas" are shown on Plate VI, "Water Service Areas in the Sacramento Valley." The area indicated as "Sacramento-Feather" is one which could obtain its water supply from a combination of the flows of the Sacramento and Feather rivers.

The ultimate amount of water required in each "water service area" was estimated in the following manner: The average water allowances in acre-feet per acre per season in each "crop group" were estimated by multiplying the unit allowances for each crop by the percentage of that crop of the total of all crops in the group and dividing the sum by 100. The average unit net use was estimated in the same manner. The net irrigable areas were estimated by means of the "zones" described in Chapter III, in each of which a certain percentage of each of the four classes of agricultural land is estimated to be irrigable. By superimposing the service areas, zones, and crop groups, the net irrigable area in that portion of each crop group within the boundary of the service area and the amount of water required for that group or portion of it were estimated. The summation of all of these requirements by groups within the service area gave the total water requirement for the area.

Table 28 gives the areas and water allowances and uses under the condition of ultimate development, for each of the water service areas in the Sacramento Valley.

TABLE 28

ULTIMATE SEASONAL WATER REQUIREMENTS OF IRRIGABLE LANDS IN SACRAMENTO VALLEY

Water service area	Gross agricultural area, in acres	Net irrigable area, in acres	Allowances, in acre-feet		Net use, in acre-feet
			Gross	Net	
Sacramento River	1,419,000	1,131,000	4,172,000	2,783,000	2,395,000
Feather River	450,000	358,000	1,395,000	931,000	797,000
Yuba River	169,000	134,000	465,000	310,000	270,000
Bear River	66,000	55,000	187,000	125,000	109,000
American River	316,000	254,000	765,000	510,000	439,000
Trinity River	309,000	171,000	444,000	296,000	252,000
Stony Creek	90,000	33,000	86,000	58,000	48,000
Cache Creek	168,000	110,000	301,000	200,000	173,000
Putah Creek	59,000	36,000	92,000	62,000	54,000
Sacramento-Feather	453,000	358,000	1,126,000	750,000	653,000
Total Sacramento Valley	3,499,000	2,640,000	9,033,000	6,025,000	5,190,000

Sacramento-San Joaquin Delta.—The ultimate uses of water in the Sacramento-San Joaquin Delta were estimated directly from present uses. The present unit consumptive uses in the delta are shown in Table 24.

Because of the method of irrigation in the delta, it is a difficult matter to differentiate between gross allowance, net allowance and net use. Much of the land is below the level of the water surfaces in the channels adjacent to or surrounding the various islands or tracts and on account of the character of the soil is naturally subirrigated. Irrigation is accomplished mainly with water diverted by siphons or gates from the surrounding channels. For the higher lands, water is diverted by pumping. The tracts are relatively small so that the source of supply is located almost at the point of use and no long conveyance canals are required.

The general method of irrigation on the lower delta lands is to use the same ditches for irrigation that are used for draining the lands and controlling elevations of the water table. The main ditches are filled and water therefrom is diverted to the fields through ditches about ten inches wide and eighteen inches deep spaced from 70 to 200 feet apart. Water is held in these ditches at certain depths below the ground surface and allowed to seep into the adjoining fields which are thereby subirrigated. The water level under the fields is regulated by raising and lowering the level of the water in the ditches by means of the irrigation inlets and drainage pumps. On the higher lands in the delta area, the usual methods of surface irrigation are used. On lands adjacent to the channels and those on which deep-rooted crops are grown, natural seepage water contributes materially to the moisture consumed by the crops and natural vegetation. Any diverted water which is not consumed is returned to the main channels and is available for immediate reuse. Therefore, taking the delta area as a unit, the gross allowance, net allowance and net use are practically the same and all are actually the consumptive use. The consumptive use in the delta includes not only the use for growing crops but evaporation from the large areas of water surface in the channels, transpiration from tules and other natural vegetation, and evaporation from levees and uncultivated land surfaces.

In estimating the ultimate use of water in the delta, it was assumed that lands now idle would be planted to the same crops that are now grown in the delta in the same proportions as under present conditions. It also was assumed that the unit consumptive uses of water would be the same as are shown in Table 24. Although the uses shown in Table 24 cover the entire year, it was estimated that only those from April to October, inclusive, need be considered as being drawn from stream flow since rainfall would normally care for the uses and losses during the winter months.

Table 29 gives the estimated ultimate consumptive uses of water in the Sacramento-San Joaquin Delta by months, and for the irrigation season and the calendar year. The total seasonal use of 1,200,000 acre-feet in the entire delta would be divided approximately 376,000 acre-feet in the Sacramento Delta and 824,000 acre-feet in the San Joaquin Delta.

Total Ultimate Irrigation Requirements for Sacramento River Basin.—The total estimated seasonal water requirements for the irrigation of all irrigable lands in the Sacramento River Basin, including the entire Sacramento-San Joaquin Delta, are given in Table 30. In this table the requirements are shown separately for the mountain valleys, the foothills, the valley floor and the delta.

TABLE 29

ULTIMATE CONSUMPTIVE USE OF WATER IN SACRAMENTO-SAN JOAQUIN DELTA

Crop or water-using agency	Ultimate area in acres	Consumptive use, in acre-feet													
		Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total seasonal April-Oct.	Total annual
Alfalfa	29,800	[1](1,800)	(2,400)	3,000	8,900	11,900	14,900	19,400	16,400	14,900	6,000	(3,000)	(2,100)	92,400	104,700
Asparagus	76,200	3,800	3,800	3,800	3,800	6,100	10,700	30,500	51,800	41,900	32,000	9,100	7,600	176,800	204,900
Beans	39,600	(2,400)	(3,200)	(3,200)	(6,300)	(7,900)	5,500	9,500	23,000	14,700	(3,600)	(2,800)	(2,000)	70,500	84,100
Beets	22,400	(1,300)	(1,800)	(1,800)	2,900	7,200	11,400	[2]13,600	[2]11,900	[2]4,500	(2,900)	(2,200)	(1,600)	54,400	63,100
Celery	10,600	(400)	(400)	(400)	(800)	(1,100)	1,100	1,100	2,100	2,600	3,200	2,100	500	12,000	15,800
Corn	49,800	(2,000)	(2,000)	(2,000)	(4,000)	(5,000)	12,000	42,300	[2]41,800	[2]19,900	5,000	(5,000)	(3,500)	130,000	144,500
Orchard	18,200	(700)	(700)	(700)	3,300	5,800	9,100	10,300	7,300	4,200	1,300	(1,300)	(900)	41,300	45,600
Grain and hay	85,400	(3,400)	(3,400)	6,000	51,200	70,900	17,100	(12,000)	(19,600)	(17,900)	(12,000)	(6,000)	(4,300)	200,700	223,800
Onions	5,200	(200)	(200)	400	700	1,400	2,600	2,200	1,000	(800)	(700)	(500)	(400)	9,400	11,100
Pasture	11,500	900	1,100	2,300	2,900	2,900	2,900	2,900	2,900	2,200	1,700	1,100	900	18,400	24,700
Potatoes	22,100	(1,300)	(1,800)	(1,800)	(3,500)	3,300	8,400	11,600	6,600	3,300	(2,000)	(1,500)	(1,100)	38,700	46,200
Seed	11,800	(700)	(900)	(900)	1,200	2,900	5,900	5,900	5,900	4,100	1,200	(1,200)	(800)	27,100	31,600
Other vegetables	9,400	(600)	(700)	1,000	1,000	2,400	4,700	4,200	4,200	2,800	1,400	900	(700)	20,700	24,600
Totals for irrigated crops	392,000	19,500	22,400	27,300	90,500	128,800	106,300	165,500	194,500	133,800	73,000	36,700	26,400	892,400	1,024,700
Willows	5,600	300	200	500	1,200	1,900	2,100	2,600	2,200	2,000	1,600	1,000	600	13,600	16,200
Tules	7,400	1,200	600	2,200	5,500	8,100	9,500	11,300	9,800	8,700	7,300	4,400	2,700	60,200	71,300
Idle land with weeds and brush below elevation 5.0 feet, U.S.G.S. datum	5,400	300	400	400	800	1,100	1,400	1,500	1,300	900	700	500	400	7,700	9,700
Non-irrigated crops and idle land above elevation 5.0 feet, U.S.G.S. datum	23,900	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Open water surface	53,200	4,300	6,900	12,200	18,100	31,900	40,400	44,700	41,500	31,900	17,600	7,400	4,300	226,100	261,200
Totals for entire delta	487,500	25,600	30,500	42,600	116,100	171,800	159,700	225,600	249,300	177,300	100.200	50,000	34,400	1,200,000	1,383,100

[1] Figures in parentheses represent consumptive use on cropped areas before planting and after harvest, or during the dormant season.
[2] Includes additional use of water by weeds during these months.

TABLE 30

ULTIMATE SEASONAL WATER REQUIREMENTS OF IRRIGABLE LANDS IN THE SACRAMENTO RIVER BASIN AND THE ENTIRE SACRAMENTO-SAN JOAQUIN DELTA

Section	Net irrigable area, in acres	Gross allowance, in acre-feet		Net allowance, in acre-feet		Net use, in acre-feet	
		Total	Average per acre	Total	Average per acre	Total	Average per acre
Mountain valleys	312,000	936,000	3.00	562,000	1.80	562,000	1.80
Foothill areas	922,000	2,305,000	2.50	1,383,000	1.50	1,383,000	1.50
Valley floor	2,640,000	9,033,000	3.42	6,025,000	2.28	5,190,000	1.97
Sacramento Delta	135,000	376,000	(1)	376,000	(1)	376,000	(1)
San Joaquin Delta	257,000	824,000	(1)	824,000	(1)	824,000	(1)
Totals	4,266,000	13,474,000		9,170,000		8,335,000	

[1] Value for net use per unit of area is not given since ultimate total requirements and use are divided among irrigation use, evaporation from delta channels, transpiration from tules and other natural vegetation and evaporation from levees and uncultivated land surfaces.

In obtaining the allowances and uses shown in Table 30, it was assumed that every acre of irrigable land in the Sacramento River Basin would be irrigated every year. The amounts in the table, therefore, should be maxima. It is not believed, however, that there will ever be such a complete use since, even with ultimate irrigation development, some land must be fallowed each year. This is particularly true of land used for rice culture which must be allowed to remain idle or be dry farmed on an average of about every fourth year. Therefore, about one-third as much rice land would not be irrigated each year as is planted. Water also was allowed for the irrigation of all grain each year but it has been found uneconomical to irrigate grain in years of ample rainfall. Grain, therefore, would require irrigation water in dry years only. Also, since irrigation of grain is so seldom needed, many fields would not be provided with irrigation facilities and would never be irrigated. It also is likely that all pasture land would not be irrigated every year and that some of the other crops for which an irrigation allowance was made would be dry farmed. While such deductions would cause considerably less use of water than is indicated by Table 30, the amounts shown in this table were used as the Sacramento River Basin requirements in all studies made during this investigation.

Endurable Deficiencies in Irrigation Supplies.

The foregoing ultimate seasonal water requirements for the irrigable lands in the Sacramento River Basin are those which would be needed for a supply without deficiency in any part of the basin. Experience and investigations show, however, that plants and trees can endure an occasional deficiency in supply without permanent damage to the perennials and in many instances without material decrease in the annual crop yield. In general, however, there is a reduction in crop production with inadequate irrigation supplies.

A full irrigation supply furnishes water not only for the consumptive use of the plant but also for evaporation from the surface during application and from the moist ground surface, and for water which is lost through percolation to depths beyond the reach of the plant roots. Less water can be used in years of deficiency in supply by careful application and by more thorough cultivation to conserve the ground moisture. In these ways the plant can be furnished its full consumptive use with much smaller amounts of water than those ordinarily applied and the yield will not be decreased. If the supply is too deficient to provide the full consumptive use, the plant can sustain life on smaller amounts but the crop yield will probably be less than normal.

It is believed from a study of such data as are available that a maximum deficiency of 35 per cent of the full seasonal requirement can be endured, if the deficiency occurs only at relatively long intervals. It is also believed that small deficiencies occurring at relatively frequent intervals can be endured. Therefore, it has been assumed in the studies for this bulletin that the estimated seasonal irrigation yield of any reservoir could have a maximum deficiency of not more than 35 per cent and that the average seasonal deficiency over the 40-year period 1889–1929 used in the studies, should be not greater than two per cent.

Requirements for Salinity Control.

In addition to the consumptive uses in the Sacramento-San Joaquin Delta shown in Table 29, water also will be required to prevent the invasion of saline water into the delta channels. Two methods of salinity control were studied. One of these would be to construct a barrier somewhere below the confluence of the Sacramento and San Joaquin rivers and the other would be to maintain sufficient fresh water flow into Suisun Bay to repel the effect of tidal action in advancing salinity. It was concluded * from studies made during the investigations of 1929–1930 that a salt water barrier at any of the three best sites for such a structure is not necessary or economically justified as a unit of the State Water Plan. It also was concluded from the same studies that the control of saline invasion, so that water supplies now or hereafter made available in the delta from the Sacramento and San Joaquin rivers could be maintained fresh and utilized for all purposes in the upper bay and delta region, could be provided without a barrier by means of fresh water releases from mountain storage reservoirs to supplement available stream flow.

Other studies ** made during the investigation show that the practical degree of control by means of stream flow would be a control at Antioch sufficient to limit the increase of salinity at that point to a mean degree of not more than 100 parts of chlorine per 100,000 parts of water with decreasing salinity upstream. The same studies show that in order to effect a positive control of salinity at Antioch to this desired degree, a flow of 3300 second-feet throughout the year, in the combined channels of the Sacramento and San Joaquin rivers, past Antioch into Suisun Bay would be required. This would amount to an average annual flow of about 2,390,000 acre-feet into the bay. Of this amount 800,000 acre-feet should pass through the channels in the Sacramento Delta and 1,590,000 acre-feet through the San Joaquin Delta channels.

* Bulletin No. 28, "Economic Aspects of a Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers," Division of Water Resources, 1931.

** Bulletin No. 27, "Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay," Division of Water Resources, 1931.

Requirements for Navigation.

It is pointed out in Chapter VII that the improvement of the upper Sacramento River for navigation could be effected by either of two methods. One would be to secure the necessary navigable depths by the installation of dams across the channel to form pools. Locks would be incorporated into these dams to provide for the passage of vessels from each pool to the adjacent one. This method is termed "canalization." The other method would be to supplement the natural stream flow by the release of water stored in upstream reservoirs in amount sufficient to provide the required navigable depths. This method has been termed "stream-flow regulation."

With the canalization method, some flow in the river would be required to care for the operation of the locks and for evaporation from the water surfaces. It has been estimated that if there were a continuous flow of 500 second-feet in the river at a point just above the inlet of the Colusa Basin drain, at Knights Landing, there would be sufficient water for the operation of the system. This flow will probably be available at nearly all times without the operation of the Kennett reservoir.

If navigation is to be maintained by the stream-flow regulation method, a much larger flow in the river will be required. For the studies made during this investigation, it has been assumed that a minimum flow of 5000 second-feet, maintained at the point above Knights Landing, would provide the required depths for navigation as far upstream as Chico Landing, if combined with some open channel improvements. This flow also would improve navigation conditions in the river from Chico Landing upstream to Red Bluff.

CHAPTER VI

FLOOD CONTROL

Before the beginning of agricultural development in the Sacramento Valley, a large part of its area, including the delta lands in Sacramento, Yolo and Solano counties and the basin lands lying between the rivers and the uplands was subject to annual or periodical overflow by flood waters from the Sacramento River and its tributary streams. This great flood plain, irregular in outline and varying in width from about two to thirty miles, extended from the mouth of the Sacramento River almost to Red Bluff, a distance of about 150 miles, and comprised an area of land exceeding one million acres. On Plate VII, "Portion of Sacramento River Basin Showing Flood Control System, Auriferous Gravels and Major Units of State Water Plan," the approximate boundary of these overflow lands is shown by the heavy dash and dot red line. A considerable portion of this flood plain was covered by a dense growth of tule. Surrounding the tule lands lay belts of overflow lands known as the "rim-lands." With the advent of agricultural development in the valley, these rim-lands were the first to come under cultivation. The higher and more fertile lands extending from the river banks back to the tule, being less often flooded and more easily accessible to water transportation, were the first to be settled. Here also flood control had its inception in the low levees, constructed along the banks of the streams by the farmers, to protect their crops from floods.

The control of floods in the Sacramento Valley is closely associated with the conservation features of the State Water Plan, as much of the land on the valley floor which ultimately would receive the regulated water supplies from the Sacramento River and its tributaries lies within the area which is subject to periodic inundation. These lands which will be developed through increased water supply and will have resulting increased property values, must be protected from the flood hazard. With the large storage reservoirs of the State Water Plan constructed and operated for flood control, floods could be so reduced in volume that the present flood control plan could be modified to include areas for which no protection is now proposed. Furthermore, a substantial increased degree of protection also would be furnished to the areas now protected from inundation by existing works. Not only would the property owners be interested in such a procedure but also the Federal and State governments which have already contributed large sums of money for the construction of works in the Sacramento Valley in cooperation with the landowners. Therefore, it was highly important that inquiry be made to determine what added degree of flood protection could be afforded the affected area, what modification of the present flood control plan could be effected, and the resulting cost thereof, by means of storage works proposed under the State Water Plan.

History of Flood Control in the Sacramento Valley.

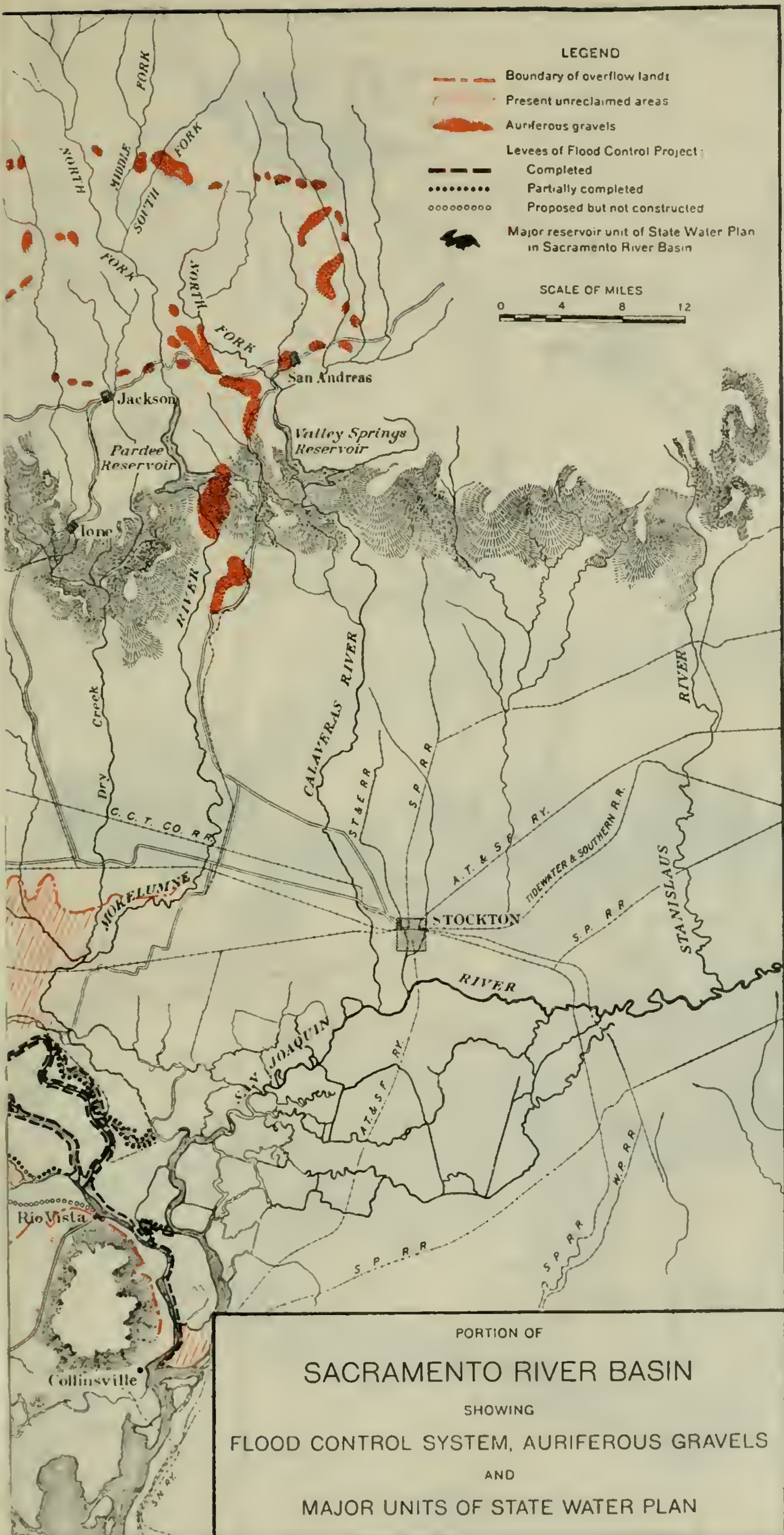
Until the year 1850, ownership of the tule lands, designated as "swamp and overflow lands," was vested in the United States government. By the passage of the "Arkansas Act" on September 28, 1850, by the United States Congress, these lands were transferred to the State of California. Between 1855 and 1868, legislation was enacted for the sale of these lands to individuals who were obligated to reclaim them either individually or by means of the formation of reclamation districts. Within a period of three years following the passing of the last act in 1868, practically all of the State's swamp lands had passed into private ownership, about one million acres being patented to individual owners.

By 1894, the levees along stream channels had been extended for many miles, and some of the more favorably located lands had been formed into districts around which levees had been constructed affording a minor degree of protection from floods. With each additional area thus leveed, the degree of protection was decreased for it and all other areas, due to increased heights of flood plane. This unsystematic method of protection against floods of whose volumes and frequencies there was little conception, and no accurate knowledge, was carried on for many years. The problems of flood control arising out of reclamation were intensified by the choking of the river channels by the washing down by recurrent floods of millions of cubic yards of hydraulic mining debris from the mountains where this form of mining had been carried on between 1853 and 1884.

Many commissions were formed, investigations and reports made, and laws enacted dealing with the reclamation, debris and flood control problems. Notable among the plans proposed for flood control and reclamation prior to 1910 were those of Manson and Grunsky in 1894 and the Dabney Commission in 1904. The former of these plans provided for the use of the stream channels to carry flood waters up to their capacities, spillways to discharge water in excess of these capacities into the basins adjacent to the rivers, and leveed by-pass channels through the basins to carry the spilled water back to the river channels at lower points. The "Dabney Plan" proposed the use of the stream channels only, by setting back the levees along the banks to provide additional capacity. Both of these plans were based on floods which had occurred prior to the dates of the reports. The floods of 1907 and 1909 proved that the projects proposed would have been inadequate.

As far back as 1884, hydraulic mining had been practically terminated by court order. The United States Congress had taken an interest in the conflict between the agricultural and mining interests and, following the injunction against hydraulic mining, appointed a commission of three officers of the Corps of Engineers, United States Army, to study the possibility of rehabilitating the mining industry, and the amount of damage to and the methods for improving and rectifying the navigable river channels. Following a report by this commission, congress on March 1, 1893, passed the "Caminetti Act" creating the California Debris Commission composed of three officers of the Corps of Engineers, United States Army, and making hydraulic mining illegal except with the permission of the commission and under conditions which would safeguard the streams.

The Debris Commission began surveys of the Sacramento Valley streams in July, 1905, and a plan for the control of floods and the improvement of the channels in the entire valley was prepared under the direction of Captain Thos. H. Jackson and submitted to congress in 1910. This plan was based on protection against floods similar to those



PORTION OF

SACRAMENTO RIVER BASIN

SHOWING

FLOOD CONTROL SYSTEM, AURIFEROUS GRAVELS

AND

MAJOR UNITS OF STATE WATER PLAN


LEGEND
Boundary of overflow lands
Present unreclaimed areas
Auriferous gravels
Levees of Flood Control Project
Completed
Partially completed
Proposed but not constructed
Major reservoir unit of State Water Plan in Sacramento River Basin
SCALE OF MILES
KENNETT RESERVOIR
KESWICK AFTERBAY
FAIRVIEW RESERVOIR
TRINITY RIVER DIVERSION
MILLSITE RESERVOIR
OROVILLE RESERVOIR
OROVILLE AFTERBAY
NARROWS RESERVOIR
CAMP FAR WEST RESERVOIR
AUBURN RESERVOIR
COLOMA RESERVOIR
PILOT CREEK RESERVOIR
WEBBER CREEK RESERVOIR
FOLSOM RESERVOIR
FOLSOM AFTERBAY
CAPAY RESERVOIR
MONTICELLO RESERVOIR
SACRAMENTO
STOCKTON
YOLO BY-PASS
SUTTER BY-PASS
Mt. Shasta
Mt. Lassen
Lake Almanor
Redding
Red Bluff
Corning
Orland
Willows
Williams
Colusa
Chico
Oroville
Marysville
Nevada City
Auburn
Roseville
Woodland
Davis
Dixon
Fairfield
Collinsville
Placerville
Jackson
San Andreas
Emigrant Gap
Downieville
Quincy
Weaverville
PORTION OF
SACRAMENTO RIVER BASIN
SHOWING
FLOOD CONTROL SYSTEM, AURIFEROUS GRAVELS
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which had occurred in 1907 and 1909. The Debris Commission plan was adopted by the State Legislature in 1911 and, with some minor revision, by the United States Congress in 1917. Between 1910 and 1925, it became apparent that certain changes in the original plan would be advisable both for construction and financing. A revised plan was therefore submitted by the Debris Commission in 1925, after cooperative studies with the State. This revised plan was adopted by the State Legislature of 1925 and later by the United States Congress and is the plan in accordance with which all flood control works in the Sacramento Valley are now being constructed.

With the adoption of the original Debris Commission flood control plan by the State Legislature in 1911, there came assurance of concerted action to replace the chaotic conditions that had prevailed up to that time and a number of large districts were organized bringing within their boundaries the greater part of the unreclaimed swamp lands not reserved for by-passes.

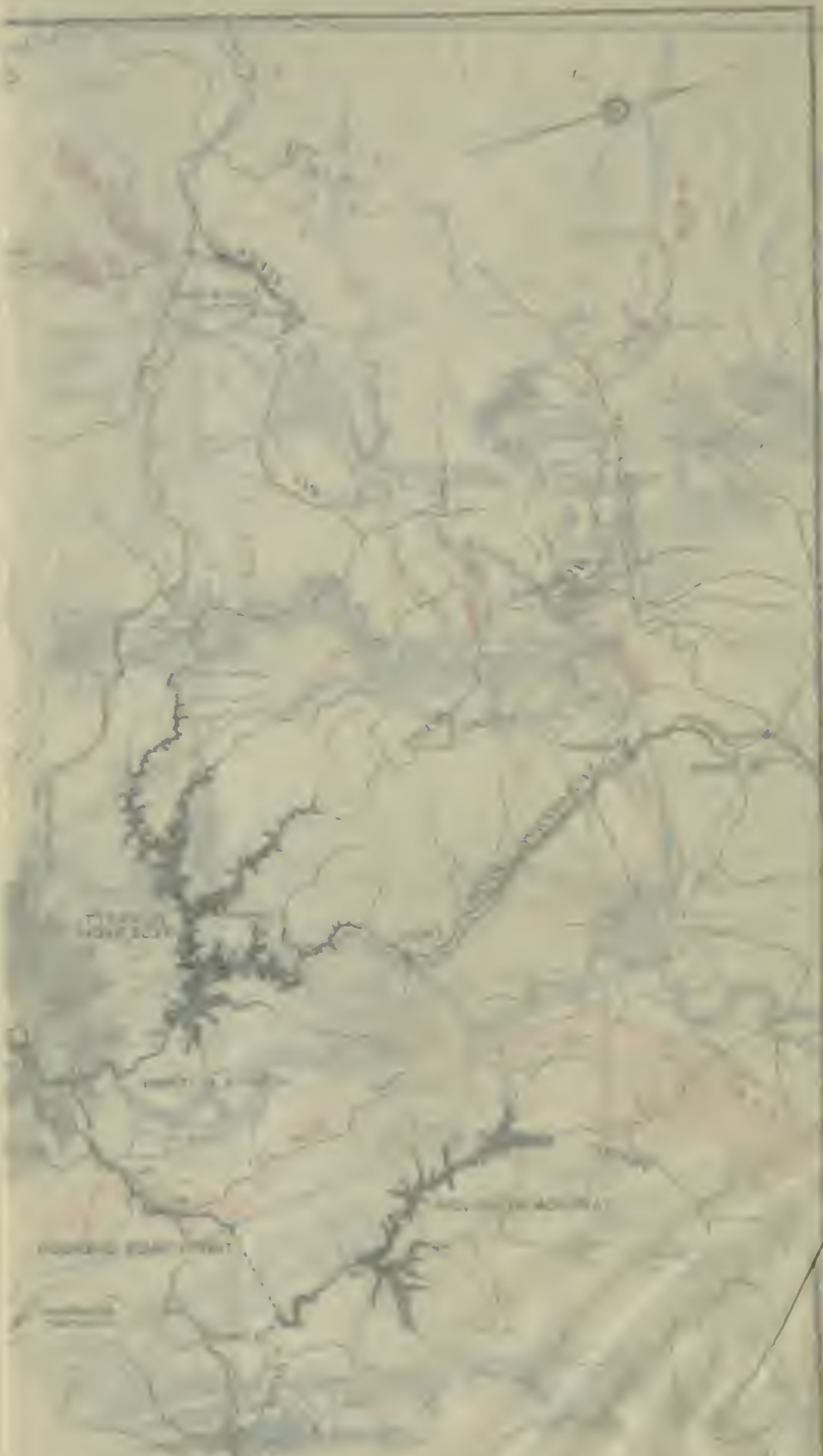
Methods of Flood Control.

There are two general methods for controlling floods. One method is to convey the flood waters of the streams undiminished in volume past the overflow areas by means of leveed channels constructed either along the natural waterways or, where the natural waterways are inadequate in capacity, through leveed by-passes. The other method is to reduce the flood flows by retention in surface reservoirs of flows in excess of the capacity of the natural waterways and to later release the water from these reservoirs at a rate which does not exceed the natural channel capacity.

The first method is the more common and is that used on the Mississippi River and in the Sacramento Valley. The only examples of the second method in California are the Los Angeles County Flood Control Project and the city of Stockton project on the Calaveras River. The first method is usually the less costly. The second method, where the reservoirs are used solely for flood control purposes, is justified only where high property values make flood channels costly or undesirable and where the close settlement and values in the territory protected permit greater expenditures for this protection. In most instances, however, even with the floods controlled by reservoirs, some leveed channels are required, so that control by this method generally resolves itself into a plan of reservoir control combined with levee systems. Sometimes this method of flood control is combined with the spreading of flood waters over absorptive areas to introduce these waters into the underground basin for storage. Where flood control by reservoirs can be combined with conservation, the cost chargeable to flood control is greatly reduced.

Sacramento Flood Control Project.

The plan for flood control in the Sacramento Valley is one by which protection is afforded by means of leveed channels. The adopted plan is generally called the "California Debris Commission Plan" or "Sacramento Flood Control Project," and has already been referred to under the history of flood control. The main features of this plan are shown on Plate VII. The plan provides for levees along the Sacramento River



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The quantities of flood flow provided for in the Debris Commission plan were based upon estimated maximum discharges that occurred during the 1907 and 1909 floods, the largest floods of record at the time of preparing the plan. The quantities for which it was recommended in the original plan that provision be made in different parts of the system are published in House Document No. 81, 62d Congress, 1st Session. In the revised plan presented in 1925, another set of recommended quantities was presented, the changes being due to changes in by-pass locations, omission of some of the works formerly proposed and further study of flood concentrations. These quantities are tabulated in full in Senate Document No. 23, 69th Congress, 1st Session. In Table 31 there are listed for the more important sections of the Sacramento Flood Control Project, the revised quantities for the estimated total concentrations between certain latitudes and the division of flow between river channels and by-pass or overflow channels.

At a special session of the legislature in 1911, the Debris Commission plan was adopted by the State for flood control in the Sacramento Valley. The same legislature created a Reclamation Board, consisting of three persons, which was empowered to pass upon and approve plans for flood control works before such works could be legally constructed. The Legislature of 1913 increased the number of members to seven, enlarged the powers of the board, created the Sacramento and San Joaquin Drainage District containing about one and three-quarters million acres of land subject to inundation in the Sacramento Valley and the San Joaquin Valley as far south as Herndon and invested the management and control of said district in the Reclamation Board.

The plans for the construction of flood control works in the Sacramento and San Joaquin valleys have been carried out largely by private agencies and reclamation and levee districts, with supervision and financial aid in recent years by the Federal and State governments acting through their respective agencies, the California Debris Commission and the Reclamation Board. Financial participation of the Federal and State governments in the construction of flood control works also indicates their interest in and recognition of responsibility for the control of floods. Each of these agencies has made appropriations to date of over $10,000,000 toward the construction of the flood control works, and their continued participation is assured by recent legislation.

The cost of the original Sacramento Flood Control Project was estimated by the California Debris Commission in 1910 to be $33,000,000.

TABLE 31

FLOOD QUANTITIES PROVIDED FOR IN CALIFORNIA DEBRIS COMMISSION PLAN FOR SACRAMENTO VALLEY

Revised as of 1925

Section of flood control project	Flow provided for, in second-feet		
	Total	In river channel	In by-pass or overflow channel
Sacramento River—			
Red Bluff to Chico Landing	260,000	260,000	----------
Chico Landing to Butte-Glenn County Line	260,000-160,000	260,000-160,000	----------
Sacramento River and Butte Basin—			
Butte-Glenn County Line to Moulton Break	260,000	160,000	100,000
Moulton Break to Colusa Weir	255,000	145,000	110,000
Colusa Weir to Butte Slough	250,000	65,000	185,000
Sacramento River and Sutter By-pass—			
Butte Slough to Tisdale By-pass	250,000	72,000	178,000
Tisdale By-pass to Nelson Bend	250,000	33,500	216,500
Nelson Bend to Fremont Weir	450,000	33,500	416,500
Sacramento River and Yolo By-pass—			
Fremont Weir to Knights Landing Cut	450,000	107,000	343,000
Knights Landing Cut to Cache Creek	469,000	107,000	362,000
Cache Creek to Sacramento By-pass	484,000	107,000	377,000
Sacramento By-pass to American River	498,000	[1]18,000	480,000
American River to Putah Creek	590,000	110,000	480,000
Putah Creek to Miner Slough	600,000	110,000	490,000
Miner Slough to Georgiana Slough	600,000	100,000	500,000
Georgiana Slough to mouth of Cache Slough	579,400	79,400	500,000
Sacramento River—			
Mouth of Cache Slough to Three-Mile Slough	579,000	579,000	----------
Three-Mile Slough to Mayberry Slough	514,000	514,000	----------
Mayberry Slough to Collinsville	497,000	497,000	----------
Feather River—			
Oroville to Yuba River	180,000	180,000	----------
Yuba River to Bear River	277,000	277,000	----------
Bear River to Nelson Bend	295,000	295,000	----------
Miscellaneous—			
Yuba River	120,000	120,000	----------
Bear River	30,000	30,000	----------
American River	128,000	128,000	----------
Stony Creek	30,000	30,000	----------
Cache Creek	20,000	20,000	----------
Putah Creek	25,000	25,000	----------

[1] Upstream.

This project was adopted by congress by the Flood Control Act of March 1, 1917, in which the Federal and State governments' shares in the cost were set at $5,600,000 each, with the implication that the remainder of the $33,000,000 would be borne by the landowners. This distribution of cost was followed until 1925. In the meantime, it became apparent that the project could not be completed under the terms of the Flood Control Act of 1917 and after an appeal to congress that body directed the Board for Rivers and Harbors to review the reports of 1910 with a view to determining whether any modification in the existing project was advisable. The report* on this modification was submitted to congress in December, 1925. In this report, it was pointed out that on account of increases of costs due to war conditions and the methods of financing, original estimated costs had been greatly exceeded and the cost of completing the project would be about $20,000,000 in addition to the $31,000,000 which had

* Senate Document No. 23, 69th Congress, 1st Session.

been spent up to that time. This made the revised estimated cost of the project about $51,000,000 of which it was recommended that about one-third be borne by the Federal government and the remainder by the State and landowners. The State had obligated itself by an act passed in 1925 * to a total contribution not to exceed $17,700,000, and the Federal government by an act called the "Curry Bill" approved May 15, 1928, obligated itself to a total contribution of $17,600,000. The remainder of the $51,000,000 is the landowners' share of the total cost.

The modified Sacramento Flood Control Project is estimated to be about 75 per cent completed with the major portions of unfinished work being along the American River opposite Sacramento, along the Feather River upstream from Honcut Creek, along the Sacramento River upstream from Colusa, where there is the largest body of unprotected lands, about 135,000 acres, in Butte Basin. The unprotected lands are shown by the areas in red shading on Plate VII. It may be noted that a considerable area of unprotected land is that reserved for by-pass and river overflow channels. Under the present plan, lands in these channels will never be protected.

In addition to those protection works which are a part of the Sacramento Flood Control Project and which are to be paid for in almost equal parts by the Federal and State governments and the landowners, other works have been and will be necessary for the complete protection of the overflow lands. These works include levees which are not along the flood control channels, and drainage systems. The cost of these works is to be borne entirely by the landowners in addition to their share of the cost of the flood control project.

It is estimated that of the original flooded area in that portion of the Great Central Valley lying north of the San Joaquin and Mokelumne rivers, about 830,000 acres, or 60 per cent, have been brought within levees and provided with some degree of protection against inundation. In accomplishing this work, it is estimated from all available records that about $98,000,000 have been spent. Of this amount, about 78 per cent has been expended by the landowners and 22 per cent, in almost equal parts, by the State and the United States government. It is evident from these figures that the protection of these lands has cost on the average in excess of $100 per acre.

With any system of flood control by leveed channels, a large portion of the flood flow is carried above the natural surface of the ground and is confined to the channel by earthen levees. The safety of the system, therefore, is determined by the strength of the levees and the sufficiency of the carrying capacity of the flood channels. The levees are subject to deterioration from settlement, cracking, and holes made by burrowing animals and, unless properly maintained, are subject at times of floods to breaks which would inundate all land protected by them. The channels also must be maintained at their full designed carrying capacity by being kept clear of all obstructive growths, or the levees may be overtopped by floods equal to or even less than the designed capacity. The Sacramento Flood Control Project is designed to accommodate floods such as occurred in 1907 and 1909 with certain allowances in freeboard on the levees to care for somewhat larger

* Chapter 176, Statutes of 1925.

amounts. Should larger floods than these occur or should the times of concentration of peak flows from several tributaries be such that more water would reach a certain section of the system than was allowed for in the design, the levees might fail and adjacent lands be inundated. This does not mean that the safety of the protection afforded by levees can not be made as great as that with any other system. Such safety, however, can be attained only by levees of ample cross section and height, well maintained, and channels of ample capacity, also well maintained. The protection afforded by the Sacramento Flood Control Project and the increased degree of protection resulting from controlling flood flows on the major streams by the reservoirs of the State Water Plan, are discussed later in this chapter.

Size and Frequency of Flood Flows.

To estimate the probable sizes of floods which may be expected in different sections of the basin and the frequency with which they may occur, analyses were made of all available data. Studies were made of the flood flows at the gaging station on each of the main streams near the foothill line and at five points of flood concentration on the valley floor. Studies also were made of the flows at certain reservoir sites which do not lie close to the foothill gaging stations but which would be suitable for flood control purposes.

The data available for these studies were mainly the records of flood flows obtained by the United States Geological Survey at its gaging stations. These data have been obtained for only a relatively short period when consideration is given to the size of floods that may occur at long intervals of time such as once in 100 and once in 1000 years. Also, it is difficult to obtain the amounts of flow at times of floods, and the peak and mean daily flows at the crest of a flood must often be estimated from extended rating curves or from stream cross sections and observed surface velocities. While the data, therefore, are not exact and a much longer period of record would be desirable, the studies have been based on these data and are believed to give the best results now obtainable.

Flood Flows at Foothill Gaging Stations.—In estimating the probable amounts of flood discharge at specified frequencies at a gaging station, the total flood flows for one, two, three, four or more days of record were tabulated in descending order of magnitude, thus giving the number of times of occurrence, or frequency, of a flood of any selected length and magnitude during the period of stream flow record. These frequencies were then converted into the probable number of times that the flow would have occurred in 100 years by multiplying the order of the frequency by 100 divided by the number of years in the period of record. These values were plotted on logarithmic paper with the vertical scale representing the frequency with which the flows would be exceeded in 100 years on the average and the horizontal scale the volume of the flow. Curves drawn to conform to the trend of these plotted points were extended to give the size of flood which may be expected to occur once in 250 years on an average. Curves drawn in this manner are shown for each of the stations studied, on Plate VIII, "Probable Frequency of Flood Flows at Foothill Gaging Stations on Major Streams of Sacramento River Basin." The curve for the American River at Fairoaks is included in another report* and is not shown on Plate VIII. The sizes of floods which it is estimated may occur with certain frequencies at the foothill gaging stations on the major streams of the Sacramento River Basin are shown in Table 32.

TABLE 32

PROBABLE FREQUENCY OF FLOOD FLOWS AT FOOTHILL GAGING STATIONS ON MAJOR STREAMS OF SACRAMENTO RIVER BASIN

Stream and location of gage	Probable maximum mean daily flow, in second-feet, exceeded on average of once in:				
	10 years	25 years	50 years	100 years	250 years
Sacramento River at Red Bluff	203,000	243,000	274,000	303,000	348,000
Sacramento River between Kennett and Red Bluff, at Red Bluff	115,000	143,000	164,000	187,000	217,000
Feather River at Oroville	138,000	177,000	204,000	231,000	267,000
Yuba River at Smartsville	83,500	115,000	142,000	170,000	212,000
Bear River at Van Trent	27,000	33,400	38,200	42,800	48,500
Stony Creek near Orland	30,700	38,000	42,300	46,000	51,200
Cache Creek at Yolo	20,400	23,200	25,000	26,500	28,000
Putah Creek at Winters	38,800	46,500	51,600	56,700	62,500
American River at Fairoaks	[1]104,000	[1]126,000	[1]144,000	[1]162,000	[1]182,000

[1] Flow exceeded on average of one day in number of years at top of column.

Flood Flows at Points of Concentration on Valley Floor.—Studies of flood concentrations at certain points on the Sacramento Valley floor were undertaken to estimate as nearly as possible the probable frequencies and volumes of flood flows at these points. The volumes of discharge used in these studies were those that would have occurred during the passing of the floods whose volumes of flow were recorded at the gaging stations at the edge of the valley floor, if the entire adopted Sacramento Flood Control Project had been in operation, Butte Basin had been reclaimed, and all works had operated without failure.

The valley floor points chosen for these studies, the total mountain drainage area tributary to each point, and the division of these total areas into metered and unmetered areas are shown in Table 33.

TABLE 33

AREAS OF MOUNTAIN DRAINAGE BASINS TRIBUTARY TO POINTS OF CONCENTRATION ON SACRAMENTO VALLEY FLOOR

Point of concentration	Total drainage area[1], in square miles	Areas having recorded measured flows		Unmetered areas	
		In square miles	In per cent of total	In square milse	In per cent of total
Sacramento River at Sacramento and Yolo By-pass at Lisbon	21,420	18,681	87	2,739	13
Sacramento River below Verona and Yolo By-pass at Fremont Weir	17,195	15,057	87½	2,138	12½
Sacramento River and Sutter-Butte By-pass opposite Colusa	11,462	9,968	87	1,494	13
Feather River below confluence of Feather and Bear rivers	5,482	5,089	93	393	7
Feather River below confluence of Feather and Yuba rivers	5,141	4,827	94	314	6

[1] Areas are from Bulletin No. 5, Division of Engineering and Irrigation, 1923.

* Bulletin No. 24, "A Proposed Major Development on American River," Division of Water Resources, 1930.

PROBABLE FREQUENCY OF FLOOD FLOWS

AT

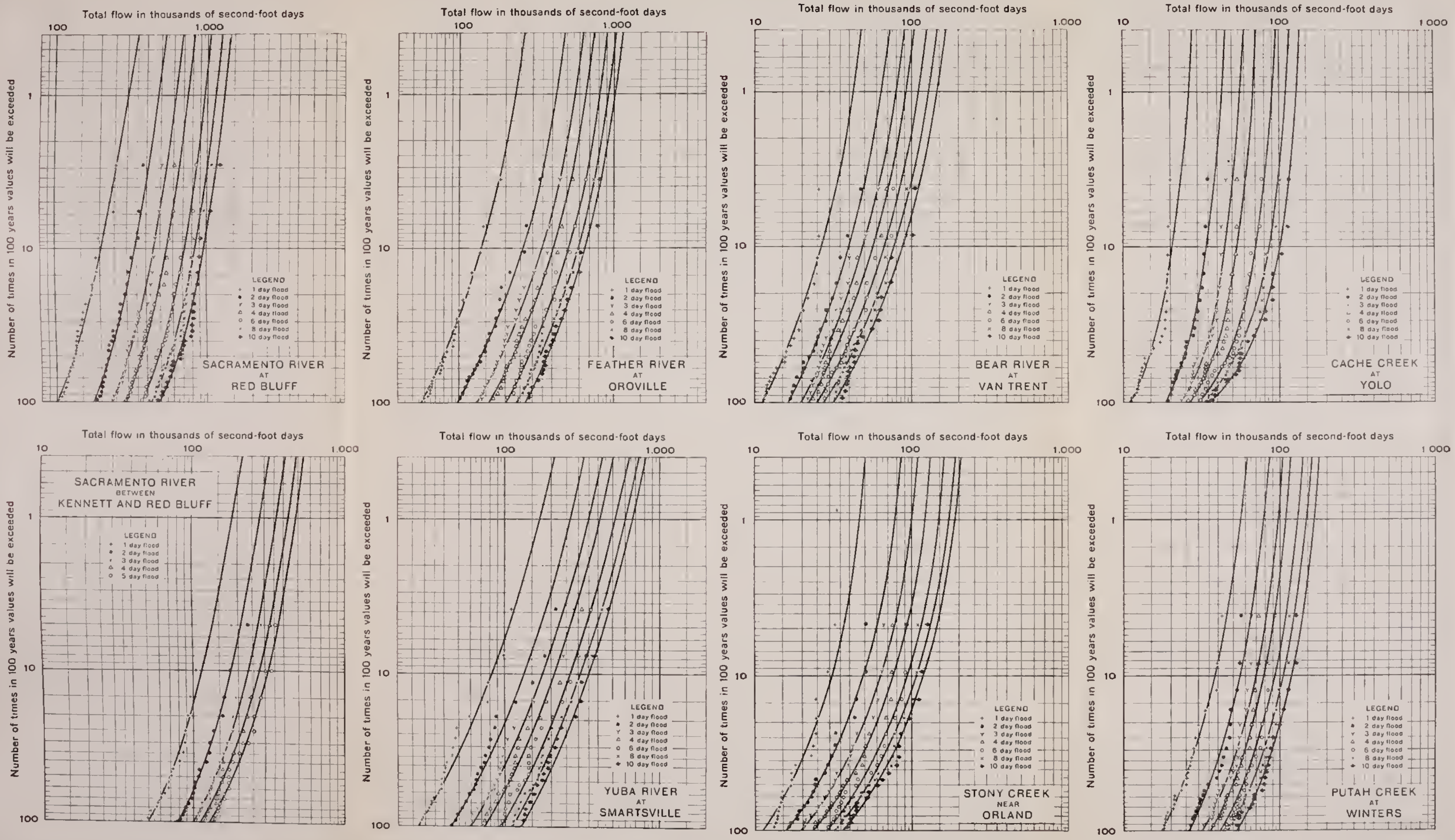
FOOTHILL GAGING STATIONS

ON

MAJOR STREAMS

OF

SACRAMENTO RIVER BASIN



PROBABLE FREQUENCY OF FLOOD FLOWS AT FOOTHILL GAGING STATIONS ON MAJOR STREAMS OF SACRAMENTO RIVER BASIN

In general, the passage of storms over the Sacramento River Basin is in a direction to favor low values of concentration at the lower valley floor stations. The order of concentration at the gaging stations of the major streams at the edge of the valley floor is usually from south to north. The distribution, duration and varying intensities of the storms are such that rarely are all the steams in flood flows of similar magnitude at the same time.

The maximum concentration at a valley floor point, produced by any flood, is dependent upon:

1. The magnitude and duration of flows past the points of concentration of the several tributaries at the edge of the valley.
2. The relative times of occurrence of these concentrations.
3. The extent to which the several flood waves are flattened and reduced in volume by absorption in channel storage.
4. The variation in distances and rates of travel of the flood waves down the tributary channels.

Rates of flood wave travel are not only different for different streams but vary with every flood and in different sections of the same stream. By the use of data on the rate of travel for floods of which there are records and by correcting these rates for the altered conditions with the completed adopted Sacramento Flood Control Project, and Butte Basin reclaimed, the lengths of time required for floods of varying magnitude to travel from the different foothill gaging stations to the points of concentration on the valley floor were estimated.

Hydrographs were prepared for each flood of record at each of the gaging stations. By applying the correction for the time of travel to these hydrographs and estimating the run-off from the unmetered areas, the times and amounts of flow, without reduction for channel storage, at each of the points of flood concentration were estimated. These flows were then corrected by the estimated amounts of reduction due to storage in the channels through which the flows would have passed. This correction was made by determining the ratios of the estimated flows, corrected for storage, to the combined uncorrected flows at the points of concentration, for the floods of 1907 and 1909 which had previously been carefully analysed, and applying the factors thus determined to the other floods of record.

Flood flows at the selected points of concentration, estimated as above described, were then analysed to estimate the probable sizes of floods which may be expected at the same points, and the frequency with which they may be expected to occur. The method used was the same as that used for the same purpose for the foothill gaging stations. The curves so derived are shown on Plate IX, "Probable Frequency of Flood Flows at Points of Concentration on Sacramento Valley Floor," and are in each case the right-hand curve for each station, indicated as the flows "without reservoir control." Table 34 shows the estimated maximum flows that would occur at the points of concentration, with certain frequencies, with the Sacramento Flood Control Project completed and Butte Basin protected and all works operated without failures.

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TABLE 34

PROBABLE FREQUENCY OF FLOOD FLOWS AT POINTS OF CONCENTRATION ON SACRAMENTO VALLEY FLOOR

Without Reservoir Control

Stream and point of concentration	Probable maximum mean daily flow, in second-feet, exceeded on average of once in:				
	10 years	25 years	50 years	100 years	250 years
Sacramento River and Sutter-Butte By-pass opposite Colusa	236,000	286,000	325,000	370,000	430,000
Sacramento River below Verona and Yolo By-pass at Fremont Weir	370,000	440,000	490,000	540,000	690,000
Sacramento River at Sacramento and Yolo By-pass at Lisbon	430,000	518,000	580,000	670,000	780,000
Feather River below confluence of Feather and Yuba rivers	250,000	320,000	365,000	400,000	445,000
Feather River below confluence of Feather and Bear rivers	258,000	330,000	379,000	430 000	460,000

Control of Floods by Reservoirs.

The control of floods by reservoirs has been a subject of intensive study by this office for some time. It has been believed by some that any reservoir constructed for power or irrigation purposes will diminish flood flows. Reservoirs utilized for these purposes only, however, are allowed to fill as rapidly as water is available and remain full as long as possible. They, therefore, are apt to have no reserve space, or only a small amount of space, available for controlling floods when they occur and dependence can not be placed upon them for this purpose. On the other hand, reservoirs constructed and operated for flood control purposes alone will usually make the cost of protection by this means greater than if it were obtained by leveed channels and by-passes. In such reservoirs, the entire space is dedicated to flood control and after the passage of a flood the reservoir is emptied and held empty in anticipation of a succeeding flood.

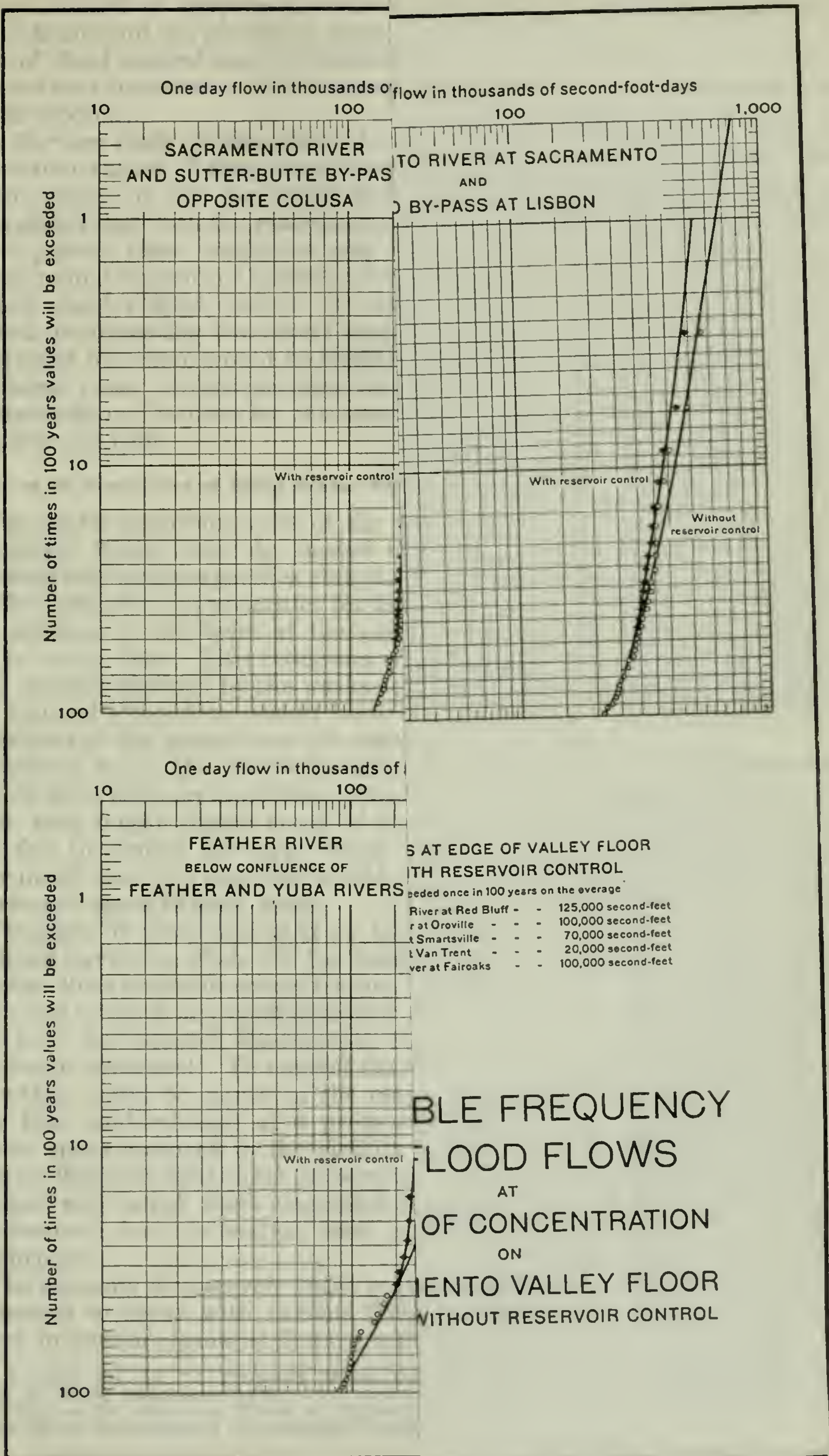
The control of floods by reservoirs was considered in 1910 by the California Debris Commission at the time it was formulating its plan for flood control in the Sacramento Valley. It, however, investigated the effect of reservoirs which were relatively small when compared with the major reservoir units of the State Water Plan. The sites also were located at points well above the valley floor and control only a small portion of the drainage area. Since the reservoir capacity was small, the flood controlled was only a small portion of that at the valley floor line, and the reservoirs were considered to be used only for flood control purposes, the Debris Commission concluded that partial control by reservoirs was not economical and this feature was not included in its plan. It did include in its report,* however, the following statement:

> "While favoring the use of reservoirs as far as possible, and considering that one of the advantages of the project herein proposed is that it lends itself to future storage possibilities, the Commission believes that it is not economical to construct reservoirs for flood control, but that such construction should be deferred until these reservoirs prove desirable for power and irrigation purposes."

In the studies by this office of the control of floods by reservoirs, particular attention was given to the coordination of flood control with conservation in the utilization of reservoirs and a report ** was rendered on this subject. It is demonstrated in this report that by utilizing

* House Document No. 81, 62d Congress, 1st Session.

** Bulletin No. 14, "The Control of Floods by Reservoirs," Division of Engineering and Irrigation, 1928.


One day flow in thousands of
flow in thousands of second-foot-days
10
100
100
1,000
SACRAMENTO RIVER
AND SUTTER-BUTTE BY-PAS
OPPOSITE COLUSA
TO RIVER AT SACRAMENTO
AND
BY-PASS AT LISBON
1
10
100
With reservoir control
With reservoir control
Without reservoir control
Number of times in 100 years values will be exceeded
One day flow in thousands of
10
100
FEATHER RIVER
BELOW CONFLUENCE OF
FEATHER AND YUBA RIVERS
S AT EDGE OF VALLEY FLOOR
ITH RESERVOIR CONTROL
eeded once in 100 years on the average
River at Red Bluff - - 125,000 second-feet
r at Oroville - - - 100,000 second-feet
t Smartsville - - - 70,000 second-feet
t Van Trent - - - 20,000 second-feet
ver at Fairoaks - - 100,000 second-feet
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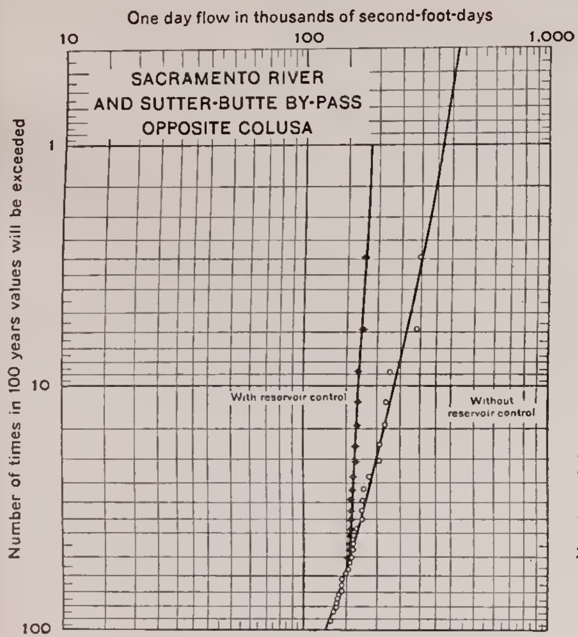

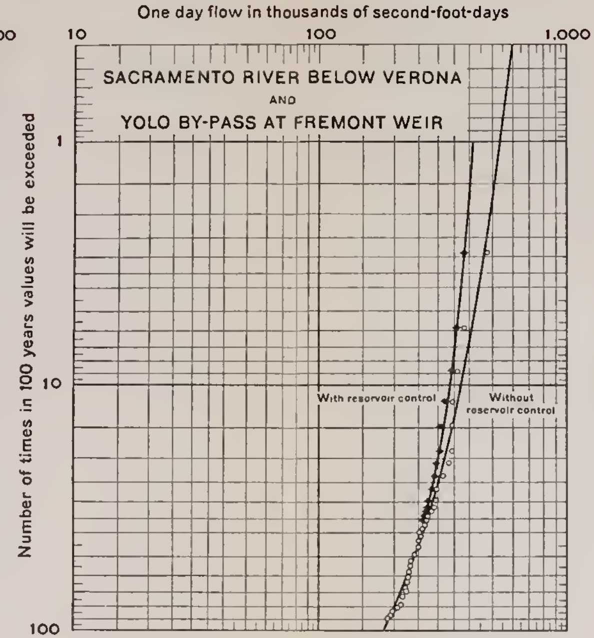

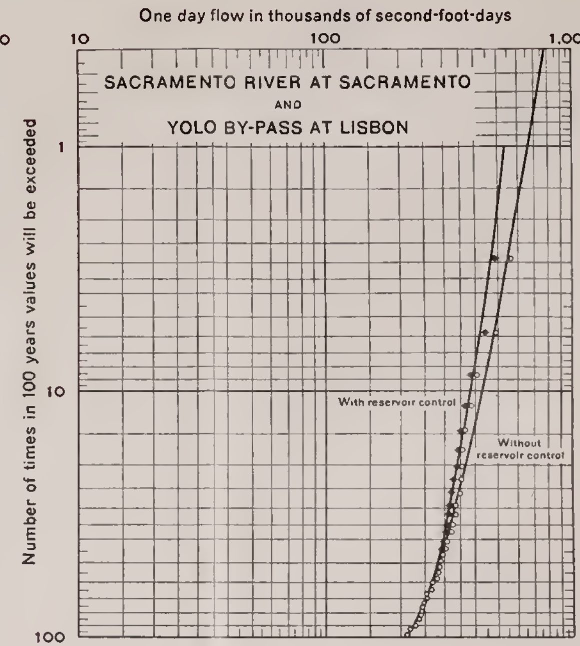

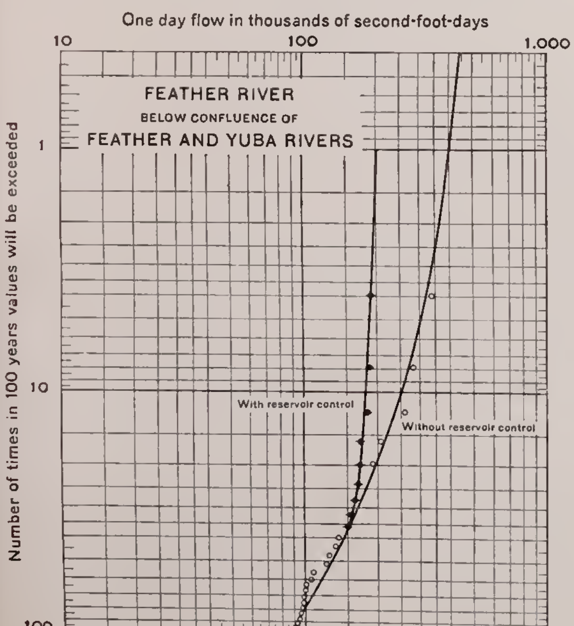

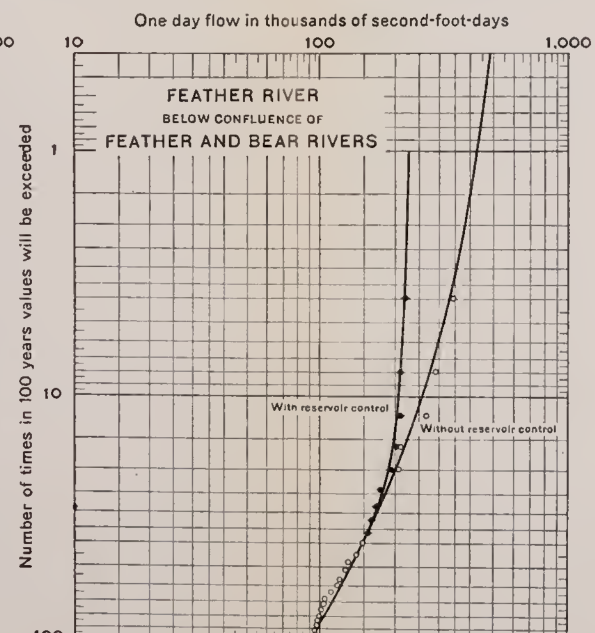

FLOWS AT EDGE OF VALLEY FLOOR
WITH RESERVOIR CONTROL

Exceeded once in 100 years on the average

Sacramento River at Red Bluff	125,000 second-feet
Feather River at Oroville	100,000 second-feet
Yuba River at Smartsville	70,000 second-feet
Bear River at Van Trent	20,000 second-feet
American River at Fairoaks	100,000 second-feet

PROBABLE FREQUENCY OF FLOOD FLOWS AT POINTS OF CONCENTRATION ON SACRAMENTO VALLEY FLOOR

WITH AND WITHOUT RESERVOIR CONTROL

varying amounts of space in a reservoir, guided by the time of occurrence of floods and the preceding climatological conditions, a substantial degree of flood control can be obtained on the larger streams of California without impairment of the conservation value of major reservoirs on these streams.

A further study of the effect of flood control by reservoirs on the conservation values of these reservoirs was made in connection with a previous study of the American River project. A report * on the studies shows that with the reservoirs operated primarily for the generation of power, there would be only a slight reduction in the total average annual amount of electric energy output if the reservoirs were operated also for flood control. It also shows that with the reservoir operated for irrigation with flood control, the seasonal yield would not be decreased but there would be slightly greater deficiencies in the supply in some years. In neither case would the reduction in the value of the conservation features by the operation for flood control be more than a few per cent.

Utilization of Reservoirs of State Water Plan for Flood Control.

The major reservoir units of the State Water Plan in the Sacramento River Basin would be located near the line of the valley floor, have relatively large capacities compared to the run-off of the streams, and offer favorable opportunities for the reduction of flood flows on the major streams of the basin at the points where they would discharge onto the valley floor. This reduction would increase the degree of protection already afforded by the works constructed under the Sacramento Flood Control Project or permit lower levees and smaller channels for the portions of the project not yet constructed. To obtain the greatest flood control value, the reservoirs should be operated for this purpose as one of their primary functions. If not operated specifically for flood control, they might absorb many of the medium and small floods but would fail to control the large floods which would occur in years of large run-off, since the reservoir would probably be filled or have insufficient reserve space in such years.

The sizes of flows indicated by the curves on Plate VIII and the right-hand curves on Plate IX for floods at the foothill gaging stations and valley floor points of concentration, respectively, are those that may be expected without any control except that provided by the levees and channels of the adopted Sacramento Flood Control Project and with Butte Basin protected. To control these flows to smaller amounts, the flood waters could be stored in the major reservoir units of the State Water Plan and released at a predetermined rate. The amounts of reservoir space required in the vicinity of each foothill gaging station to reduce floods at that point to certain controlled flows, and also the frequency with which these controlled flows may be exceeded, with the space reserved for this control, were estimated from studies made for that purpose.

The amounts of reservoir space required to control floods that may be expected to occur with various frequencies at each of the gaging stations, to certain regulated flows, are shown ** on Plate X, "Reservoir

* Bulletin No. 24, "A Proposed Major Development on the American River," Division of Water Resources, 1930.

** Curves for American River at Fairoaks are shown in Bulletin No. 24, "A Proposed Major Development on American River," Division of Water Resources, 1930.

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Utilization of Reservoirs of State Water Plan for Flood Control.

The major reservoir units of the State Water Plan in the Sacramento River Basin would be located near the line of the valley floor, have relatively large capacities compared to the run-off of the streams, and offer favorable opportunities for the reduction of flood flows on the major streams of the basin at the points where they would discharge onto the valley floor. This reduction would increase the degree of protection already afforded by the works constructed under the Sacramento Flood Control Project or permit lower levees and smaller channels for the portions of the project not yet constructed. To obtain the greatest flood control value, the reservoirs should be operated for this purpose as one of their primary functions. If not operated specifically for flood control, they might absorb many of the medium and small floods but would fail to control the large floods which would occur in years of large run-off, since the reservoir would probably be filled or have insufficient reserve space in such years.

The sizes of flows indicated by the curves on Plate VIII and the right-hand curves on Plate IX for floods at the foothill gaging stations and valley floor points of concentration, respectively, are those that may be expected without any control except that provided by the levees and channels of the adopted Sacramento Flood Control Project and with Butte Basin protected. To control these flows to smaller amounts, the flood waters could be stored in the major reservoir units of the State Water Plan and released at a predetermined rate. The amounts of reservoir space required in the vicinity of each foothill gaging station to reduce floods at that point to certain controlled flows, and also the frequency with which these controlled flows may be exceeded, with the space reserved for this control, were estimated from studies made for that purpose.

The amounts of reservoir space required to control floods that may be expected to occur with various frequencies at each of the gaging stations, to certain regulated flows, are shown ** on Plate X, "Reservoir

* Bulletin No. 24, "A Proposed Major Development on the American River," Division of Water Resources, 1930.

** Curves for American River at Fairoaks are shown in Bulletin No. 24, "A Proposed Major Development on American River," Division of Water Resources, 1930.

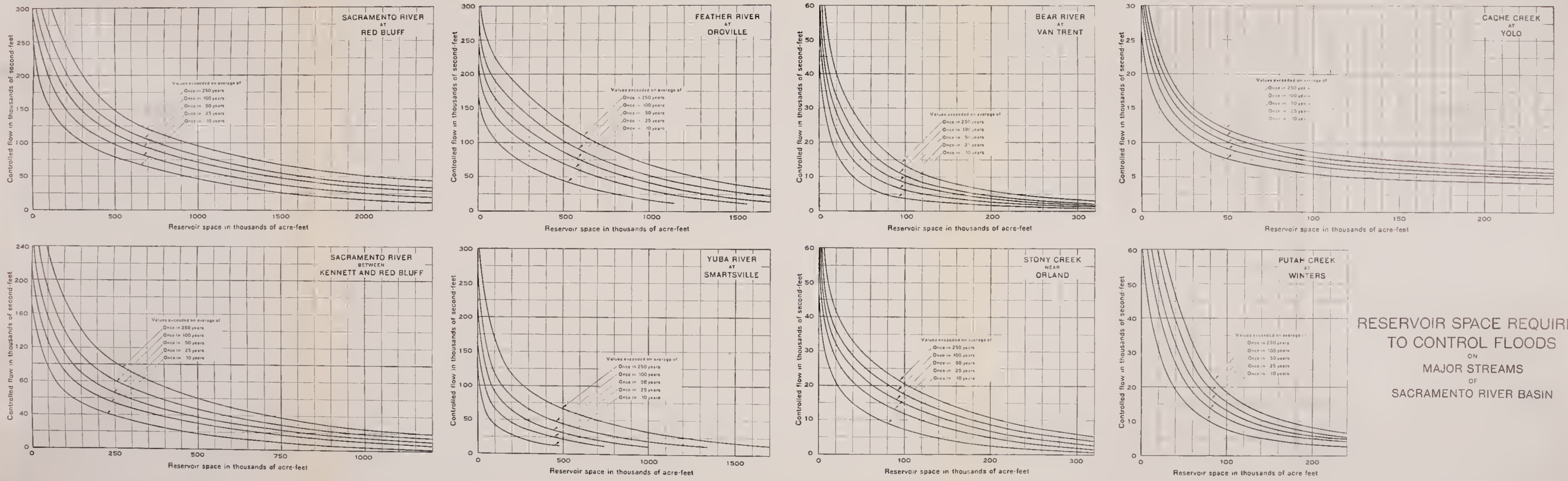
Space Required to Control Floods on Major Streams of Sacramento River Basin.'' In deriving these curves, the data were taken from the flood frequency curves on Plate VIII. From the latter curves, the total volume of flow for one, two, three, four, etc., day floods were tabulated for some selected frequency, say a volume exceeded once in 100 years on the average. Using the amount of run-off shown by this table for a one-day flood, a line representing the amounts of reservoir space required to control the flow to amounts from zero to its full volume was drawn on the plate. This was repeated for total flows of two, three, four, etc., days and a curve was drawn tangent to all of these lines. From this curve, the amounts of space required to control a flood of total volume exceeded once in 100 years on the average to various amounts of regulated flow can be obtained. By this same method, the curves for floods of other frequencies were derived. From the curves on Plate X, the amounts of reservoir space required to control floods that might be exceeded from once in 10 years to once in 250 years on the average, to certain controlled flows, can be obtained. Several controlled flows and the reservoir spaces required to prevent these controlled flows being exceeded oftener than at certain intervals are shown for the major streams in Table 35.

TABLE 35

RESERVOIR SPACE REQUIRED TO CONTROL FLOODS ON MAJOR STREAMS OF SACRAMENTO RIVER BASIN

Stream and location of point of control	Controlled flow, in second-feet	Reservoir space, in acre-feet, required to prevent controlled flow being exceeded on average of more than once in:				
		10 years	25 years	50 years	100 years	250 years
Sacramento River at Red Bluff	75,000	546,000	751,000	928,000	1,080,000	1,338,000
	100,000	310,000	476,000	608,000	737,000	924,000
	125,000	180,000	295,000	410,000	512,000	649,000
Sacramento River between Kennett and Red Bluff, at Red Bluff	75,000	82,000	147,000	207,000	283,000	395,000
	100,000	47,000	87,000	126,000	178,000	262,000
	125,000	24,000	53,000	83,000	123,000	184,000
Feather River at Oroville	80,000	210,000	416,000	550,000	678,000	870,000
	100,000	119,000	279,000	404,000	521,000	695,000
	120,000	58,000	175,000	288,000	399,000	558,000
Yuba River at The Narrows near Smartsville	60,000	49,000	129,000	220,000	342,000	577,000
	70,000	36,000	93,000	171,000	272,000	470,000
	80,000	25,000	68,000	132,000	219,000	385,000
	100,000	11,000	43,000	83,000	142,000	266,000
Bear River at Camp Far West dam	15,000	24,000	40,000	54,000	69,200	90,000
	20,000	15,500	26,100	37,500	50,000	66,200
	25,000	9,500	17,900	25,900	35,800	49,800
American River at Fairoaks[1]	25,000	690,000	640,000	680,000	720,000	780,000
	50,000	285,000	340,000	380,000	430,000	490,000
	75,000	125,000	190,000	235,000	270,000	320,000
	100,000	15,000	100,000	140,000	175,000	235,000
Stony Creek near Orland	15,000	39,500	73,500	99,500	121,000	148,000
	20,000	22,000	45,000	64,500	82,000	103,000
	25,000	12,500	27,000	40,000	55,000	73,000
Cache Creek at Yolo	10,000	29,200	40,300	50,500	60,000	71,500
	15,000	10,600	17,000	21,200	25,700	29,700
	20,000	3,700	7,300	10,300	13,000	15,900
Putah Creek near Winters	10,000	79,000	106,000	124,000	143,000	168,000
	20,000	37,500	54,500	65,500	78,000	92,500
	30,000	21,000	34,500	43,500	53,500	64,500

[1] Reservoir space is that required to prevent controlled flow being exceeded on average of more than one day in number of years shown at top of column.



RESERVOIR SPACE REQUIRED TO CONTROL FLOODS ON MAJOR STREAMS OF SACRAMENTO RIVER BASIN

Studies also were made* to determine the period during which reserve space should be held in a reservoir and the amount of this space at different times throughout the period. From these studies the following rule has been formulated for use in operating the reservoirs of the State Water Plan in the Sacramento River Basin, in which floods would be controlled:

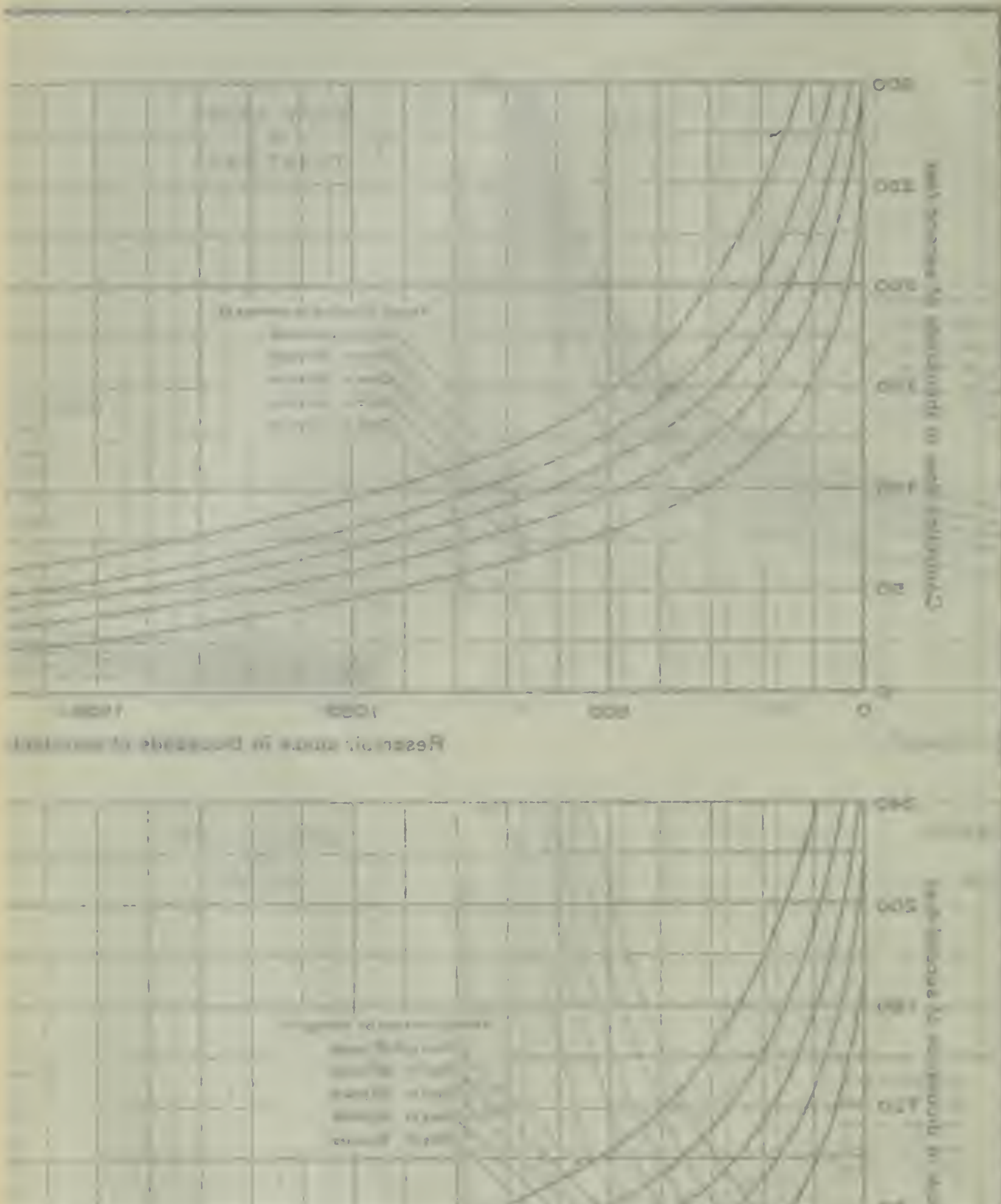
> Some space would be held in reserve for flood control from November 1st to May 1st in each flood season whenever the total precipitation up to any date in the season is more than 50 per cent of the normal precipitation to the same date. The flood control reserve would be increased at a uniform rate from zero on November 1st to the maximum amount on December 1st. The maximum space would be held in reserve from December 1st to April 1st, except for the decrease during the control of flood flows, and then decreased at a uniform rate to zero on May 1st.

While the above rule should give quite satisfactory operation of reservoirs on streams having watersheds rising to high elevations, since these reservoirs would have melting snow run-off to fill the space reserved for flood control, it might not give satisfactory irrigation conditions with reservoirs dependent entirely upon rainfall run-off for a water supply. With reservoirs of this latter type, it is probable that the amount of reserve space should be varied with the conditions affecting run-off throughout the season.

Increased Degree of Protection With Flood Control by Reservoirs of State Water Plan.—By comparing the flood quantities provided for in the several sections of the adopted Sacramento Flood Control Project, as shown in Table 31, with the probable flood concentration quantities in these same sections with the flood control project completed, as shown by the right-hand curves on Plate IX, it will be seen that the project provides protection against floods of varying frequencies at different points in the valley. Table 39 on page 144, gives the project quantities at each of the five points of concentration studied and the number of times on an average that these quantities may be expected to be exceeded in 100 years. From this table, it appears that the adopted project does not give an equal degree of protection to all of the reclaimed lands. To give equal protection by the leveed channel plan of flood control, the capacities of the channels in certain parts of the system would have to be increased by increasing the proposed heights of levees along these channels.

Another method of increasing the degree of protection is by reducing the flood flows at the foothill line to smaller amounts by means of storage of the peak flows in the reservoirs of the State Water Plan. Such control is proposed in the reservoirs of the plan on the Sacramento River and streams on the east side of the Sacramento Valley. These reservoirs, the space reserved and the control obtained are shown in Table 36.

* Bulletin No. 14, "The Control of Floods by Reservoirs," Division of Engineering and Irrigation, 1928.



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* Bulletin No. 14, "The Control of Floods by Reservoirs," Division of Engineering and Irrigation, 1928.

TABLE 36

SPACE TO BE RESERVED IN RESERVOIRS OF STATE WATER PLAN FOR CONTROLLING FLOODS TO CERTAIN SPECIFIC AMOUNTS

Reservoir	Stream	Point of control	Maximum space reserved, in acre-feet	Controlled flow, in second-feet	Number of times controlled flow would be exceeded, on the average
Kennett	Sacramento River	Red Bluff	512,000	[1]125,000	Once in 14 years
Oroville	Feather River	Oroville	521,000	100,000	Once in 100 years
Narrows	Yuba River	Smartsville	272,000	70,000	Once in 100 years
Camp Far West	Bear River	Van Trent	50,000	20,000	Once in 100 years
Folsom	American River	Fairoaks	[2]175,000	[2]100,000	One day in 100 years

[1] Mean daily flow on day of flood crest. Floods would be controlled to 125,000 second-feet maximum flow exceeded once in 100 years on the average, except when this amount is exceeded by the uncontrolled run-off between Kennett reservoir and Red Bluff. Flows greater than 125,000 second-feet would continue for only a short time.

[2] With an additional 90,000 acre-feet of reserve space in Auburn reservoir, the controlled flow could be reduced to 76,000 second-feet exceeded one day in 100 years on the average. With an additional 90,000 acre-feet of reserve space in Auburn reservoir and 35,000 acre-feet in Coloma reservoir, the controlled flow could be reduced to 80,000 second-feet exceeded one day in 250 years on the average.

In Table 36, the controlled flow on the American River is shown as 100,000 second-feet. This control could be obtained by the reservation of 175,000 acre-feet of space in the Folsom reservoir alone. If 300,000 acre-feet of space were reserved in the Folsom, Auburn and Coloma reservoirs on the American River and its forks, the flow could be reduced to 80,000 second-feet at Fairoaks, exceeded one day in 250 years on the average. In the discussion in the remainder of this chapter, however, a controlled flow of 100,000 second-feet at Fairoaks is used.

If control of floods by the reservoirs on the major streams of the Sacramento River Basin listed in Table 36 had been in effect during the period of stream flow record on these streams, and if the flows had been controlled to the following amounts—

Sacramento River at Red Bluff	125,000 second-feet
Feather River at Oroville	100,000 second-feet
Yuba River at Smartsville	70,000 second-feet
Bear River at Van Trent	20,000 second-feet
American River at Fairoaks	100,000 second-feet

there would have been a reduction in the maximum mean daily flows of twenty floods on the Sacramento River, six on the Feather River, four on the Yuba River, six on the Bear River, and two on the American River. A constant discharge equal to the maximum regulated flow would be maintained from the time the natural stream flow would reach this amount until the reservoir had been drawn down to reserve space level after the passage of the flood, at which time the natural flow would be less than the maximum controlled flow. Under these conditions, there might be times when the maximum controlled flows would concentrate in full volume at the points of concentration. The maximum concentration with reservoir control, however, would usually be determined by the combination of the controlled flows with the flows from unregulated streams.

Flood flows at the five valley floor points of concentration were estimated for the floods which have occurred during the period of stream flow record, with the flood flows at the gaging stations of five of the major streams controlled to the amounts stated in the paragraph above. With the values of concentrated flows thus obtained, frequency curves were drawn in the same manner as previously described for the foothill gaging stations. These curves are shown on Plate IX and are in each case the left-hand curve for each station, indicated as the flows "with reservoir control." The amounts of flow at these five points on the valley floor, that would be exceeded with certain frequencies, are shown in Table 37.

TABLE 37

PROBABLE FREQUENCY OF FLOOD FLOWS AT POINTS OF CONCENTRATION ON SACRAMENTO VALLEY FLOOR

With Reservoir Control

Stream and point of concentration	Probable maximum mean daily flow, in second-feet, exceeded on average of once in:			
	10 years	25 years	50 years	100 years
Sacramento River and Sutter-Butte By-pass opposite Colusa	168,000	175,000	180,000	186,000
Sacramento River below Verona and Yolo By-pass at Fremont Weir	337,000	370,000	392,000	410,000
Sacramento River at Sacramento and Yolo By-pass at Lisbon	385,000	450,000	490,000	535,000
Feather River below confluence of Feather and Yuba rivers	178,000	190,000	195,000	201,000
Feather River below confluence of Feather and Bear rivers	210,000	218,000	221,000	226,000

In Table 38, comparisons are made of the sizes of floods which it was estimated would concentrate at the five valley floor points without and with control by reservoirs, for floods which may be exceeded with various frequencies in 100 years, on the average. These flood flows were derived from computations based on mean daily flows for floods which have occurred during the period of record.

TABLE 38

FLOOD FLOWS AT POINTS OF CONCENTRATION ON SACRAMENTO VALLEY FLOOR

Without and with Reservoir Control

Frequency with flood flows may be exceeded - times in 100 years, on the average	Probable maximum mean daily flow, in second-feet, in:									
	Sacramento River and Sutter-Butte By-pass opposite Colusa		Sacramento River below Verona and Yolo By-pass at Fremont Weir		Sacramento River at Sacramento and Yolo By-pass at Lisbon		Feather River below confluence of:			
							Feather and Yuba rivers		Feather and Bear rivers	
	Without reservoir control	[1]With reservoir control	Without reservoir control	[1]With reservoir control	Without reservoir control	[1]With reservoir control	Without reservoir control	[1]With reservoir control	Without reservoir control	[1]With reservoir control
1	370,000	186,000	540,000	410,000	670,000	535,000	400,000	201,000	430,000	226,000
2	325,000	180,000	490,000	392,000	580,000	490,000	365,000	195,000	379,000	221,000
4	286,000	175,000	440,000	370,000	518,000	450,000	320,000	190,000	330,000	218,000
10	236,000	168,000	370,000	337,000	430,000	385,000	250,000	178,000	258,000	210,000

[1] With following controlled flows: Sacramento River at Red Bluff, 125,000 second-feet; Feather River at Oroville, 100,000 second-feet; Yuba River at Smartsville, 70,000 second-feet; Bear River at Van Trent, 20,000 second-feet; and American River at Fairoaks, 100,000 second-feet.

In Table 39, there are shown the quantities for which it has been recommended that works be provided in the adopted Sacramento Flood

Control Project, and the number of times in 100 years, on the average, that these quantities would be exceeded without and with control by reservoirs.

TABLE 39

FREQUENCIES WITH WHICH QUANTITIES OF FLOW PROVIDED FOR IN THE ADOPTED SACRAMENTO FLOOD CONTROL PROJECT MAY BE EXPECTED TO BE EXCEEDED

Without and with Reservoir Control

	Points of concentration on Sacramento Valley floor				
	Sacramento River and Sutter-Butte By-pass opposite Colusa	Sacramento River at Verona and Yolo By-pass at Fremont Weir	Sacramento River at Sacramento and Yolo By-Pass at Lisbon	Feather River below confluence of	
				Feather and Yuba rivers	Feather and Bear rivers
Project quantity, in second-feet	260,000	470,000	600,000	277,000	295,000
Probable number of times quantity may be exceeded in 100 years, on the average—					
Without reservoir control	6.5	2.5	1.80	7.3	6.3
With reservoir control[1]	Less than once	Less than once	Less than once	Less than once	Less than once

[1] With following controlled flows: Sacramento River at Red Bluff, 125,000 second-feet; Feather River at Oroville, 100,000 second-feet; Yuba River at Smartsville, 70,000 second-feet; Bear River at Van Trent, 20,000 second-feet; and American River at Fairoaks, 100,000 second-feet.

It may be seen from Table 39 that the operation of the reservoirs shown in Table 36 specifically for flood control, employing the reserve space assigned to each reservoir for the purpose of controlling floods to the specified flows, would result in a substantial reduction of floods and in an increased degree of protection to the areas subject to overflow, particularly those within the Sacramento Flood Control Project, and therefore, would decrease the potential annual flood damages in those areas.

In the foregoing discussions, it has been assumed that floods would be controlled to 125,000 second-feet, at Red Bluff, exceeded once in 100 years, on an average. This control would be possible if the 512,000 acre-feet of storage space were available in the vicinity of Red Bluff. No site for a safe dam has been found so far in this vicinity, however, and therefore no reservoir near Red Bluff is included in the State Water Plan. The reservation of space in the Kennett reservoir for flood control is proposed, but about 28 per cent of the watershed of the Sacramento River above Red Bluff lies between Red Bluff and the Kennett dam site, and the Kennett reservoir, therefore, is not in a position to control flood flows originating in this area. It may be seen from the curves on Plate VIII that a flow of 187,000 second-feet, exceeded once in 100 years, on the average, may originate from the area between Red Bluff and Kennett. At the time of the passage of such a crest, all flow from above the Kennett reservoir could be held at that point and the maximum flow at Red Bluff, exceeded once in 100 years on the average, with flood control in the Kennett reservoir, therefore, would be 187,000 second-feet. From the same curves on Plate VIII, it may be seen that a flow of 125,000 second-feet from the area between Red Bluff and Kennett would be exceeded seven times in 100 years or once in fourteen years, on an average.

Table 40 sets forth, for various points on the Sacramento Valley floor, the flood flows exceeded once in 100 years, on an average, except as noted, without and with reservoir control. These flows are those that would obtain with the completed adopted Sacramento Flood Control Project, the protection of Butte Basin, the control of floods in the Kennett reservoir to the amounts above stated and the control of floods in the other reservoirs listed in Table 36 to the controlled flows shown in the same table.

TABLE 40

FLOOD FLOWS AT SEVERAL POINTS IN SACRAMENTO VALLEY

Without and with Reservoir Control

Stream and point of concentration	Maximum mean daily flow, in second-feet		Number of times flow would be exceeded, on the average
	Without reservoir control	With reservoir control	
Sacramento River at Red Bluff	303,000	[1]187,000	Once in 100 years
Sacramento River at Red Bluff	218,000	[1]125,000	Once in 14 years
Sacramento River and Sutter-Butte By-Pass opposite Colusa	370,000	250,000	Once in 100 years
Sacramento River and Sutter-Butte By-pass opposite Colusa	254,000	170,000	Once in 14 years
Sacramento River at Sacramento and Yolo By-pass at Lisbon	670,000	535,000	Once in 100 years
Feather River below confluence with Yuba River	400,000	201,000	Once in 100 years
Feather River below confluence with Bear River	430,000	226,000	Once in 100 years
American River at Fairoaks	185,000	80,000	Once in 250 years

[1] Floods would be controlled to 125,000 second-feet maximum flow exceeded once in 100 years on the average, except when this amount is exceeded by the uncontrolled run-off between Kennett reservoir and Red Bluff. Flows greater than 125,000 second-feet would continue for only a short time.

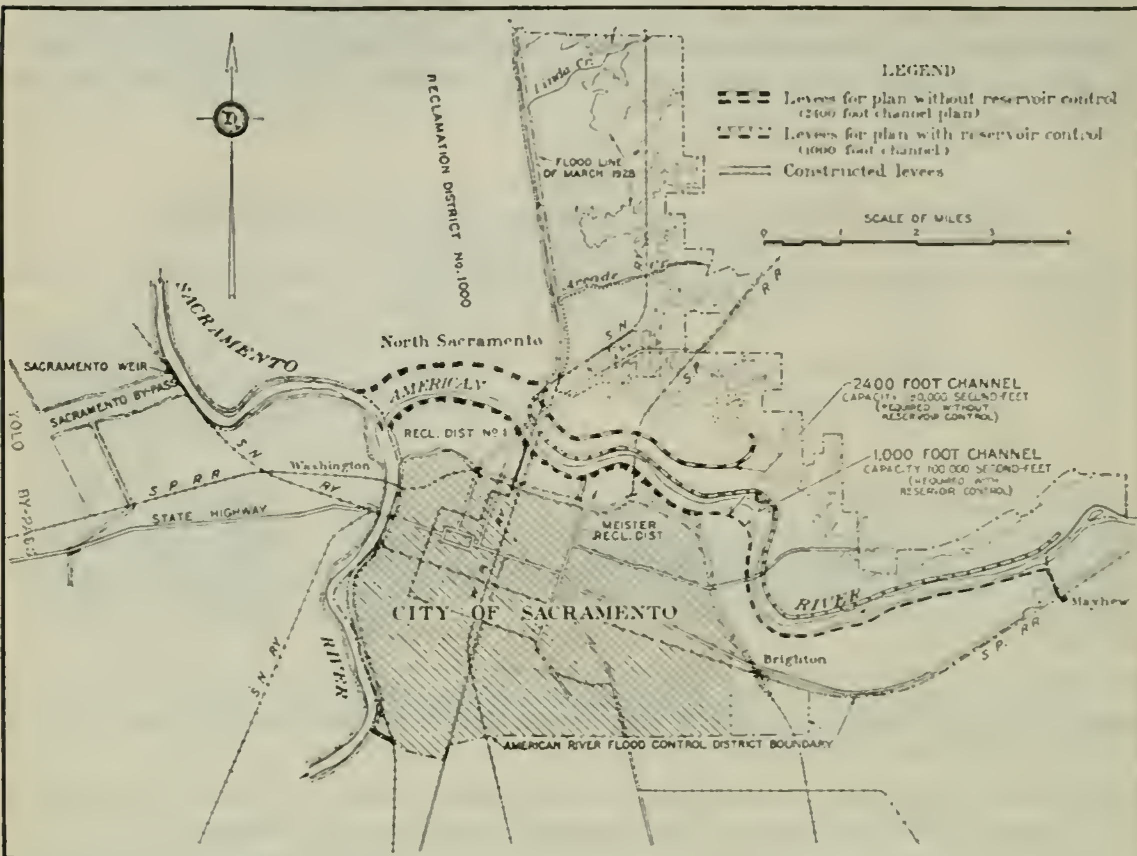
Effect of Utilization of Reservoirs of State Water Plan for Flood Control on Uncompleted Portions of Sacramento Flood Control Project.

It has been stated in an earlier portion of this chapter that the major unprotected areas which it is feasible to protect, are those along the American River opposite Sacramento, along the Feather River upstream from Honcut Creek, and along the Sacramento River upstream from Colusa. Reduction in the size of flood flows in these streams by reservoir control would greatly facilitate the protection of these areas.

American River.—The unprotected areas along the American River, while not large, include the city of North Sacramento and a considerable area of bottom land of excellent quality, and is crossed by one of the main state highways.

The State Legislature of 1927, at the request of interested parties, created the American River Flood Control District, which comprises the above areas, the city of Sacramento and contiguous unincorporated areas. The boundaries of this district and the area inundated by the flood of 1928 are shown on Plate XI. "Plans for Flood Control on American River." Owing to the large volume of flood discharge from the American River watershed, only a portion of these lands can be protected under conditions of unregulated flows, the remainder being necessary for an overflow flood channel. The greatest interest in protection from floods, therefore, centers in the urban districts of Sacramento and North Sacramento. While the city of Sacramento is well protected under present conditions, North Sacramento has no protection whatever and consequently suffers various amounts of damage from inundation in every flood year.

PLATE XI



PLANS FOR FLOOD CONTROL
ON
AMERICAN RIVER

Plans were recently adopted * by the American River Flood Control District for flood control works to protect lands along the south bank of the river from its mouth to a point opposite Mayhew, and on the north side of the river, the city of North Sacramento and its immediate vicinity, as shown on Plate XI. This plan contemplates protection from unregulated flood flows and proposes a channel of 2400 feet minimum width with a capacity of 180,000 second-feet. During the flood of March 25, 1928, the estimated crest flow at Fairoaks gaging station was 184,000 second-feet and at Sacramento 160,000 second-feet, the ratio being 1.15 to 1. The ratio of the same crest flow, 184,000 second-feet, to mean daily flow, 120,000 second-feet, at Fairoaks was 1.53 to 1. A flood of similar characteristics to produce a crest flow of 180,000 second-feet at Sacramento would have a crest flow at Fairoaks of 207,000 second-feet and a mean daily flow of 135,000 second-feet which, according to a curve shown in another report,** would be exceeded on an average of three days in 100 years, or one day in 33 years, on an average.

* Since the completion of the manuscript for this bulletin, bonds have been voted and contracts let for the construction of the works of the district.

** Bulletin No. 24, "A Proposed Major Development on American River," Division of Water Resources, 1930.

A very complete analysis of flood flows on the American River, the effect of the reservoirs of the State Water Plan in reducing the size of these flood flows, and the effect of the use of the reservoirs for flood control on their conservation values, was made during a previous investigation and the results of these studies are given in another report.* These studies show that by utilizing 175,000 acre-feet of space in the proposed Folsom reservoir, all floods would be regulated to a maximum discharge of 100,000 second-feet at Fairoaks gaging station with the probability that this flow would not be exceeded on an average of more than one day in 100 years. With the Auburn and Coloma reservoirs of the American River unit of the State Water Plan also constructed and operated for flood control, and with a total of 300,000 acre-feet of space reserved for flood control in these two reservoirs and the Folsom reservoir, the flow at Fairoaks could be controlled to 80,000 second-feet, exceeded on an average of one day in 250 years, or the 100,000 second-feet controlled flow could be maintained with the probability that it would be exceeded considerably less often than one day in 250 years, on the average. With control of floods by the Folsom reservoir alone, the flood protection works along the American River could be designed for a capacity of 100,000 second-feet, which would require a flood channel with an average width of only 1000 feet, as shown on Plate XI, and would give lower flood plane elevations than would be reached by the 180,000 second-foot flow in the 2400-foot channel. Also, with floods controlled by the Folsom reservoir, the protected lands would have an increased degree of protection since a flow of 180,000 second-feet might be exceeded on an average of three days in 100 years without reservoir control and the flow of 100,000 second-feet, with reservoir control, would be exceeded only one day in 100 years, on an average. In addition to the increased degree of protection, the cost of the levees and channel would be less and, the flood channel being confined practically to the river channel, nearly all the overflow lands could be protected and urban development could be carried almost to both banks of the river.

In the report to the Board of Trustees of the American River Flood Control District on flood control of the American River, under date of December, 1929, costs are given for protection of the district with plans embracing either the 1000-foot channel or the 2400-foot channel, as follows:

Total estimated costs with 2400-foot channel, 180,000 second-feet capacity	$2,257,218
Total estimated costs with 1000-foot channel, 100,000 second-feet capacity	1,426,065
Difference in total costs in favor of 1000-foot channel plan	$831,153

This saving of $831,153 by adopting the 1000-foot channel plan would be partly offset by the cost of flood control works in the Folsom dam, the net amount of which is estimated to be $590,000. The net saving in money, therefore, would be reduced to about $240,000.

* Bulletin No. 24, "A Proposed Major Development on American River," Division of Water Resources, 1930.

On the basis of cost per acre, the advantage is greatly in favor of the 1000-foot channel plan. Adding the cost of the district's works to the cost of the flood control works at the reservoir, the comparison becomes:

Plan	*Total cost*	*Acres protected*	*Average cost per acre*
2400-foot channel	$2,257,218	6544	$345
1000-foot channel	2,016,065	9883	204

The saving in cost under the 1000-foot channel plan, therefore, would be about a quarter of a million dollars, or $141 per acre. An additional area of land of 3340 acres also would be protected and this land would be greatly increased in value.

Feather River.—On no other stream in northern California is the peril of floods so great or so imminent as along the Feather River. On both banks of the stream from its junction with the Sutter By-pass to Oroville, the agricultural lands have been intensively developed to deciduous orchards and vineyards. From Marysville downstream to the mouth of Bear River, the capacity of the existing flood channel does not exceed 175,000 second-feet, a volume of flood flow expected to be exceeded once in four years, on the average. As a consequence, frequent breaches of levees have occurred. In Table 39, it is shown that the existing flood control project for this section when completed will provide protection only against a flood of a size expected to be exceeded on an average of once in fourteen years. Therefore, either under existing conditions or with the Sacramento Flood Control Project completed, the channel capacity may be exceeded at frequent intervals and the lands along both sides of the river endangered from overflow through the failure of the levees. On the other hand, with the flood control project completed and with flood flows controlled by the reservoirs of the State Water Plan on the Feather, Yuba and Bear rivers, the probability of damage from floods is so slight as to be negligible, for, as may be seen from Table 39 and Plate IX, a flood of such size that it would exceed the design capacity of the channel would occur with a frequency of much less than once in 100 years, on the average.

Upstream from Marysville, only a small portion of the levees has been raised to conform to the grade adopted in the Debris Commission plan while north of the Gridley bridge practically no levees have been constructed. No levees are proposed along the east bank north of Honcut Creek. Without levees on the west side, floods in excess of 100,000 second-feet will overtop the bank for a considerable distance and flow westward across improved lands, some of the water finding its way into Butte Basin. It is probable that the levees proposed for the Sacramento Flood Control Project will be constructed along this section of the river before a reservoir suitable for flood control is built in the lower Feather River canyon. These levees according to the Debris Commission plan would provide a channel capacity from Oroville to Marysville of 180,000 second-feet. This capacity is not quite equivalent to the maximum mean daily flow of record at Oroville which was 187,000 second-feet on March 19, 1907. From

Plate VIII, it may be seen that a mean daily flow of 180,000 second-feet at Oroville may be exceeded on an average of 3.6 times in 100 years or once in 27.8 years. Plate X shows that if 521,000 acre-feet of storage space were reserved for flood control in a reservoir in the canyon just above Oroville, flood flows could be reduced to 100,000 second-feet exceeded once in 100 years, on the average. If the flood control project were completed and the Feather River channel above Marysville had a capacity of 180,000 second-feet, flows could be controlled to this amount, exceeded on an average of once in 100 years, by the reservation of only 100,000 acre-feet of storage space. By the reservation of 521,000 acre-feet, the project levees would give protection against a flood that would occur with a frequency much less than once in 100 years, on an average. The control of floods by the Oroville reservoir, therefore, would permit the construction of lower levees from Oroville to Marysville or, if the project levees were constructed, would give a greatly increased degree of protection.

Sacramento River.—Plate VII shows that there is a large area of unprotected land along the Sacramento River above Colusa, most of which, about 135,000 acres, lies in Butte Basin. The protection of the land in Butte Basin is not proposed in the adopted Sacramento Flood Control Project since this would require the construction of a large by-pass through the basin and the extension of the levee along the east side of the Sacramento River. A plan for such protection is shown on Plate XII, "Plans for Flood Control in Butte Basin." Such construction would be expensive and it was believed that the benefits would not be equivalent to the cost. If, however, the maximum flood flows were reduced by reservoir control on the upper Sacramento River, the cost of the works necessary for the protection of Butte Basin would be reduced to a reasonable amount. A plan for protection with the flows controlled by reservoirs also is shown on Plate XII.

Table 39 shows that the flood control project channel capacity of 260,000 second-feet opposite Colusa would be exceeded once in fifteen years, on an average, without reservoir control. If the lands in Butte Basin were protected by a system of works designed for the project quantity of 260,000 second-feet, these works would be endangered by flows of a grater magnitude on an average of once in fifteen years. While these flows might not be large enough to overtop the levees, they would encroach on the freeboard and decrease the degree of protection. The cost of the works for protecting the lands in Butte Basin against a flow of 260,000 second-feet, divided between the Sacramento River and the by-pass through the basin, has been estimated to be about $12,680,000.

Plate IX shows that with a reservoir on the upper Sacramento River constructed and operated for flood control, the expected flow at Colusa exceeded on an average of once in fifteen years, would be 170,000 second-feet. Protection works designed for this quantity, therefore, would give the same degree of protection as those designed for the adopted Sacramento Flood Control Project quantity. This volume of flow could be confined to the river flood channel as far south as Colusa, at which point the flow in excess of the river channel capacity downstream from Colusa could be diverted through a short by-pass channel into Butte Slough By-Pass, as shown on Plate XII.

PLATE XII

PLANS FOR FLOOD CONTROL

IN

BUTTE BASIN

Under these conditions, the lands in Butte Basin could be protected with the degree of protection above set forth at a cost of about $3,250,000. This would permit a total saving in the cost of protection works of around $9,430,000 and would protect about 7000 acres more land than would be possible with protection against flood flows uncontrolled by reservoirs.

Estimates made, indicate that the drainage area tributary to the Sacramento River downstream from Kennett and upstream from Colusa might produce a flood at Colusa almost equal to the Sacramento Flood Control Project quantity of 260,000 second-feet on an average of once in 100 years. The effect of flood control by use of Kennett reservoir, therefore, would be to increase the degree of protection afforded by works constructed for the flood control project quantities. Without the Kennett reservoir operated for flood control, the project quantity might be exceeded on an average of once in fifteen years, but with the reservoir operated for flood control, the quantity probably would not be exceeded oftener than an average of once in 100 years.

Flood Control Value of Reservoirs of State Water Plan.

In the foregoing paragraphs the benefits that would be derived from the construction and operation of the Folsom and Kennett reservoirs in reducing the cost of protection of unprotected lands along the Sacramento and American rivers, respectively, have been shown. The effect of the Oroville reservoir in facilitating flood control along the Feather River above Honcut Creek and in increasing the degree of protection afforded by the works provided for in the Sacramento Flood Control Project also has been pointed out.

The Corps of Engineers, United States Army, recently completed a very comprehensive study showing the flood damages in the Sacramento Valley and the value of the operation of the major reservoir units of the State Water Plan in the Sacramento River Basin for flood control, in increasing the protection of the lands protected by the Sacramento Flood Control Project.

The methods employed by the Army engineers in estimating flood frequencies, flood damages and evaluation of the reservoirs for flood control have been made available by the Division Engineer, Pacific Division. The estimates of flood damages in the Sacramento Valley and Sacramento-San Joaquin Delta were based on those resulting from a flood of the size that would be exceeded only once in 200 years on the average. For these estimates, it was assumed that the Sacramento Flood Control Project was 100 per cent completed and that all channels would be maintained at full capacity. Butte Basin was assumed to remain unprotected as is proposed in the adopted flood control project. The Sacramento Valley and delta were divided into twelve zones in each of which it was assumed that the design capacity of the flood control project would be exceeded with certain frequencies at which flood damages would commence. The probable submerged area in the Sacramento Valley and delta resulting from a flood of 200 year frequency also was established and was divided into other areas of 100, 60 and 40 per cent damage from submergence, these factors being determined by the probable time the lands would remain submerged.

Consideration was also given to the losses that would accrue to several different kinds of development due to flooding.

For each zone, estimates were made of the average annual damages to be expected with the adopted flood control project and the expected damages with the combined flood control project and flood control by reservoirs of the State Water Plan. The differences between the two damages would be the value of flood control by reservoirs unless an equivalent added protection could be secured at lower cost by increasing flood channel capacities.

Damages were estimated for the submerged area of the valley as of the year 1930. For some items it was assumed that the damages would not increase and for others that they would become greater with increased development. Therefore, an estimate also was made of the damages as of the year 1950. The average of the estimated damages as of 1930 and 1950 was taken as the adopted damage for estimating values of further control of floods by reservoirs or enlarged leveed channels. In estimating the damages as of 1950, it was assumed that damages to railroads and levees and from erosion and costs of unwatering, would not increase. It also was assumed that urban damages and damages to live stock, highways and buildings would increase in direct proportion to the population increase in northern California. Damages to agriculture were estimated to increase, but not until after 1940 on account of the present state of agricultural development.

In estimating the flood control values of the major reservoir units of the State Water Plan, consideration also was taken of the cost of obtaining an equivalent increased protection by increased flood channel capacity, as previously mentioned. If the cost of obtaining the increased protection by levees and channels was less than the reduction in average annual flood damages capitalized at four per cent, the lesser cost was used as the flood control value of the reservoir. The flood control evaluation of the principal major reservoir units of the State Water Plan in the Sacramento River Basin, estimated as above described, are shown in Table 41, the data for which were made available by the Division Engineer.

TABLE 41

ESTIMATED FLOOD CONTROL VALUATION OF PRINCIPAL MAJOR RESERVOIR UNITS OF STATE WATER PLAN FOR SACRAMENTO RIVER BASIN

Estimate by Division Engineer, United States War Department

Reservoirs	Reduction in average annual flood damage	[1]Evaluation for flood control
Kennett	$163,994	$4,100,000
Oroville and Narrows	305,548	5,655,000
American River Unit (Folsom, Auburn and Coloma)	53,984	515,000

[1] Based on reduction in average annual flood damage, capitalized at 4 per cent, except when equivalent protection could be secured at a smaller figure by means of levees. In the latter case, estimated cost of levees is used.

While the valuations of the reservoirs for flood control shown in Table 41 are considerable amounts, they represent only those under the conditions set forth in the foregoing paragraphs. No values have been added for the decreased costs of protection along the American and Sacramento rivers that would be made possible by the operation of the reservoir units on the streams for flood control. The values also are based on conditions with Butte Basin remaining unprotected. If this basin were reclaimed, which is not at all unlikely in the future, the frequencies with which floods downstream from the basin would exceed the flood control project capacities would be increased and correspondingly the values of the reservoirs for flood control would be increased. The values also are based on the average damages that would result from flooding during the twenty-year period, 1930–1950. This is a relatively short period when compared to the lives of the reservoirs and it is probable that damages should be based on the increased values over a much longer period than twenty years.

All of the benefits evaluated and those mentioned above are direct benefits. In addition to these there are certain indirect benefits, the values of which might amount to a considerable sum. These benefits should be evaluated and added to the direct benefits in arriving at the capitalized values of the flood control benefits from the operation of the reservoirs for this purpose.

CHAPTER VII

NAVIGATION

Navigation on the Sacramento River is an important element in the transportation facilities in the Sacramento River Basin and is closely related to the State Water Plan. The water-borne commerce in the basin is large and substantial investments have been made in floating equipment and in terminal facilities. However, through the development of irrigation in the Sacramento Valley and the effect of hydraulic mining in the Sierra Nevada, the navigability of the Sacramento River has been greatly impaired and transportation has been almost abandoned on its tributaries. The economic importance of maintaining navigation on the Sacramento River is recognized generally by the local shippers, the State and the Federal government. The latter agency, in accord with its well established policy, has expended substantial sums in maintaining and improving the navigability of this stream. The low stream flow during recent dry years coupled with the increased irrigation diversions resulted in the reduction of depths in the Sacramento River above the city of Sacramento in the summer and fall months to such an extent that navigation was abandoned on this section of the river during these months. Such a condition is not desirable and points to the conclusion that the navigability of the Sacramento River, particularly above the city of Sacramento, should be improved.

The improvement of the Sacramento River for navigation could be effected by either of two methods. One would be to secure the necessary navigable depths by the installation of dams across the stream channel which would form pools above the dams and by incorporating locks in the dams to provide for the passage of the vessels. This is termed "canalization." The other method would be to supplement the stream flow by the release of water stored in upstream surface reservoirs in amounts sufficient at the proper time to provide the required depths for navigation. This method may be termed "stream-flow regulation." In the latter method, some dredging and wing dams would be required in certain sections of the stream. If the river were canalized, little or no additional water supply would be required, except perhaps in unusually dry years.

Under the stream-flow regulation method, an opportunity is afforded to improve and restore navigation on the Sacramento and Feather rivers by the utilization of the reservoirs of the State Water Plan for that purpose. The reservoirs which could be so utilized are the Kennett on the upper Sacramento River, Oroville on the Feather River, Narrows on the Yuba River and Folsom, Auburn and Coloma on the American River. The American River reservoirs would be useful in aiding navigation on the Sacramento River below the city of Sacramento and for a short distance up the American River. The Oroville and Narrows reservoirs could be utilized toward restoring navigation on the Feather River to a certain extent, and in aiding navigation below its confluence with the Sacramento River. The Kennett reservoir would be strategically located to improve the Sacramento River for navigation from its mouth upstream to Red Bluff, a distance of 249 miles. Therefore, it was deemed desirable to inquire into the feasibility and practicability of operating the foregoing reservoirs in the aid and improvement of navigation on the Sacramento River, particularly when combined with irrigation, salinity control, flood control and the generation of power.

Historical Summary.

The early settlement and the development of both the mining and agricultural industries in the Great Central Valley of California were greatly facilitated by the navigability of the rivers. Prior to the discovery of gold, the total population was small and white settlers were few in number. Navigation on the rivers of the valley was almost nonexistent. Early records indicate that the first large boat to use the Sacramento River was a thirty-ton schooner operated by Captain Sutter in 1840 between New Helvetia (Sacramento) and the Russian colony on the coast. Until 1848, it was the only boat regularly operated on the river.

Following the discovery of gold, immigrants rushed into the State in large numbers. They came either across the plains in caravans, by sea around Cape Horn, or trans-shipped by the Isthmus of Panama. Just what percentage the overland travel was of the total is not definitely known, but it is believed that the larger number of immigrants came by sea. The chief port of entry was San Francisco. While a great many disembarked at that place, a large number continued up the river to the inland ports in the same vessels that had carried them around Cape Horn or up the coast from Panama. For many years, the rivers remained the main arteries of communication and traffic between the mining communities and the outside world. Hydraulic mining debris had not yet begun to accumulate in the valley floor stream channels and there were no diversions of stream flows other than those for mining purposes, and these waters were returned to the rivers above the rim of the valley floor so that there was no impairment of the flow in the navigable channels. Under these conditions, ocean-going ships found easy access to the wharves and harbors of Stockton and Sacramento and even as far upstream as Marysville on the Feather River.

River transportation also developed between San Francisco and Sacramento, Stockton, and Marysville which were the principal terminals for the stage and freight lines running into the mining districts of the Sierra Nevada and State of Nevada. The amount of tonnage carried in the '50s and '60s is not recorded but it must have been large. Early writers state that at times the river at Sacramento was so crowded with shipping as to make loading and maneuvering difficult and confused. Rates were high, operators had a practical monopoly of trade, and carried on a profitable business.

In the early '70s water-borne commerce on the river began to suffer from competition by railroad lines. Rates were reduced, and the railroad, by granting rebates was able in some cases, to entirely eliminate river traffic. Coincident with the coming of railroad transportation was the descent of mining debris into the streams encumbering them with a deposit of sand and gravel amounting to a fill of over 7.5 feet at Sacramento and double that depth at Marysville. Subsequent to this time, for a number of years, river commerce was of little importance.

Traffic to Marysville ceased and has never been resumed to any great extent. Only the very light draft boats could reach Sacramento except for a few months of the year. Following close upon the incursion of mining debris came the closing down of the hydraulic mines which resulted in the falling off of commerce which was largely dependent upon the demands of the mining industry. Deep water vessels disappeared from the river and a desultory trade was left to the river boats plying between San Francisco and river ports.

The first congressional recognition given to the Sacramento River was on March 3, 1875, when an appropriation was made for improving navigation by the removal of snags and the construction of brush jetties. Since that date several appropriations have been made and the navigation project variously revised.

In 1893, congress passed "An act to create the California Debris Commission and regulate hydraulic mining in the State of California," which is sometimes called the "Caminetti Act." This act created the California Debris Commission with a membership of three officers of the corps of engineers, United States Army, and designated as some of the principal duties of the commission, the following:

> "That it shall be the duty of said commission to mature and adopt such plan or plans from examination, and surveys already made and from such additional examinations and surveys as it may deem necessary as will improve the navigability of all the rivers comprising said systems,* deepen their channels, and protect their banks.
>
> "Such plan or plans shall be matured with a view of making the same effective against the encroachment of and damage from debris resulting from mining operations, natural erosion, or other causes, with a view of restoring, as near as practicable and the necessities of commerce and navigation demand, the navigability of said rivers to the condition existing in eighteen hundred and sixty, and permitting mining by the hydraulic process, as the term is understood in said State, to be carried on, provided the same can be accomplished without injury to the navigability of said rivers or the lands adjacent thereto."

The most authentic evidence of what the condition of the Sacramento River had been was the survey of 1850 made by Commander Cadwalader Ringgold. In this year, the waterways from the Golden Gate to the confluence of the Sacramento and American rivers were surveyed. From the charts made from this survey, it has been ascertained that the minimum depth in the Sacramento River below Sacramento at lowest water was about 7 feet. This shallow depth was encountered at a point below the present site of Isleton.

The existing project for the improvement of navigation on the Sacramento River was adopted by several acts of Congress. The first of these was that approved March 3, 1899, which provided for a depth of 7 feet below Sacramento. Another act of July 25, 1912, provided for work above Sacramento and an act of January 21, 1927, provided for a 10-foot channel depth below Sacramento.

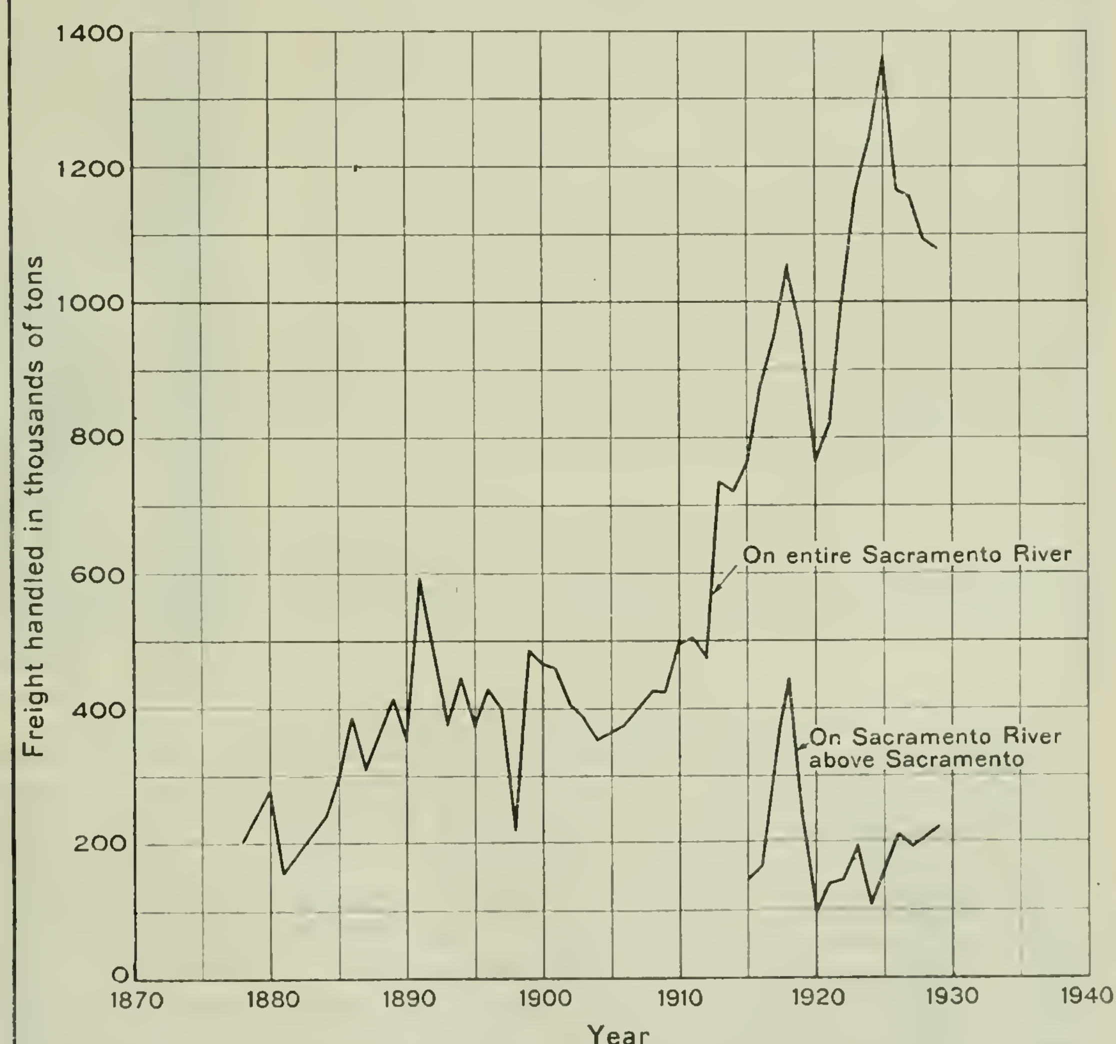
Growth of Navigation.

The revival of navigation has been mainly dependent upon and has kept pace with the growth of agriculture. Transportation from the areas bordering the rivers is furnished by floating equipment, railroads and trucks. The main line railroads are located on the higher land well back from the rivers and mostly above the rim of the flood plane but in recent years branch lines have been extended into the territory

* Sacramento and San Joaquin rivers.

along the rivers. The cost of truck haul to the river banks or railroad often determines whether the greatest economy of transportation is by rail or water. Good highways have been and are now being built into the areas bordering the rivers and much hauling of produce is done by trucks directly to the main centers of population. However, stimulated by transportation demands and protected from ruinous competition by State rate regulation, commerce on the Sacramento River has grown to proportions greater than ever before. This growth is shown by the upper graph on Plate XIII, "Growth of Commerce on Sacramento River," and by Table 42 which shows the number of tons of freight handled and its value, each year, as these data are given in the reports of the Chief of Engineers, United States Army. In this table and on the graph, it was attempted to eliminate all materials handled by the United States government for the improvement of the river channel and all water transported as freight.

PLATE XIII



GROWTH OF COMMERCE

ON

SACRAMENTO RIVER

TABLE 42

GROWTH OF COMMERCE ON SACRAMENTO RIVER

Year	Freight, in tons	Value, in dollars
1878	202,930	
1879		
1880	279,660	
1881	156,750	
1882		
1883		
1884	240,480	
1885	293,480	
1886	385,990	
1887	310,300	
1888		
1889	412,190	
1890	349,890	
1891	596,520	
1892	483,770	
1893	376,810	
1894	445,350	
1895	370,520	
1896	430,260	
1897	398,990	
1898	225,880	
1899	489,240	
1900	465,730	
1901	457,080	
1902	404,900	
1903	383,720	
1904	353,160	
1905	365,960	
1906	375,000	
1907	400,000	
1908	425,000	
1909	425,000	$29,750,000
1910	496,150	29,522,150
1911	505,290	32,139,050
1912	477,290	27,755,330
1913	733,590	35,856,790
1914	721,000	38,211,760
1915	766,940	38,027,700
1916	875,780	46,908,090
1917	947,690	96,820,990
1918	1,053,510	113,991,120
1919	953,530	78,574,160
1920	764,140	53,279,490
1921	819,570	51,856,940
1922	1,008,510	60,386,530
1923	1,159,490	62,460,240
1924	1,241,510	58,618,000
1925	1,366,780	80,495,800
1926	1,168,700	85,311,480
1927	1,157,750	78,615,360
1928	1,092,290	77,745,190
1929	1,079,240	74,084,050

The table shows that the peak year was 1925 when 1,366,780 tons of freight were handled. The value of the freight during this year, however, was not as great as in 1918 when 1,053,510 tons with a value of $113,991,120, were handled. From 1890 to 1909, the tonnage did not increase, on the average. In 1912, the tonnage was only about 52,000 tons greater than in 1909 but from 1912 to 1918 there was a large increase amounting to 576,000 tons per year. During the 10-year period, 1920–1929, inclusive, the tonnage fluctuated between the high point of 1925 and the low point of 764,140 tons in 1920, the average for the period being 1,086,000 tons per year. In the same 10-year period, the values of the freight ranged from the high of $85,311,480 in 1926 to a low of $51,856,940 in 1921 with an average value for the period of $68,285,500 per year.

Very few ocean-going ships navigate the Sacramento River as far upstream as the city of Sacramento and these only at times of high water. The commerce on the river is carried on mostly by means of vessels designed especially for river traffic but many of these are much larger than the ocean-going ships once commonly seen on the river. Much of the produce carried by these river vessels is transferred to ocean-going ships at San Francisco Bay ports or to rail carriers at river or bay ports and is carried by them to foreign markets or markets in other parts of the United States. The river commerce therefore is not only intrastate but also a unit of the foreign and interstate commerce of California.

There are now over 40 individuals and companies operating freight-carrying vessels on the Sacramento River. Most of the vessels are stern-wheel steamers and small motor-driven screw tugs. Both of these are used to a large extent for the towing of barges. The largest steamer operating regularly below Sacramento has a length of 250 feet, a beam of 58 feet and a draft when loaded of 8 feet. Smaller steamers are used on the river above Sacramento, the largest being 150 feet in length with a beam of 33 feet and a draft when loaded of 3 feet. The barges have sizes up to a length of 232 feet with a 42-foot beam. In 1929, the total net registered tonnage of all steamers, motor vessels and barges on upstream trips was 2,145,840 and the total net registered tonnage for all vessels on downstream trips was 1,911,260.

While the increase in commerce on the Sacramento River is notable, it is less than would have occurred had the development of the navigation project upstream from Sacramento been completed and channel conditions permanent and adequate for the class of navigation equipment operated on the river. In 1924, the following statement was made by the District Engineer, United States War Department, in his report* on the preliminary examination of the Sacramento and San Joaquin rivers:

> "The amount of freight available for carriage on the river between Colusa and the city of Sacramento has increased enormously in recent years and the only company operating vessels on this stretch for several years has had more freight offered than the available equipment could carry under existing channel conditions."

TABLE 43

GROWTH OF COMMERCE ON SACRAMENTO RIVER ABOVE SACRAMENTO

Year	Freight, in tons	Value, in dollars
1915	146,720	----------
1916	168,160	----------
1917	323,000	34,928,030
1918	443,050	49,229,620
1919	237,960	19,805,560
1920	94,570	5,454,250
1921	139,750	5,878,360
1922	145,650	5,188,840
1923	192,010	6,341,770
1924	109,160	3,517,920
1925	163,560	8,505,020
1926	212,990	8,297,720
1927	195,210	9,165,870
1928	208,370	8,043,630
1929	223,570	9,032,320

* House Document No. 123, 69th Congress, First Session.

The annual tonnages of freight carried on the Sacramento River above Sacramento and the values of this freight, for the 15-year period 1915–1929, inclusive, are shown in Table 43. The variations in tonnage are shown by the lower graph on Plate XIII.

Existing Navigation Project.

The existing project for the improvement of navigation on the Sacramento River extends from its mouth to Red Bluff, a distance of 249 miles. This project was adopted by a river and harbor act approved March 3, 1899, and two acts since that time. The controlling depths during the low water season are:

	Miles	*Minimum depth, in feet*
Mouth to Sacramento	59.0	10
Sacramento to Colusa	86.2	4
Colusa to Chico Landing	51.3	3

Beyond Chico Landing, 52.4 miles to Red Bluff, such depth is to be maintained as is practicable.

The Feather River is a navigable stream to a point a short distance above the mouth of the Yuba River and the American River, with sufficient water, could be navigated for about two miles above its mouth. Navigation on both of these streams, however, has been negligible for many years.

Progress toward the completion of the Sacramento River project has been steady. Reclamation projects along the river have been of great assistance in the work as vast quantities of material have been dredged from the river channel and placed upon the levees. In addition to this benefit, the confining of flood flows to the channel has promoted scouring and the transportation of mining debris and the products of natural erosion downstream to the bay. The condition of the project as of the present date as given* by the Division Engineer, Pacific Division, United States War Department, is as follows:

"Project depth has been secured in the new 10-foot channel to Sacramento, and this channel as a whole is about 90 per cent completed. Due to the amounts of water drawn from upper reaches for irrigation, and to the low natural flow, project depths are not maintained in summer above Sacramento. The controlling low water depth between Sacramento and Colusa is from 2½ to 3½ feet, dependent upon the season, between Colusa and Sidds Landing, 179 miles above the mouth (8 miles above Butte City) from 2 to 2½ feet. There is no regular navigation above Sidds Landing, and no maintenance work has been done above this point since 1921. Navigation is usually maintained, subject to considerable delay, to Colusa throughout the year. Above Colusa navigation has been suspended entirely from about the middle of June to the middle of August or September.

"During the high water period from February to May considerably better than project depths usually obtain and boats drawing 4 feet can be taken to Red Bluff except when obstructed by snags above Sidds Landing. Wing dams have been built and maintained at practically all shoals below Sacramento and above Sacramento to the mouth of the Feather River. Dredging to supplement action of the wing dams and to maintain project depth in Sacramento Harbor is being done annually, also snagging below Sidds Landing."

Large investments have been made in terminal facilities along the Sacramento River. Between the mouth of the river and Sacramento, excluding Rio Vista, there are seventeen large wharves, about thirty-six large warehouses and many small warehouses and landings. At Rio Vista there are 1440 lineal feet of wharves with warehouse facilities, at Sacramento there are 4734 lineal feet of wharves with 230,700 square

* House Document No. 791, 71st Congress, Third Session.

feet of warehouse space, and at West Sacramento there are 360 lineal feet of wharves and 108,560 square feet of warehouse space. There are no large wharves between Sacramento and Chico Landing but there are a number of small landings. Along this stretch of the river, there are 47 warehouses all close to the river bank. About one-half of these warehouses are between Sacramento and Colusa and half between Colusa and Chico Landing.

Potential Commerce.

Under existing conditions, river transportation is in competition with that by railroads and truck lines. The Sacramento River is paralleled by two lines of the Southern Pacific Railroad, and the Western Pacific Railroad and the Sacramento Northern (electric) Railway. The area tributary to the river is traversed by many improved highways over which motor trucks may be easily operated. The more direct routes of rail and highway carriers offer greater flexibility of operation particularly with reference to terminal facilities and gives them an advantage with present conditions of navigation, in competing for the transportation business of the area. An analysis of motor truck transportation was recently made by the Corps of Engineers, United States Army, and the conclusions* of the Division Engineer, Pacific Division, are as follows:

> "In recent years the development of motor truck transportation in California has been rapid and at the expense of both the railway and the waterway. A careful analysis of the situation, however, leads to the conclusion that while the motor truck has undoubtedly come to stay, the present volume of its traffic in the Great Central Valley is stimulated by rates less than actual transportation costs and can not be maintained. After the inevitable readjustment, the railroad will remain the principal competitor of the waterway in the movement of the bulk commodities."

Since navigation on the Sacramento River below the city of Sacramento is now well maintained, discussion will be confined to further improvement of the section of the river above Sacramento. On this section of the river, navigation facilities should be improved. The past and present tonnage carried on this portion of the river has been shown in Table 43. Excluding the years 1920 and 1924, which were seasons of low run-off and in which navigation on the upper Sacramento River was greatly impaired by low stream flow, the tonnage carried in the other years during the past decade indicate a growth in commerce of about 75 per cent during the period. Data collected and made available by the Division Engineer, United States War Department, show that railroads competing with transportation by water carried about 367,000 tons of freight in 1928 into and out of the counties of Sutter, Colusa, Butte and Glenn, and that in addition to this there were 208,000 tons carried on the river, or a total for both means of transportation of 575,000 tons moving on and parallel to the river, into and out of the area. The Division Engineer estimates that if there were a dependable six foot depth of channel from Sacramento to Chico Landing, the waterway would now be carrying at least one-half of the total commerce of the area. He also forecasts that the commerce on the river would increase at the rate of 50 per cent per decade up to 1960, that

* House Document No 791, 71st Congress, Third Session.

the potential commerce on the Sacramento River upstream from Sacramento would be as follows:

1930—280,000 tons
1940—420,000 tons
1950—630,000 tons
1960—945,000 tons

and that the average annual tonnage for the 30-year period would be 570,000 tons.

Improvement of Navigation on Sacramento River above Sacramento.

Navigation above Sacramento can be improved in either of two ways, by "canalization" or by "stream-flow regulation," as these terms have been defined near the beginning of this chapter.

The Corps of Engineers, United States Army, has made preliminary studies to determine the cost of canalization features of the Sacramento River between Sacramento and Chico Landing and the results of these studies are shown in a recent report* by the Division Engineer. He estimates that canalization for the maintenance of a six-foot channel depth would require the construction of six movable dams, with locks incorporated into them for the passage of vessels. The locks would be 56 feet wide and 360 feet long and would have lifts of 14 to 21 feet. The estimated capital cost of canalization of this section of the river, including the necessary levees and dredging, is $7,400.000. The annual costs were estimated to be $350,000.

The Division Engineer also estimates that a dependable channel depth of six feet could be provided in the Sacramento River between the city of Sacramento and Chico Landing by the method of stream-flow regulation. To maintain this depth he estimates that few or no additions to the present contraction works would be necessary as far upstream as Colusa but that from Colusa to Chico Landing several channel contractions and dykes and some dredging and snagging would be required. It was estimated by him that the work between Colusa and Chico Landing would have an initial cost of $330,000. He also estimated that to maintain the channel from Sacramento to Chico Landing would cost $55,000 per year, which is the same as the present cost of maintenance of the section from Sacramento to Sidds Landing, which is not as far upstream as Chico Landing.

Effect of Operation of Units of State Water Plan on Navigation.

The operation of the Kennett reservoir on the upper Sacramento River to maintain a flow of not less than 5000 second-feet in the Sacramento River, if combined with the contraction, dredging, snagging and maintenance work proposed by the Army engineers, would provide required depths for navigation as far upstream as Chico Landing and would improve present depths upstream to Red Bluff. It would also effect a considerable reduction in the cost of maintaining the ten-foot project channel depth below Sacramento.

The Oroville and Narrows reservoirs on the Feather and Yuba rivers, respectively, would have some effect in improving navigation

* House Document No. 791, 71st Congress, Third Session.

conditions on the Feather River but would only improve those on the Sacramento River below the mouth of the Feather River. The Army engineers believe that such an improvement would not affect the Sacramento River far enough upstream to have any real value in rate reductions and therefore no material navigation benefit on the Sacramento River would result from these reservoirs.

The American River reservoirs, Folsom, Auburn and Coloma, if operated for salinity control, navigation, and to supply irrigation water to the Sacramento-San Joaquin Delta or San Joaquin Valley, would increase the low water flows in the American River and in the Sacramento River below Sacramento. This would have some effect in improving navigation conditions on the lower American River and, if navigation on the upper Sacramento River were not improved by the operation of the Kennett Reservoir, would have some effect in reducing the maintenance costs for navigation below Sacramento. These reservoirs would have no effect on the Sacramento River above Sacramento.

Economic Value of Improvement of Navigation Conditions.

As previously stated, the reservoirs of the American River unit and the Oroville and Narrows reservoirs would effect some reduction in the present annual cost of maintaining the ten-foot depth of channel in the Sacramento River below Sacramento and the latter two reservoirs would improve conditions between Sacramento and the mouth of the Feather River. However, since Kennett reservoir, if operated for the improvement of navigation as one of its principal functions, also would accomplish these same benefits, the value of the American River, Oroville and Narrows reservoirs for the improvement of navigation on the Sacramento River would be small, if anything, with Kennett reservoir in operation. No values in dollars have been placed on the improvements that would be effected by reservoirs other than the Kennett.

The effect of navigation conditions on the Sacramento River above Sacramento is reflected by the freight rates on shipments by water. Comparative freight rates for rail and water transportation on certain bulk commodities between San Francisco and three points in the Sacramento Valley, as quoted by the Railroad Commission of California, are given in Table 44. It may be seen from this table that the rates by water to Colusa on most commodities are either almost equal to, or higher than, the rates by rail, and that to Butte City, the rates by water are higher on all items. These higher rates may be accounted for by the inadequate channel depths and the intermittent character of navigation. The difference in the rates, however, is actually not quite as extreme as is indicated by the table since the water rates in some cases include a handling charge which is not included in the rail rate.

In arriving at the value of the benefits that would result from further improvement of navigation on the Sacramento River above Sacramento, the Army engineers in recent studies that have been made available by the Division Engineer, have based their estimates on the savings in transportation costs on freight that would be moved on this improved section of the waterway only. Their method of estimating the present and future tonnage of freight which would be moved over an improved waterway into and out of the area which they considered tributary to the river above Sacramento has already been given under "Potential Commerce." The tributary area was taken as the counties of Colusa, Sutter, Butte and Glenn, which extend only as far north as Chico and Stony Creeks, and does not include any of Yolo County. In estimating the present tonnage of freight movements no allowance was made for shipments by motor trucks, which are undoubtedly considerable amounts.

TABLE 44

RAIL AND WATER FREIGHT RATES

Commodity	Rates, per ton, between San Francisco and—					
	Sacramento		Colusa		Butte City	
	Rail	Water	Rail	Water	Rail	Water
	90.3 miles	108.1 miles	134.3 miles	194.4 miles	147 miles	220.3 miles
Canned food products	$2 50	$2 10	$7 60	$5 90	$5 00	$7 50
Fruits, dried	3 00	2 30	4 30	3 85	4 60	5 20
Fuel oil	2 30	2 10	3 60	5 90	3 60	7 50
Gasoline	2 40	2 10	4 60	5 90	4 60	7 50
Grain	2 10	2 10	3 60	3 50	3 60	4 10
Hay	2 00	3 40	3 50	4 05	3 20	4 05
Rice (paddy)	3 70	2 10	3 60	3 50	3 60	4 10

From a study of present transportation costs and freight rates and those which should exist after the improvement of navigation on the Sacramento River above Sacramento, the Army engineers estimated that the average saving in transportation costs on freight moving over the improved waterway should be at least 50 cents per ton. Using their method of applying this 50 cents per ton saving to the estimated average annual tonnage of freight moved on the Sacramento River above Sacramento, the average of 570,000 tons per year for the next thirty years would give a total average annual saving of $285,000 for the same period. This amount capitalized at four per cent gives $7,125,000 as the value of the proposed improvement of the Sacramento River from Sacramento to Chico Landing, in the interest of navigation.

No detailed study has been made by this division of the economic value of the improvement of navigation on the Sacramento River. It is believed, however, that certain changes should be made in the method used by the Army engineers in obtaining such values, and that with such changes considerably greater values would result.

In determining the value of improvement in navigation conditions on other rivers throughout the United States, the stream has been considered by the Army engineers as a whole and has not been divided, as has been done on the Sacramento River, into separate units. If this were done for the Sacramento River, shipments to and from the entire Sacramento Valley, instead of those from four counties, would be considered as a unit in estimating the value of the improved navigation. Also, the potential water-borne commerce is likely to be drawn not only from those counties actually bordering on the river but from some of the more distant foothill and mountain areas as well. Considerable freight is now shipped by motor truck between the San Francisco Bay area and Sacramento and these mountain sections, and much of this commerce, with adequate navigation facilities, would be carried by water for part of the distance.

In estimating the value of improved navigation conditions in reducing freight rates, the Army engineers have applied a saving of 50 cents per ton to the potential water-borne tonnage on the Sacramento River above Sacramento only. The reduction in rates on freight transported by water, which would undoubtedly follow the improvement of navigation conditions and might be even much greater than 50 cents per ton, would also probably compel a corresponding reduction in rates by competitive rail and truck transportation facilities. The benefit value of improved navigation in reducing transportation costs therefore should not be confined to shipments by water only, but should be applied to all freight moving into and out of the entire Sacramento Valley which is capable of being moved over the waterway.

While the Army engineers have based their estimated value of the improvement of navigation above Sacramento on the potential shipments in the 30-year period 1930–1960, it is believed that a longer period is justified. The use of a longer period would probably give an increased average annual tonnage and an increased saving in transportation costs.

By incorporating all of the above changes into the method of estimating the value of improved navigation on the Sacramento River above Sacramento, this value undoubtedly would be much larger than that obtained by the Army engineers. It is even probable that the value would be at least equal to the cost of improvement of navigation by the canalization of the river from Sacramento to Red Bluff.

If these same improved navigation conditions could be obtained with the Kennett reservoir operating for that purpose, and it is believed at this time that they could be so obtained with some additional channel improvement, the value of the reservoir for the improvement of navigation would be equal to the cost of canalization of the river less the cost of open channel improvements with stream regulation.

CHAPTER VIII

POWER DEVELOPMENT AND VALUES

In the State Water Plan for the Sacramento River Basin, it is proposed that hydroelectric power plants be installed where the generation of hydroelectric energy is economically feasible. The power resource is a valuable one. The revenues which could be obtained from the sale of electric energy would be of substantial assistance in financing the projects because in most instances the potential energy output is large. Therefore, it is important and desirable not only to estimate the amount of electric energy which could be generated at each particular project but also to study and determine, as nearly as possible, the rate at which the electric energy output could be absorbed in the available power market, the total time required for such absorption under certain conditions and the unit values of the energy outputs at the points of generation. The studies and analyses of the power outputs for the several units are described in Chapter IX. The other items are discussed in this chapter, preceded by a general discussion of the electric power development in California.

Present Development.

The electric power system of California as of December 31, 1930, included 113 hydroelectric plants, total capacity 1,725,635 kilovolt amperes, and 28 steam-electric plants, total capacity 1,113,195 kilovolt amperes, or a grand total of all plants of 2,838,830 kilovolt amperes; and extensive interconnected transmission and distribution systems serving all except the sparsely settled portions of the State. The locations of the hydroelectric and steam-electric plants, main transmission lines and main substations as of December 31, 1930, are shown on Plate XIV, "Electric Power Production and Transmission Systems in California, December 31, 1930." The proposed power plants of the State Water Plan also are shown. The features shown on the plate are listed, with their index numbers or letters, in Table 45.

TABLE 45

EXISTING POWER PLANTS AND MAIN SUBSTATIONS IN CALIFORNIA, DECEMBER 31, 1930, AND PROPOSED POWER PLANTS OF STATE WATER PLAN

EXISTING POWER PLANTS

Group	*System*	*Company and plant*	*Classification*	*Index number*	*Capacity in kilovolt amperes*
Northern	I	CALIFORNIA OREGON POWER CO.			
		Fall Creek	Hydroelectric	1	2,750
		Copco No. 1	Hydroelectric	2	25,000
		Copco No. 2	Hydroelectric	3	30,000
		Shasta River	Hydroelectric	4	360
		Headlight	Hydroelectric	5	----

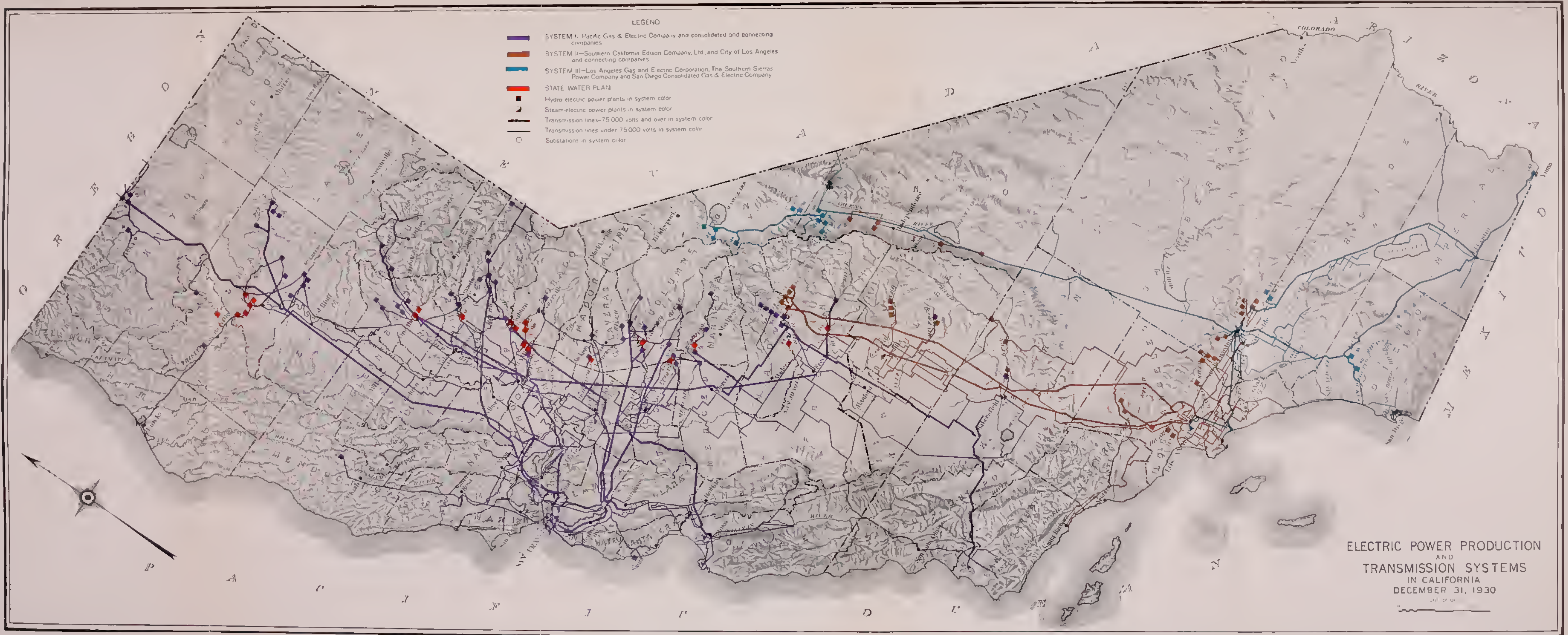

LEGEND
SYSTEM I—Pacific Gas & Electric Company and consolidated and connecting companies
SYSTEM II—Southern California Edison Company, Ltd., and City of Los Angeles and connecting companies
SYSTEM III—Los Angeles Gas and Electric Corporation, The Southern Sierras Power Company and San Diego Consolidated Gas & Electric Company
STATE WATER PLAN
Hydro electric power plants in system color
Steam-electric power plants in system color
Transmission lines—75,000 volts and over in system color
Transmission lines under 75,000 volts in system color
Substations in system color
ELECTRIC POWER PRODUCTION
AND
TRANSMISSION SYSTEMS
IN CALIFORNIA
DECEMBER 31, 1930

TABLE 45—Continued

EXISTING POWER PLANTS AND MAIN SUBSTATIONS IN CALIFORNIA, DECEMBER 31, 1930, AND PROPOSED POWER PLANTS OF STATE WATER PLAN

Group	*System*	*Company and plant*	*Classification*	*Index number*	*Capacity in kilovolt amperes*
Northern	I	PACIFIC GAS AND ELECTRIC CO. AND ITS SUBSIDIARY COMPANIES			
		Pit No. 1	Hydroelectric	6	70,000
		Pit No. 3	Hydroelectric	7	81,000
		Hat Creek No. 1	Hydroelectric	8	12,500
		Hat Creek No. 2	Hydroelectric	9	12,500
		Eureka	Steam-electric	10	9,000
		Junction City	Hydroelectric	11	1,970
		Kilarc	Hydroelectric	12	3,000
		Cow Creek	Hydroelectric	13	1,500
		Volta	Hydroelectric	14	7,000
		Coleman	Hydroelectric	15	16,500
		Inskip	Hydroelectric	16	6,000
		South	Hydroelectric	17	4,000
		De Sabla	Hydroelectric	18	13,000
		Centerville	Hydroelectric	19	6,400
		Lime Saddle	Hydroelectric	20	2,000
		Coal Canyon	Hydroelectric	21	1,000
		Bullards Bar	Hydroelectric	22	8,125
		Colgate	Hydroelectric	23	15,575
		Spaulding No. 1 and No. 2	Hydroelectric	24	11,750
		Spaulding No. 3	Hydroelectric	24–a	7,000
		Deer Creek	Hydroelectric	25	6,875
		Drum	Hydroelectric	26	55,000
		Alta	Hydroelectric	27	2,000
		Halsey	Hydroelectric	28	12,500
		Wise	Hydroelectric	29	12,500
		El Dorado	Hydroelectric	30	25,000
		American River	Hydroelectric	31	6,105
		Folsom	Hydroelectric	32	3,750
		Sacramento, Station "B"	Steam-electric	33	17,500
		Electra	Hydroelectric	34	20,000
		Spring Gap	Hydroelectric	35	7,500
		Stanislaus	Hydroelectric	36	34,000
		Phoenix	Hydroelectric	37	1,875
		Melones	Hydroelectric	38	27,000
		Stockton	Steam-electric	39	1,500
		North Beach	Steam-electric	40	27,000
		San Francisco, Station "A"	Steam-electric	41	80,000
		Oakland, Station "C"	Steam-electric	42	62,000
		Monterey	Steam-electric	43	1,000
		Salinas	Steam-electric	43–a	300
		Potter Valley	Hydroelectric	46	9,000
Northern	I	CITY OF SAN FRANCISCO			
		Cherry Creek	Hydroelectric	44	3,000
		Moccasin Creek	Hydroelectric	45	80,000
Northern	I	EAST BAY MUNICIPAL UTILITY DIST.			
		Pardee	Hydroelectric	34–a	18,750
Northern	I	UTICA MINING CO.			
		Murphy	Hydroelectric	47	1,500
		Angels	Hydroelectric	48	650
Northern	I	COAST COUNTIES GAS AND ELECTRIC CO.			
		Big Creek (Swanton)	Hydroelectric	49	990
Northern	I	WEST SIDE LUMBER CO.			
		Tuolumne	Steam-electric	52	----
Northern	I	SIERRA PACIFIC POWER CO.			
		Farad	Hydroelectric	53	1,500
Northern	I	GREAT WESTERN POWER CO. OF CALIFORNIA			
		Caribou	Hydroelectric	54	66,670
		Bucks Creek	Hydroelectric	55	50,000
		Las Plumas	Hydroelectric	56	65,000
		North Beach	Steam-electric	57	16,000
		Phelan	Steam-electric	58	1,500
		Bush	Steam-electric	59	5,000
		Oakland	Steam-electric	60	10,500
		Hunters Point	Steam-electric	60–a	43,750

TABLE 45—Continued

EXISTING POWER PLANTS AND MAIN SUBSTATIONS IN CALIFORNIA, DECEMBER 31, 1930, AND PROPOSED POWER PLANTS OF STATE WATER PLAN

Group	System	Company and plant	Classification	Index number	Capacity in kilovolt amperes
Northern	I	PACIFIC GAS AND ELECTRIC CO. AND ITS SUBSIDIARY COMPANIES			
		Pit No. 1	Hydroelectric	6	70,000
		Pit No. 3	Hydroelectric	7	81,000
		Hat Creek No. 1	Hydroelectric	8	12,500
		Hat Creek No. 2	Hydroelectric	9	12,500
		Eureka	Steam-electric	10	9,000
		Junction City	Hydroelectric	11	1,970
		Kilarc	Hydroelectric	12	3,000
		Cow Creek	Hydroelectric	13	1,500
		Volta	Hydroelectric	14	7,000
		Coleman	Hydroelectric	15	16,500
		Inskip	Hydroelectric	16	6,000
		South	Hydroelectric	17	4,000
		De Sabla	Hydroelectric	18	13,000
		Centerville	Hydroelectric	19	6,400
		Lime Saddle	Hydroelectric	20	2,000
		Coal Canyon	Hydroelectric	21	1,000
		Bullards Bar	Hydroelectric	22	8,125
		Colgate	Hydroelectric	23	15,575
		Spaulding No. 1 and No. 2	Hydroelectric	24	11,750
		Spaulding No. 3	Hydroelectric	24–a	7,000
		Deer Creek	Hydroelectric	25	6,875
		Drum	Hydroelectric	26	55,000
		Alta	Hydroelectric	27	2,000
		Halsey	Hydroelectric	28	12,500
		Wise	Hydroelectric	29	12,500
		El Dorado	Hydroelectric	30	25,000
		American River	Hydroelectric	31	6,105
		Folsom	Hydroelectric	32	3,750
		Sacramento, Station "B"	Steam-electric	33	17,500
		Electra	Hydroelectric	34	20,000
		Spring Gap	Hydroelectric	35	7,500
		Stanislaus	Hydroelectric	36	34,000
		Phoenix	Hydroelectric	37	1,875
		Melones	Hydroelectric	38	27,000
		Stockton	Steam-electric	39	1,500
		North Beach	Steam-electric	40	27,000
		San Francisco, Station "A"	Steam-electric	41	80,000
		Oakland, Station "C"	Steam-electric	42	62,000
		Monterey	Steam-electric	43	1,000
		Salinas	Steam-electric	43–a	300
		Potter Valley	Hydroelectric	46	9,000
Northern	I	CITY OF SAN FRANCISCO			
		Cherry Creek	Hydroelectric	44	3,000
		Moccasin Creek	Hydroelectric	45	80,000
Northern	I	EAST BAY MUNICIPAL UTILITY DIST.			
		Pardee	Hydroelectric	34–a	18,750
Northern	I	UTICA MINING CO.			
		Murphy	Hydroelectric	47	1,500
		Angels	Hydroelectric	48	650
Northern	I	COAST COUNTIES GAS AND ELECTRIC CO.			
		Big Creek (Swanton)	Hydroelectric	49	990
Northern	I	WEST SIDE LUMBER CO.			
		Tuolumne	Steam-electric	52	----
Northern	I	SIERRA PACIFIC POWER CO.			
		Farad	Hydroelectric	53	1,500
Northern	I	GREAT WESTERN POWER CO. OF CALIFORNIA			
		Caribou	Hydroelectric	54	66,670
		Bucks Creek	Hydroelectric	55	50,000
		Las Plumas	Hydroelectric	56	65,000
		North Beach	Steam-electric	57	16,000
		Phelan	Steam-electric	58	1,500
		Bush	Steam-electric	59	5,000
		Oakland	Steam-electric	60	10,500
		Hunters Point	Steam-electric	60–a	43,750

TABLE 45—Continued

EXISTING POWER PLANTS AND MAIN SUBSTATIONS IN CALIFORNIA, DECEMBER 31, 1930, AND PROPOSED POWER PLANTS OF STATE WATER PLAN

Group	System	Company and plant	Classification	Index number	Capacity in kilovolt amperes
Northern	I	SAN JOAQUIN LIGHT AND POWER CORPORATION			
		Mountain King	Hydroelectric	62	350
		Merced Falls	Hydroelectric	63	4,000
		Crane Valley	Hydroelectric	64	1,000
		San Joaquin No. 1	Hydroelectric	65	16,000
		San Joaquin No. 1-A	Hydroelectric	66	425
		San Joaquin No. 2	Hydroelectric	67	3,000
		San Joaquin No. 3	Hydroelectric	68	3,750
		Kerckhoff	Hydroelectric	69	42,600
		Balch	Hydroelectric	70	33,000
		Tule River	Hydroelectric	71	6,000
		Kern Canyon	Hydroelectric	72	10,600
		Bakersfield	Steam-electric	73	26,550
		Midway	Steam-electric	74	25,000
		Betteravia	Steam-electric	75	2,500
Northern	I	MERCED IRRIGATION DISTRICT			
		Exchequer	Hydroelectric	76	31,250
Northern	I	TURLOCK-MODESTO IRRIGATION DIST.			
		Don Pedro	Hydroelectric	77	33,740
		La Grange	Hydroelectric	78	4,750
		Modesto	Steam-electric	79	1,250
Northern	I	UNITED STATES NATIONAL PARK SERVICE			
		Yosemite Park	Hydroelectric	80	2,500
Southern	II	SOUTHERN CALIFORNIA EDISON CO., LTD.			
		Big Creek No. 1	Hydroelectric	81	80,500
		Big Creek No. 2	Hydroelectric	82	70,000
		Big Creek No. 2-A	Hydroelectric	83	90,000
		Big Creek No. 3	Hydroelectric	84	84,000
		Big Creek No. 8	Hydroelectric	85	60,000
		Kaweah No. 1	Hydroelectric	86	2,500
		Kaweah No. 2	Hydroelectric	87	3,500
		Kaweah No. 3	Hydroelectric	88	3,500
		Visalia	Steam-electric	89	6,900
		Tule River	Hydroelectric	90	2,500
		Kern River No. 3	Hydroelectric	91	35,000
		Borel	Hydroelectric	92	10,000
		Kern River No. 1	Hydroelectric	93	20,000
		Azusa	Hydroelectric	94	1,500
		Sierra	Hydroelectric	95	600
		Lytle Creek	Hydroelectric	96	500
		Fontana	Hydroelectric	97	2,400
		Santa Ana No. 1	Hydroelectric	98	3,000
		Santa Ana No. 2	Hydroelectric	99	1,000
		Santa Ana No. 3	Hydroelectric	100	1,500
		Mill Creek No. 1	Hydroelectric	101	750
		Mill Creek No. 2–3	Hydroelectric	102	3,250
		Redondo	Steam-electric	103	48,750
		Long Beach	Steam-electric	104	414,250
		San Antonio Creek No. 1	Hydroelectric	105	750
		San Antonio Creek No. 2	Hydroelectric	106	500
		San Antonio Creek No. 3 (Upland)	Hydroelectric	107	400
Southern	II	CITY OF LOS ANGELES			
		Big Pine No. 3	Hydroelectric	108	4,000
		Division Creek No. 1	Hydroelectric	109	160
		Division Creek No. 2	Hydroelectric	110	600
		Cottonwood No. 1	Hydroelectric	111	1,500
		Haiwee	Hydroelectric	112	6,000
		San Francisquito No. 1	Hydroelectric	113	72,657
		San Francisquito No. 2	Hydroelectric	114	35,000
		San Fernando	Hydroelectric	115	7,000
		River Power	Hydroelectric	116	3,600
		Franklin Canyon	Hydroelectric	117	2,500

TABLE 45—Continued

EXISTING POWER PLANTS AND MAIN SUBSTATIONS IN CALIFORNIA, DECEMBER 31, 1930, AND PROPOSED POWER PLANTS OF STATE WATER PLAN

Group	*System*	*Company and plant*	*Classification*	*Index number*	*Capacity in kilovolt amperes*
Southern	II	CITY OF PASADENA			
		Pasadena	Steam-electric	118	38,077
Southern	III	LOS ANGELES GAS AND ELECTRIC CORPORATION			
		Alameda Street	Steam-electric	119	90,950
		Seal Beach	Steam-electric	120	81,250
Southern	III	THE SOUTHERN SIERRAS POWER CO.			
		Mill Creek	Hydroelectric	121	3,330
		Poole (Leevining Creek No. 1)	Hydroelectric	122	12,500
		Leevining Creek No. 3	Hydroelectric	123	2,500
		Rush Creek	Hydroelectric	124	11,250
		Adams Auxiliary	Hydroelectric	125	3,000
		Adams Main	Hydroelectric	126	6,250
		Bishop Creek No. 2	Hydroelectric	127	6,750
		Bishop Creek No. 3	Hydroelectric	128	8,400
		Bishop Creek No. 4	Hydroelectric	129	6,750
		Bishop Creek No. 5	Hydroelectric	130	3,545
		Bishop Creek No. 6	Hydroelectric	131	2,220
		San Bernardino	Steam-electric	132	11,250
		San Gorgonio No. 1	Hydroelectric	133	1,875
		San Gorgonio No. 2	Hydroelectric	134	938
		Blythe	Gas-electric	135	418
Southern	III	SAN DIEGO CONSOLIDATED GAS AND ELECTRIC CO.			
		Station "A"	Steam-electric	137	12,500
		Station "B"	Steam-electric	138	78,500
Southern	III	ESCONDIDO MUTUAL WATER CO.			
		Rincon	Hydroelectric	139	300
		Bear Valley	Hydroelectric	140	300
Southern	III	UNITED STATES RECLAMATION SERVICE			
		Yuma	Hydroelectric	141	2,000

MAIN SUBSTATIONS

Group	*System*	*Company and substation*	*Index letter*
Northern	I	PACIFIC GAS AND ELECTRIC CO.	
		Vaca-Dixon	A
		Contra Costa	B
		Newark	C
Northern	I	GREAT WESTERN POWER CO. OF CALIFORNIA	
		Antioch	D
		Golden Gate	E
		Brighton	F
Northern	I	SAN JOAQUIN LIGHT AND POWER CORPORATION	
		Wilson	G
Southern	II	SOUTHERN CALIFORNIA EDISON CO., LTD.	
		Vestal	H
		Eagle Rock	I
		Laguna Bell	J
		Lighthipe	K
		La Fresa	L

TABLE 45—Continued

EXISTING POWER PLANTS AND MAIN SUBSTATIONS IN CALIFORNIA, DECEMBER 31, 1930, AND PROPOSED POWER PLANTS OF STATE WATER PLAN

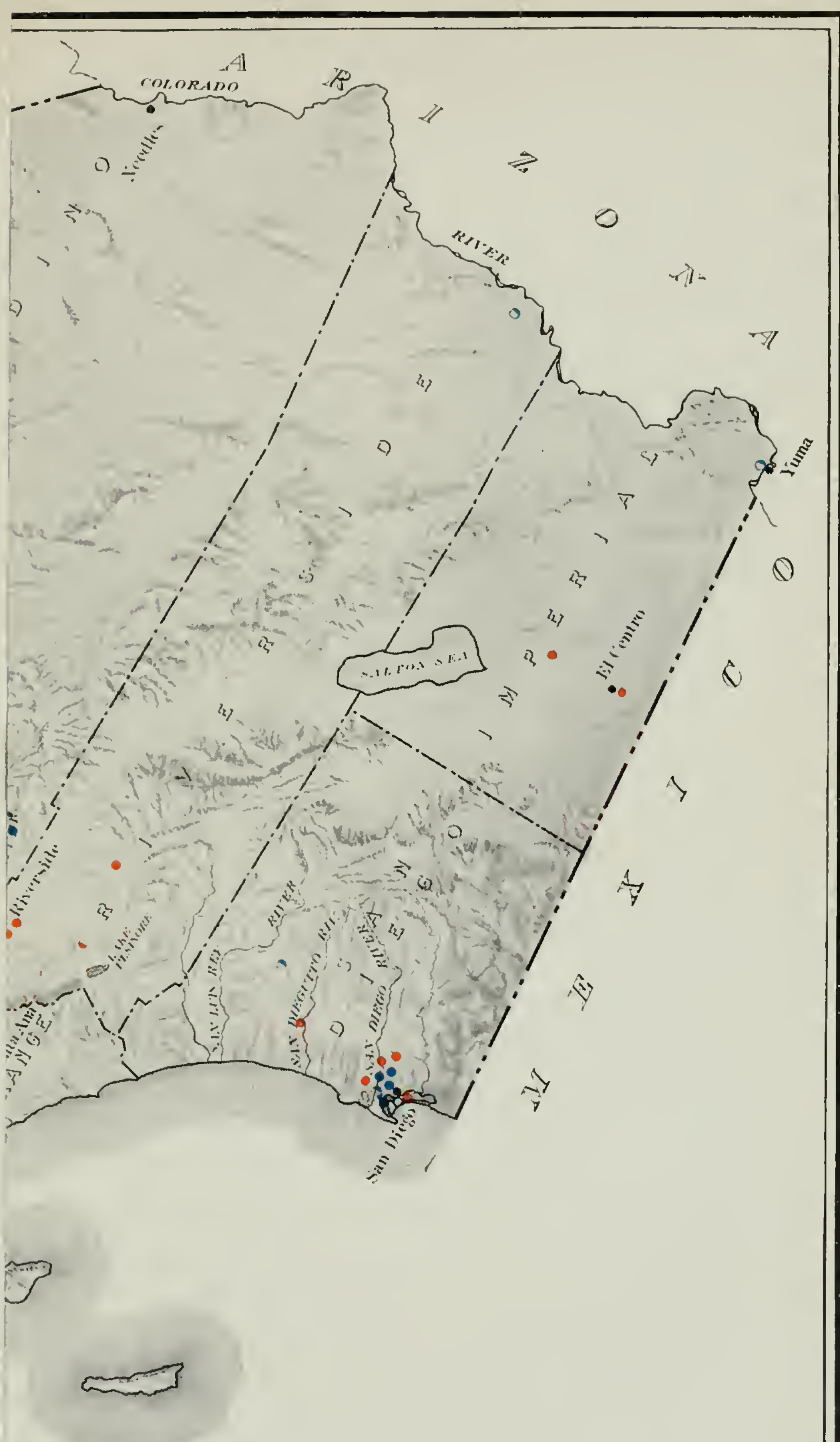
PROPOSED POWER PLANTS OF STATE WATER PLAN

Group	*Plant*	*Classification*	*Index number*	*Capacity in kilovolt amperes*
State Water Plan	Kennett	Hydroelectric	I	Initial, 275,000 Ultimate, 400,000
	Keswick	Hydroelectric	II	50,000
	Trinity Diversion No. 1	Hydroelectric	III	62,000
	Trinity Diversion No. 2	Hydroelectric	IV	59,000
	Trinity Diversion No. 3	Hydroelectric	V	19,000
	Trinity Diversion No. 4	Hydroelectric	VI	53,000
	Oroville	Hydroelectric	VII	280,000
	Oroville Afterbay	Hydroelectric	VIII	34,000
	Narrows	Hydroelectric	IX	160,000
	Auburn	Hydroelectric	X	85,000
	Pilot Creek	Hydroelectric	XI	25,000
	Coloma	Hydroelectric	XII	40,000
	Webber Creek	Hydroelectric	XIII	20,000
	Folsom	Hydroelectric	XIV	100,000
	Folsom Afterbay	Hydroelectric	XV	25,000
	Pardee	Hydroelectric	XVI	18,750
	Melones	Hydroelectric	XVII	68,000
	Don Pedro	Hydroelectric	XVIII	120,000
	Exchequer	Hydroelectric	XIX	31,250
	Friant	Hydroelectric	XX	Initial, 30,000 Ultimate, 40,000
	Pine Flat	Hydroelectric	XXI	40,000

The large hydroelectric plants are located mainly on the streams of the west slope of the Cascade Range and Sierra Nevada from the Klamath River on the north to the Kern River on the south, and on the Los Angeles Aqueduct near Saugus. There are smaller developments on the east slope in Nevada, Mono and Inyo counties, and in southern California on the Los Angeles Aqueduct and several small streams. The larger steam-electric plants are located at tide water on San Francisco Bay, near Los Angeles, and on San Diego Bay, near the main load centers, where adequate condensing water and cheap fuel are available. Steam-electric plants also are located in the San Joaquin Valley near the oil fields gas supply. Primary transmission lines operating at high voltage extend from the main sources of hydroelectric power to the power market centers near San Francisco Bay and Los Angeles. The electric energy output in California in 1929 totaled 8,806,000,000 kilowatt hours, of which 6,374,000,000 kilowatt hours were produced by hydroelectric plants.

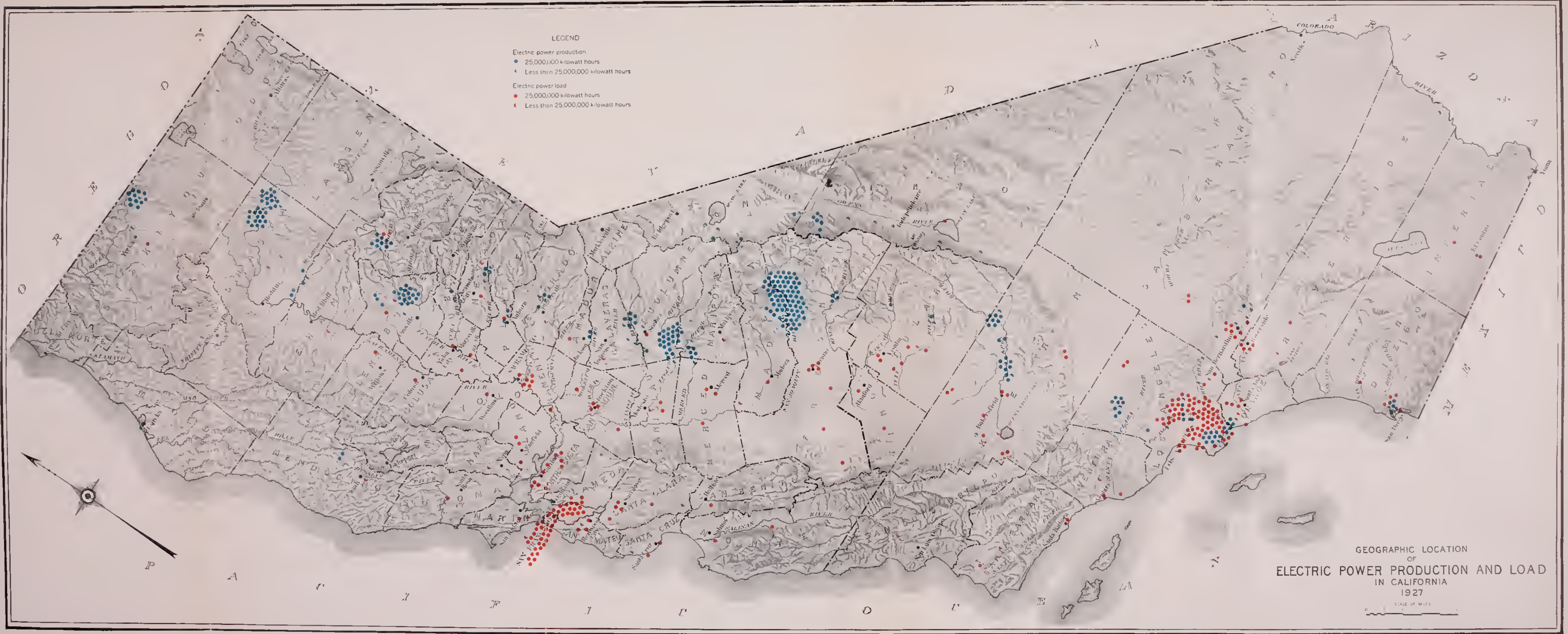
The last twenty years have witnessed rapid growth of the electric power market and the systems rendering service thereto in California. Consolidation of the producing and transmission agencies has continued to the point where their properties now can be readily grouped into three main systems, each fully connected to, and in general operating as a unit of the state-wide system. In a previous report,* the transmission companies were grouped into four main systems. During 1930, two of these systems were consolidated by the purchase by the Pacific Gas and Electric Company of the Great Western Power Company of California, the San Joaquin Light and Power Corporation, and subsidiaries. The three systems into which the electric power development now logically groups itself are indicated by the three different colors on Plate XIV. These are as follows:

* Bulletin No. 20, "Report on Kennett Reservoir Development," Division of Engineering and Irrigation, 1929.



GEOGRAPHIC LOCATION
OF
ELECTRIC POWER PRODUCTION AND LOAD
IN CALIFORNIA
1927

SCALE OF MILES
10 0 10 20 30 40


LEGEND
Electric power production
25,000,000 kilowatt hours
Less than 25,000,000 kilowatt hours
Electric power load
25,000,000 kilowatt hours
Less than 25,000,000 kilowatt hours
OREGON
NEVADA
ARIZONA
MEXICO
PACIFIC OCEAN
DEL NORTE
SISKIYOU
MODOC
LASSEN
MENDOCINO
COLUSA
YOLO
MARIN
ALAMEDA
SANTA CLARA
SANTA CRUZ
SAN BENITO
MARIPOSA
MERCED
STANISLAUS
TUOLUMNE
ALPINE
AMADOR
CALAVERAS
EL DORADO
LOS ANGELES
SAN BERNARDINO
RIVERSIDE
SAN DIEGO
IMPERIAL
SANTA BARBARA
VENTURA
KERN
TULARE
FRESNO
COLORADO RIVER
GEOGRAPHIC LOCATION
OF
ELECTRIC POWER PRODUCTION AND LOAD
IN CALIFORNIA
1927

System I includes the Pacific Gas and Electric Company and its subsidiary companies, Great Western Power Company of California, San Joaquin Light and Power Corporation, and Midland Counties Public Service Corporation; the California-Oregon Power Company; Coast Counties Gas and Electric Company; City of San Francisco; Modesto and Turlock Irrigation Districts; Merced Irrigation District; and East Bay Municipal Utility District.

System II includes mainly the Southern California Edison Company, Ltd., City of Los Angeles and City of Pasadena.

System III includes Los Angeles Gas and Electric Corporation, the Southern Sierras Power Company and San Diego Consolidated Gas and Electric Company.

System I, as indicated on Plate XIV, extends from the Oregon line to Bakersfield and supplies practically all of the electric energy requirements of California north of Tehachapi and west of the Sierra Nevada with the exception of parts of Fresno, Tulare and Kern counties. Its transmission system is in reasonable proximity to the proposed power plants of the State Water Plan in the Great Central Valley, shown on Plate XIV, and it is the only system serving an electric power market economically served by these developments. It is this system and the market served by it which must absorb the electric energy to be generated as a by-product in connection with any water storage development in northern and central California.

Systems II and III serve the power market of southern California. That market is too far removed from the contemplated developments of the State Water Plan in the Sacramento River Basin to be considered available for utilization of electric energy produced by the units of the plan in that basin. Furthermore, the construction of Hoover Dam and power plant on the Colorado River will furnish a large block of energy for absorption by the southern California market.

Distribution of Present Power Load.

Plate XV, "Geographic Location of Electric Power Production and Load in California, 1927," shows for that year the geographic distributions of the electric power production and the load or market. Since 1927, the trend has been toward increased production of electric energy by steam-electric plants. At present a greater proportion of the output than that indicated on Plate XV would be represented as coming from steam-electric plants located in the San Francisco Bay area and near Los Angeles. The distribution of the market, however, remains relatively the same as shown on this plate.

Table 46 sets forth the energy production for the years 1927, 1928 and 1929, and also the load, as indicated by substation output for the year 1927, distributed among the companies.

System I includes the Pacific Gas and Electric Company and its subsidiary companies, Great Western Power Company of California, San Joaquin Light and Power Corporation, and Midland Counties Public Service Corporation; the California-Oregon Power Company; Coast Counties Gas and Electric Company; City of San Francisco; Modesto and Turlock Irrigation Districts; Merced Irrigation District; and East Bay Municipal Utility District.

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Table 46 sets forth the energy production for the years 1927, 1928 and 1929, and also the load, as indicated by substation output for the year 1927, distributed among the companies.

TABLE 46

ELECTRIC ENERGY PRODUCTION AND LOAD BY COMPANIES

California Plants

Group, system and company	Energy production						Substation output, 1927 load	
	Kilowatt hours			Per cent of total				
	1927	1928	1929	1927	1928	1929	Kilowatt hours	Per cent of total
Northern group—								
System I:								
California-Oregon Power Company	290,300,000	259,200,000	187,800,000	7.3	6 1	4.1	24,200,000	0 8
Pacific Gas and Electric Company System—								
Pacific Gas and Electric Company	1,682,300,000	1,823,300,000	2,137,500,000	42.5	42.8	46.6	1,888,400,000	59.8
Great Western Power Company of California	675,400,000	897,500,000	1,058,600,000	17.0	21.1	23.1	645,600,000	20.4
San Joaquin Light and Power Corporation	504,400,000	467,500,000	524,100,000	12.7	10.9	11.4	515,200,000	16.3
Totals, Pacific Gas and Electric Company System	2,862,100,000	3,188,300,000	3,720,200,000	72.2	74.8	81.1	3,049,200,000	96.5
Coast Counties Gas and Electric Company	4,200,000	4,000,000	1,800,000	0.1	0.1	-------	36,700,000	1.2
Utica Mining Company	19,000,000	15,400,000	14,300,000	0.5	0.4	0.3	-------	---
West Side Lumber Company	1,600,000	1,400 000	1,100,000	0.1	0.1	-------	-------	--
Sierra Pacific Power Company	7,800,000	8,100,000	6,400,000	0.2	0.2	0.1	4,100,000	0 1
City of San Francisco	538,400,000	530,100,000	464,800,000	13.6	12.4	10.1	-------	-------
Merced Irrigation District	126,600,000	107,900,000	60,800,000	3.2	2.5	1.3	-------	---
Turlock-Modesto Irrigation District	101,300,000	137,900,000	126,300,000	2.6	3.2	2.8	43,700,000	1.4
United States National Park Service	7,700,000	7,300,000	7,900,000	0.2	0.2	0.2	-------	---
Totals, Northern group	3,962,000,000	4,259,600,000	4,591,400,000	100 0	100.0	100.0	3,157,900,000	100.0
Per cent of total for state	-------	-------	--	54 2	53 4	52 1	--	52.3

Southern group—								
System II:								
Southern California Edison Company, Ltd.	2,419,500,000	2,731,300,000	3,149,900,000	72.3	73.6	74.7	1,711,600,000	59.4
City of Los Angeles	268,800,000	264,300,000	290,800,000	8.0	7.1	6.9	567,900,000	19.7
City of Pasadena	31,600,000	35,200,000	57,600,000	1.0	1.0	1.4	49,400,000	1.7
Totals, System II	2,719,900,000	3,030,800,000	3,498,300,000	81.3	81.7	83.0	2,328,900,000	80.8
System III:								
Los Angeles Gas and Electric Corporation	247,100,000	269,700,000	304,100,000	7.4	7.3	7.2	247,200,000	8.6
The Southern Sierras Power Company	265,100,000	252,800,000	223,800,000	7.9	6.8	5.3	178,100,000	6.2
San Diego Consolidated Gas and Electric Company	109,900,000	148 700,000	181,200,000	3.3	4.0	4.3	126,800,000	4.4
United States Reclamation Service	5,200,000	7,300,000	7,700,000	0.1	0.2	0.2	--------	--------
Totals, System III	627,300,000	678,500,000	716,800,000	18.7	18.3	17.0	552,100,000	19.2
Totals, Southern group	3,347,200,000	3,709,300,000	4,215,100,000	100.0	100.0	100.0	2,881,000,000	100.0
Per cent of total for state	--------	--------	--------	45.8	46.6	47.9	--------	47.7
Grand totals, entire state	7,309 200,000	7,968,900,000	8,806,500,000	100.0	100.0	100.0	6,038 900,000	100.0

Table 47 sets forth the electric energy requirements by counties. In this table, the substation output is given for 1927, and for 1929 a figure is shown which is the sales or substation output in each county corrected for losses to give the equivalent energy output at the power plants to supply the use in the county. The figures for 1929 were developed by the United States Forest Service office at San Francisco.

TABLE 47

ELECTRIC ENERGY REQUIREMENTS BY COUNTIES

Group, district and county	Substation output—year 1927			Energy output prorated to counties—1929[1]		
	Kilowatt hours	Per cent of Group total	Per cent of State total	Kilowatt hours	Per cent of Group total	Per cent of State total
Northern group—						
District 1:						
Butte	35,516,000			37,303,000		
Colusa	20,175,000			24,295,000		
Del Norte				441,000		
Glenn	21,161,000			24,660,000		
Humboldt	14,451,000			20,889,000		
Lake				5,578,000		
Lassen				2,071,000		
Mendocino	5,535,000			6,690,000		
Modoc				603,000		
Napa	4,884,000			20,391,000		
Nevada	33,901,000			37,150,000		
Placer	19,858,000			31,997,000		
Plumas	31,523,000			33,454,000		
Shasta	16,162,000			21,774,000		
Sierra				2,936,000		
Siskiyou	20,584,000			28,047,000		
Sonoma	24,306,000			53,599,000		
Sutter	22,236,000			21,648,000		
Tehama	8,351,000			14,501,000		
Trinity	6,899,000			1,334,000		
Yolo	21,683,000			32,826,000		
Yuba	52,313,000			62,004,000		
Sub-totals, District 1	359,538,000	11.2	6.0	484,191,000	10.5	5.5
District 2:						
Alpine						
Amador	22,846,000			22,473,000		
Calaveras	12,802,000			40,672,000		
El Dorado	2,449,000			3,655,000		
Sacramento	172,146,000			237,793,000		
San Joaquin	123,287,000			186,615,000		
Solano	68,792,000			57,232,000		
Stanislaus	67,451,000			61,669,000		
Tuolumne	18,824,000			20,947,000		
Sub-totals, District 2	488,597,000	15.3	8.1	631,056,000	13.8	7.2
District 3:						
Alameda	449,920,000			640,403,000		
Contra Costa	244,397,000			394,018,000		
Marin	32,073,000			52,978,000		
Santa Clara	131,575,000			263,030,000		
San Francisco	685,775,000			939,966,000		
San Mateo	91,031,000			122,157,000		
Sub-totals, District 3	1,634,771,000	51.1	27.1	2,412,552,000	52.7	27.4
District 4:						
Monterey	50,271,000			100,447,000		
San Benito	20,823,000			38,064,000		
Santa Cruz	50,591,000			57,829,000		
Sub-totals, District 4	121,685,000	3.8	2.0	196,340,000	4.3	2.2
Totals, Districts 1 to 4, inclusive	2,604,591,000	81.4	43.2	3,724,139,000	81.3	42.3

[1] Substation output or sales corrected for losses to give equivalent output at generating point. Developed by United States Forest Service office at San Francisco.

TABLE 47—Continued

Group, district and county	Substation output—year 1927			Energy output prorated to counties—1929[1]		
	Kilowatt hours	Per cent of		Kilowatt hours	Per cent of	
		Group total	State total		Group total	State total
Northern group—Continued						
District 5:						
Fresno	171,885,000			286,579,000		
Kern	256,869,000			321,493,000		
Kings	43,863,000			86,663,000		
Madera	33,457,000			53,423,000		
Mariposa	3,000,000			5,413,000		
Merced	69,341,000			77,685,000		
San Luis Obispo	16,423,000			25,709,000		
Sub-totals, District 5	594,838,000	18.6	9.8	856,965,000	18.7	9.8
Totals, Northern group	3,199,429,000	100.0	53.0	4,581,104,000	100 0	52 1
Southern group—						
District 6:						
Inyo	8,188,000			45,003,000		
Mono				1,615,000		
Santa Barbara	57,766,000			95,581,000		
Tulare[2]	157,694,000			273,960,000		
Sub-totals, District 6	223,648,000	7.9	3.7	416,159,000	9.9	4.7
District 7:						
Los Angeles	1,859,426,000			2,921,411,000		
Orange	138,361,000			179,023,000		
Ventura	56,814,000			120,339,000		
Sub-totals, District 7	2,054,601,000	72.3	34.0	3,220,773,000	76.5	36.7
District 8:						
Imperial	40,257,000			51,466,000		
Riverside	132,809,000			107,182,000		
San Bernardino	239,016 000			248,160,000		
San Diego	126,801,000			167,804,000		
Sub-totals, District 8	538,883,000	19.0	8.9	574,612,000	13.6	6.5
Not segregated	22,295,000	0.8	0.4			
Totals, Southern group	2,839,427,000	100.0	47.0	4,211,544,000	100.0	47.9
Grand totals, entire state	6,038,856,000		100.0	8,792,648,000		100.0

[1] Substation output or sales corrected for losses to give equivalent output at generating point. Developed by United States Forest Service office at San Francisco.
[2] Served almost entirely by Southern California Edison Company.

The counties are grouped approximately on the same basis as the systems in Table 46. Tulare County is included in the southern group since it is served by the Southern California Edison Company. Parts of Kern and Fresno counties also are served by the Southern California Edison Company, but, to offset this, part of Santa Barbara County is served by the San Joaquin Light and Power Corporation system.

It may be seen from Tables 46 and 47 that System I, which serves the territory that must absorb the electric energy outputs of the power plants of the major units of the State Water Plan in the Sacramento River Basin, produced almost 4,600,000,000 kilowatt hours of electric energy or more than 50 per cent of the entire production in California in 1929. This amount was about 630,000,000 kilowatt hours or 16 per cent greater than the production in 1927. Approximately 50 per cent of the electric energy consumed in the territory served by the system is used in an area 50 miles in radius from the San Francisco Bay district.

Growth of Power Load.

To illustrate the growth of electric power development in California, tables and diagrams are given to show the annual increase in the installation of electric power generators and in the amount of electric energy generated.

Table 48 sets forth for the northern and southern groups and the entire state, the installed capacities in kilovolt amperes of hydroelectric and steam-electric plants as of December 31st of each year from 1911 to 1929. These data are depicted graphically on Plate XVI, "Installed Electric Power Generator Capacities in California, 1911–1929."

Table 49 sets forth the electric power production in kilowatt hours for the northern and southern groups and for the entire state for the period 1913 to 1929 and Plate XVII, "Electric Power Production in California, 1913–1929," shows graphically the average power production, by months, in kilowatts, for the same years for the same grouping of systems.

Table 50 and Plate XVIII, "Past and Estimated Future Growth of Electric Power Production in California, 1913–1950," set forth in figures and graphically, respectively, the actual growth of load for the years 1913 to 1929, and the estimated growth from 1930 to 1950, for the northern and southern groups and the entire state. It may be noted from the table that the load growth of the northern group, or System I, is estimated to increase at a rate of a little over 5 per cent per year from 1930 to 1940 and at a rate of about 4 per cent per year from 1940 to 1950. The load growth is estimated to be at a rate of 324,000,000 to 406,000,000 kilowatt hours per year from 1935 to 1940 and at a rate of 326,000,000 to 464,000,000 kilowatt hours per year from 1940 to 1950. The total electric energy production in 1940 is estimated to be 1,802,000,000 kilowatt hours per year greater than in 1935 and the production in 1950 is estimated to be 3,914,000,000 kilowatt hours per year greater than in 1940.

The load growth of the northern group excluding the market served by the San Joaquin system* which is somewhat distant from the power producing units of the State Water Plan in the Sacramento River Basin, is estimated to be at about the same percentage rates as for the entire group. The load growth for this portion of the northern group is estimated to be at a rate of 265,000,000 to 334,000,000 kilowatt hours per year from 1935 to 1940 and at a rate of 267,000,000 to 380,000,000 kilowatt hours per year from 1940 to 1950. The total electric energy production in 1940 is estimated to be 1,476,000,000 kilowatt hours per year greater than in 1935 and the production in 1950 is estimated to be 3,203,000,000 kilowatt hours per year greater than in 1940.

* San Joaquin Light and Power Corporation, Midland Counties Public Service Corporation, Turlock and Modesto Irrigation Districts and Merced Irrigation District.

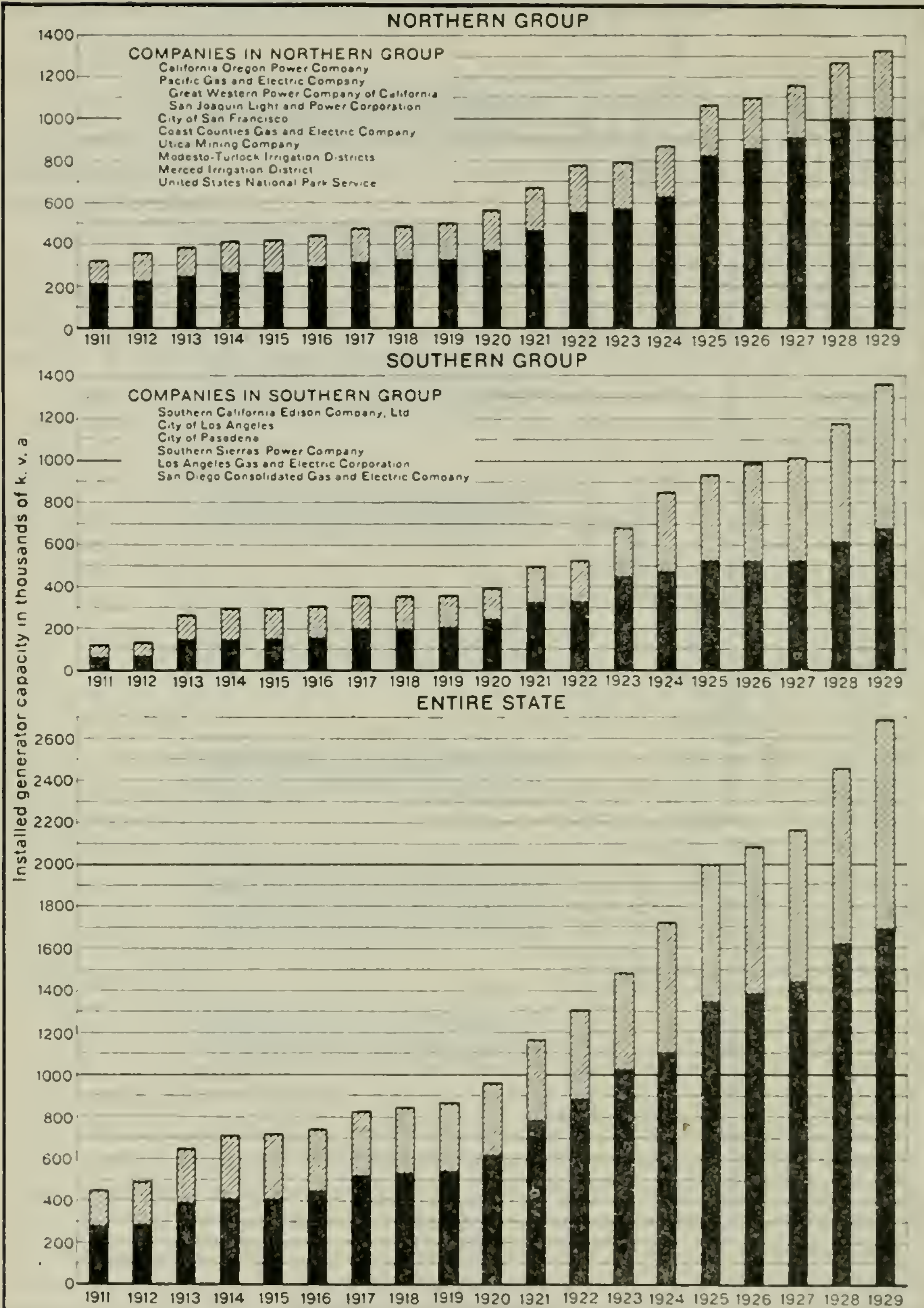
TABLE 48

ELECTRIC POWER INSTALLATION IN CALIFORNIA AT END OF EACH YEAR, 1911-1929

Installations in kilovolt amperes

Year	Northern group			Southern group			Entire state		
	Hydroelectric	Steam-electric	Total	Hydroelectric	Steam-electric	Total	Hydroelectric	Steam-electric	Total
1911	216 620	104,075	320,695	65,760	60,077	125,837	282,380	164,152	446,532
1912	222,620	136,675	359,295	65,760	69,877	135,637	288,380	206,552	494,932
1913	246,620	139,275	385,895	148,010	112,317	260,327	394,630	251,592	646,222
1914	265,120	154,275	419,395	148,010	149,067	297,077	413,130	303,342	716,472
1915	266,995	158,975	425,970	148,610	149,067	297,677	415,605	308,042	723,647
1916	294,800	150,250	445,050	153,610	148,912	302,522	448,410	299,162	747,572
1917	318,825	159,250	478,075	204,516	151,646	356,162	523,341	310,896	834,237
1918	334,175	159,110	493,285	204,516	151,646	356,162	538,691	310,756	849,447
1919	334,100	174,110	508,210	207,941	151,247	359,188	542,041	325,357	867,398
1920	377,850	186,610	564,460	243,941	153,847	397,788	621,791	340,457	962,248
1921	461,797	211,610	673,407	326,941	173,797	500,738	788,738	385,407	1,174,145
1922	556,197	223,360	779,557	334,341	194,197	528,538	890,538	417,557	1,308,095
1923	571,572	229,250	800,822	452,224	234,647	686,871	1,023,796	463,897	1,487,693
1924	631,670	242,925	874,595	473,474	376,797	850,271	1,105,144	619,722	1,724,866
1925	822,670	242,925	1,065,595	522,974	412,345	935,319	1,345,644	655,270	2,000,914
1926	858,920	242,925	1,101,845	522,974	466,945	989,919	1,381,894	709,870	2,091,764
1927	915,545	242,925	1,158,470	527,924	485,695	1,013,619	1,443,469	728,620	2,172,089
1928	1,011,235	270,675	1,281,910	617,924	560,695	1,178,619	1,629,159	831,370	2,460,529
1929	1,016,685	313,850	1,330,535	681,575	679,095	1,360,670	1,698,260	992,945	2,691,205

PLATE XVI



INSTALLED ELECTRIC POWER GENERATOR CAPACITIES IN CALIFORNIA 1911-1929

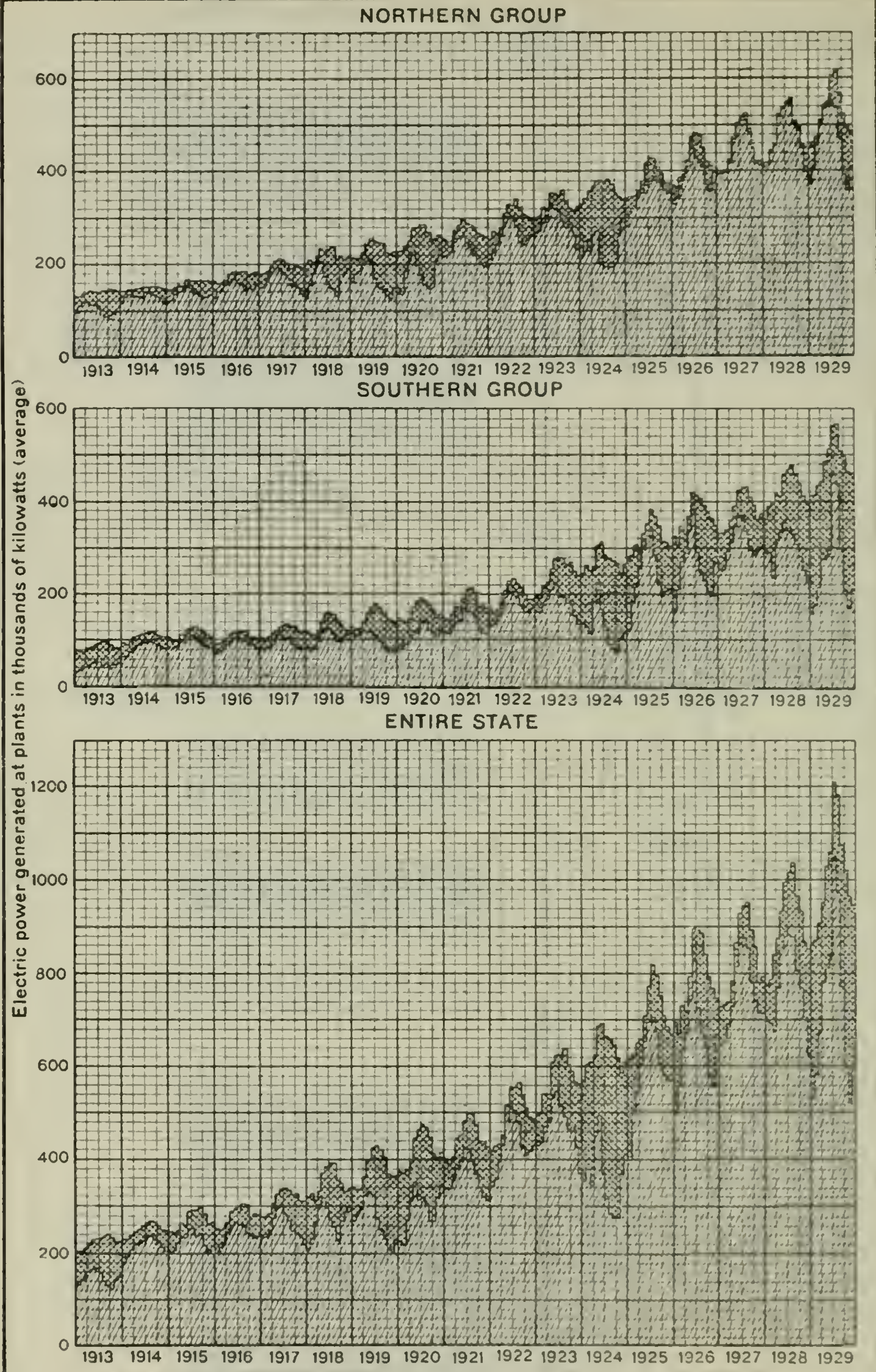
TABLE 49

ANNUAL ELECTRIC POWER PRODUCTION IN CALIFORNIA, 1913-1929

Output in kilowatt hours

Year	Northern group				Southern group				Entire state			
	Hydroelectric	Steam-electric	Total	Per cent steam-electric	Hydroelectric	Steam-electric	Total	Per cent steam-electric	Hydroelectric	Steam-electric	Total	Per cent steam-electric
1913	895,000,000	310,000,000	1,205,000,000	25.7	387,000,000	371,000,000	758,000,000	48.9	1,282,000,000	681,000,000	1,963,000,000	34.7
1914	1,115,000,000	147,000,000	1,262,000,000	11.6	751,000,000	174,000,000	925,000,000	18.8	1,866,000,000	321,000,000	2,187,000,000	14.7
1915	1,157,000,000	220,000,000	1,377,000,000	16.0	811,000,000	170,000,000	981,000,000	17.3	1,968,000,000	390,000,000	2,358,000,000	16.5
1916	1,303,000,000	210,000,000	1,513,000,000	13.9	785,000,000	135,000,000	920,000,000	14.7	2,088,000,000	345,000,000	2,433,000,000	14.2
1917	1,432,000,000	254,000,000	1,686,000,000	15.1	801,000,000	230,000,000	1,031,000,000	22.3	2,233,000,000	484,000,000	2,717,000,000	17.8
1918	1,460,000,000	440,000,000	1,900,000,000	23.2	893,000,000	265,000,000	1,158,000,000	22.9	2,353,000,000	705,000,000	3,058,000,000	23.1
1919	1,439,000,000	554,000,000	1,993,000,000	27.8	884,000,000	411,000,000	1,295,000,000	31.7	2,323,000,000	965,000,000	3,288,000,000	29.3
1920	1,540,000,000	683,000,000	2,223,000,000	30.7	984,000,000	437,000,000	1,421,000,000	30.8	2,524,000,000	1,120,000,000	3,644,000,000	30.7
1921	1,972,000,000	354,000,000	2,326,000,000	15.2	1,192,000,000	353,000,000	1,545,000,000	22.8	3,164,000,000	707,000,000	3,871,000,000	18.3
1922	2,244,000,000	340,000,000	2,584,000,000	13.2	1,506,000,000	225,000,000	1,731,000,000	13.0	3,750,000,000	565,000,000	4,315,000,000	13.1
1923	2,489,000,000	361,000,000	2,850,000,000	12.7	1,589,000,000	568,000,000	2,157,000,000	26.3	4,078,000,000	929,000,000	5,007,000,000	18.6
1924	2,040,000,000	1,140,000,000	3,180,000,000	35.8	1,072,000,000	1,234,000,000	2,306,000,000	53.5	3,112,000,000	2,374,000,000	5,486,000,000	43.3
1925	3,117,000,000	267,000,000	3,384,000,000	7.9	2,000,000,000	730,000,000	2,730,000,000	26.7	5,117,000,000	997,000,000	6,114,000.000	16.3
1926	3,505,000,000	271,000,000	3,776,000,000	7.2	2,115,000,000	950,000,000	3,065,000,000	31.0	5,620,000,000	1,221,000,000	6,841,000,000	17.9
1927	3,926,000,000	36,000,000	3,962,000,000	0.9	2,714,000,000	633,000,000	3,347,000,000	18.9	6,640,000,000	669,000,000	7,309,000,000	9.2
1928	4,186,000,000	74,000,000	4,260,000,000	1.7	2,590,000,000	1,119,000,000	3,709,000,000	30.2	6,776,000,000	1,193,000,000	7,969,000,000	15.0
1929	4,046,000,000	545,000,000	4,591,000,000	11.9	2,327,000,000	1,888,000,000	4,215,000,000	44.8	6,373,000,000	2,433,000,000	8,806,000,000	27.6

PLATE XVII

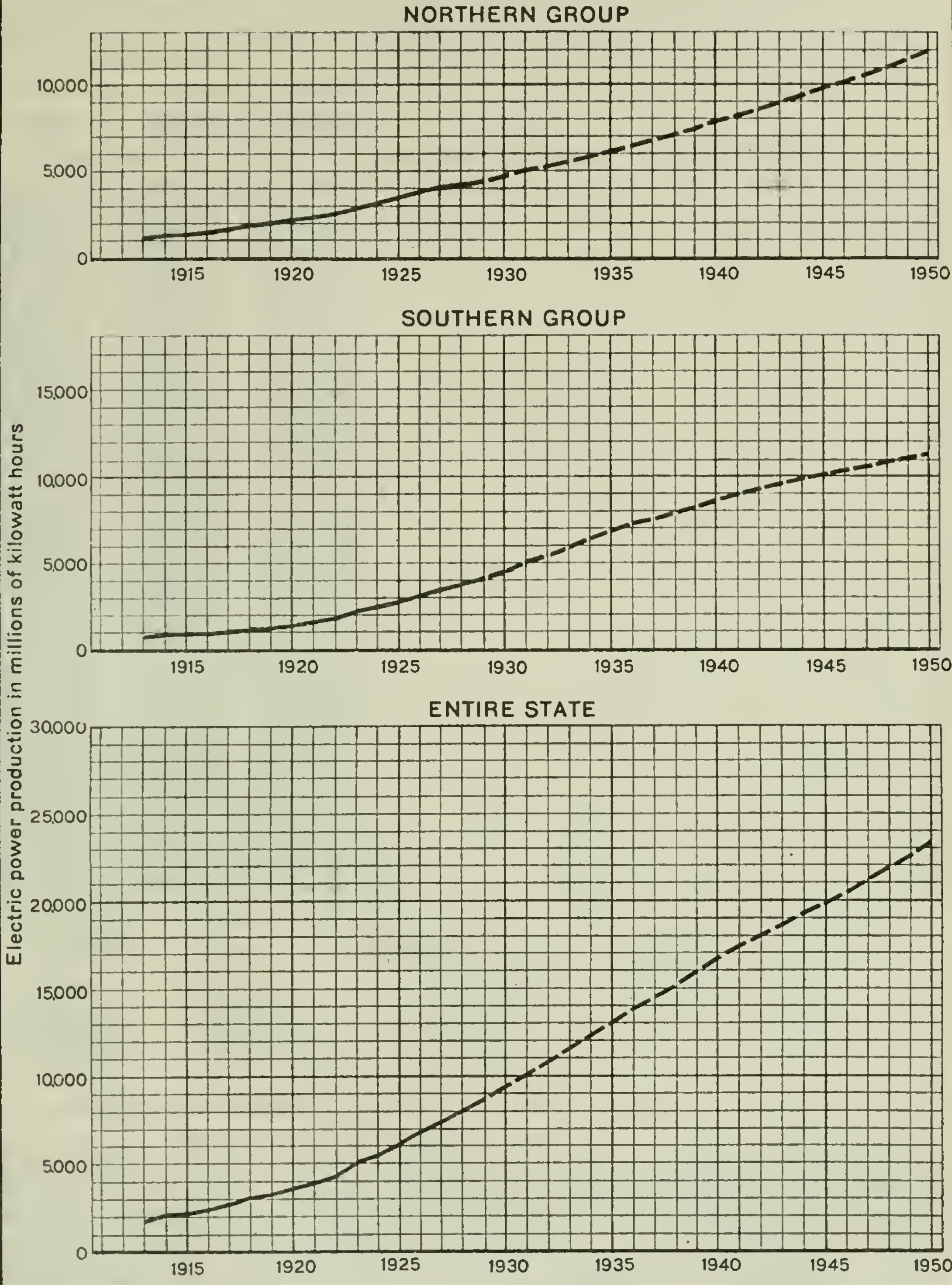


ELECTRIC POWER PRODUCTION
IN CALIFORNIA
1913-1929

POWER PRODUCED BY HYDROELECTRIC PLANTS

POWER PRODUCED BY STEAM-ELECTRIC PLANTS

PLATE XVIII



PAST AND ESTIMATED FUTURE GROWTH OF ELECTRIC POWER PRODUCTION IN CALIFORNIA 1913-1950

——— ELECTRIC POWER PRODUCTION FOR PAST YEARS

— — — ESTIMATED ELECTRIC POWER PRODUCTION FOR FUTURE YEARS

TABLE 50

ELECTRIC ENERGY PRODUCTION IN CALIFORNIA, 1913-1950

Actual output of California plants, 1913-1929. Estimated output requirements, 1930-1950

Year	Kilowatt hours		
	Northern group	Southern group	Entire state
1913	1,205,000,000	758,000,000	1,963,000,000
1914	1,262,000,000	925,000,000	2,187,000,000
1915	1,377,000,000	981,000,000	2,358,000,000
1916	1,513,000,000	920,000,000	2,433,000,000
1917	1,686,000,000	1,031,000,000	2,717,000,000
1918	1,900,000,000	1,158,000,000	3,058,000,000
1919	1,993,000,000	1,295,000,000	3,288,000,000
1920	2,223,000,000	1,421,000,000	3,644,000,000
1921	2,326,000,000	1,545,000,000	3,871,000,000
1922	2,584,000,000	1,731,000,000	4,315,000,000
1923	2,850,000,000	2,157,000,000	5,007,000,000
1924	3,180,000,000	2,306,000,000	5,486,000,000
1925	3,384,000,000	2,730,000,000	6,114,000,000
1926	3,776,000,000	3,065,000,000	6,841,000,000
1927	3,962,000,000	3,347,000,000	7,309,000,000
1928	4,260,000,000	3,709,000,000	7,969,000,000
1929	4,591,000,000	4,215,000,000	8,806,000,000
1930[1]	4,822,000,000	4,589,000,000	9,411,000,000
1931[1]	5,074,000,000	5,068,000,000	10,142,000,000
1932	5,340,000,000	5,502,000,000	10,842,000,000
1933	5,618,000,000	5,933,000,000	11,551,000,000
1934	5,912,000,000	6,406,000,000	12,318,000,000
1935	6,220,000,000	6,875,000,000	13,095,000,000
1936	6,544,000,000	7,254,000,000	13,798,000,000
1937	6,884,000,000	7,630,000,000	14,514,000,000
1938	7,240,000,000	8,003,000,000	15,243,000,000
1939	7,616,000,000	8,329,000,000	15,945,000,000
1940	8,022,000,000	8,695,000,000	16,717,000,000
1941	8,348,000,000	9,031,000,000	17,379,000,000
1942	8,687,000,000	9,319,000,000	18,006,000,000
1943	9,040,000,000	9,605,000,000	18,645,000,000
1944	9,408,000,000	9,889,000,000	19,297,000,000
1945	9,788,000,000	10,126,000,000	19,914,000,000
1946	10,186,000,000	10,361,000,000	20,547,000,000
1947	10,598,000,000	10,636,000,000	21,234,000,000
1948	11,026,000,000	10,909,000,000	21,935,000,000
1949	11,472,000,000	11,091,000,000	22,563,000,000
1950	11,936,000,000	11,357,000,000	23,293,000,000

[1] Since the preparation of this manuscript, the actual outputs, in kilowatt hours, for 1930 and 1931 have become available and are:

Year	*Northern group*	*Southern group*	*Entire state*
1930	4,769,742,000	4,287,194,000	9,056,936,000
1931	4,739,463,000	4,226,318,000	8,965,781,000

Absorption of Electric Energy Output of Plants of the State Water Plan.

Potential outputs of electric energy from all of the power plants proposed in connection with the major reservoir units of the State Water Plan in the Sacramento River Basin were estimated for two plans of operation, one on the basis of reservoir operation primarily for the production of power and the other with reservoir operation primarily for irrigation. The methods used in making these estimates are described in Chapter IX. The average annual amount of energy produced would generally be less with the reservoir operated primarily for irrigation than for power. Lessened flexibility of operation and the resulting characteristics of energy output also would be such as to reduce the value of energy produced below the value with power requirements controlling.

The primary object of any of the major reservoir units, however, is to regulate the run-off to make it available for irrigation, salinity control and navigation and to control flood flows. Power must be considered as a by-product. All of the reservoirs would not be operated for all of the above uses but all would ultimately be operated primarily for irrigation, or irrigation and salinity control combined. The reservoirs on the larger streams also would be operated for flood control and the Kennett reservoir, located on a navigable stream, would be operated to improve navigation.

As previously stated, studies were made for all of the proposed power plants to estimate the electric energy output under the conditions of reservoir operation primarily for the generation of power and primarily for irrigation. It is believed, however, that the first unit to be constructed in the Sacramento River Basin would be operated to control floods; to supply water for the irrigation of lands along the river on which it is located and the lands in the Sacramento-San Joaquin Delta; to furnish water for salinity control; and, if on a navigable stream, water to improve navigation. As a second step in the operation of an initial unit, the reservoir would be operated for the above uses and also to furnish a supplementary irrigation supply to lands in the San Joaquin Valley. Under both of these methods of operation of an initial unit, electric energy would be generated incidental to the other uses. The amount of energy so generated was estimated for the Kennett reservoir unit and the American River unit.

The full supply of water from units constructed after the initial unit would probably not be needed for irrigation, or irrigation and salinity control, immediately upon the completion of the reservoir. The initial operation of such units, therefore, may be expected to approach the condition of operation primarily for the generation of power.

The annual electric energy output from the Kennett power plant or power plants constructed in connection with other major units of the State Water Plan is sufficient in amount under any method of operation to require coordination of the development with the program of construction to be carried on by the power producing agencies serving the market, if the output is to be absorbed readily. In the following text, Kennett power plant will be used as an example in the discussion of different factors involved in absorbing and evaluating the electric energy output. These same factors would apply to any other major unit of the State Water Plan.

It has been stated in another section of this chapter that the estimated growth of load or market requirements, in the northern group would be at a rate of 324,000,000 to 406,000,000 kilowatt hours per year in the 5-year period 1935–1940. The total load in 1940 is estimated to be 1,802,000,000 kilowatt hours per year greater than in 1935. The growth of load in the same area for the 5-year period 1940–1945 is estimated to be at a rate of 326,000,000 to 380,000,000 kilowatt hours per year and the total load in 1945 is estimated to be 1,766,000,000 kilowatt hours per year greater than in 1940. The growth of load in the 5-year period 1945–1950 is estimated to be at a rate of 398,000,000 to 464,000,000 kilowatt hours per year and the total load in 1950 is estimated to be 2,148,000,000 kilowatt hours per year greater than in 1945.

It is estimated that the average annual output of the Kennett reservoir and Keswick afterbay power plants, described in Chapter IX, in the 40-year period 1889–1929, when operated primarily for the generation of power, would have been 1,622,800,000 kilowatt hours per year. On account of the characteristics of this output, however, a market somewhat in excess of the estimated plant outputs would have to be developed to absorb them fully. The length of time required to absorb the outputs of the Kennett and Keswick plants, therefore, would depend upon the year that they are brought into production. It is believed that the period of absorption would not be more than four to six years.

Upon completion of the Kennett reservoir unit, assuming it to be the initial development and 1940 as the earliest date of completion, the additional supply of energy would enter the market of the northern group where the estimated load then being served would be about eight billion kilowatt hours annually. The demands of the territory at that time would of necessity be fully served by the existing agencies. From the standpoint of economic absorption of electric energy output of plants such as those proposed for the Kennett reservoir unit, the amount of steam-electric energy produced at the time of completion of the project is important. The tendency at the present time in California is for the power companies to install steam-electric rather than hydroelectric plants, owing to increased efficiency of steam-electric generation and decreased cost of fuel. It is essential that the development by the State and by the power producing agencies be so coordinated that a material increase in steam-electric produced energy will have occurred by the time the Kennett development is completed. By this procedure, and provided definite contracts are entered into, it would be possible for the existing power-producing agencies to so adjust their progress in development that the load could be absorbed readily. The output of the Kennett and Keswick power plants could be utilized upon completion of the plants to carry the load being carried by steam-electric plants. By discontinuing steam-electric development to take care of the following year's growth of load prior to bringing in the first unit at Kennett, and the completion of the Kennett and Keswick plants in one year thereafter, only about three-fifths of the output would actually be competing with the fuel price of steam-electric energy. Within about four years after completion of the Kennett and Keswick plants, the entire output would be absorbed by load growth and would justify full compensation. Conditions of absorption of the output of other plants would be similar.

The electric energy output of the Kennett and Keswick power plants would represent approximately 20 per cent of the load of System I in 1940. Much more extreme problems than the absorption of this output have been faced and overcome by power companies in the past. In 1921, the Great Western Power Company brought in on its own system a power development representing more than 40 per cent of its then existing load. In 1925, the Pacific Gas and Electric Company did likewise.

With the reasonable coordination of State development with that of the power companies and municipalities, the electric energy output of any of the units of the State Water Plan could be readily absorbed.

Value of Electric Energy Output.

The value of the energy output from the plants contemplated in connection with the State Water Plan depends upon its characteristics, point of delivery and cost of energy from other and competitive sources. The energy from a power plant with a dependable kilowatt and kilowatt hour output in dry years, especially in the late summer months of such years, is more valuable than the energy from plants where failure of output occurs in critical years. The electric power market available to plants in the Sacramento River Basin is largely in or near the San Francisco Bay area and energy produced or delivered nearest the load center will be the most valuable, other things being equal. Study of the load served by System I, excluding the San Joaquin system,* indicates the load center to be in Contra Costa County near Concord.

Three bases have been used in estimating the value of energy from the proposed plants. These bases are the same as those used in a report,** published in 1929, on the Kennett development. They are:

1. Cost of energy from other hydroelectric plants.
2. Wholesale price of energy as indicated by existing contracts.
3. Cost of energy from steam-electric plants.

The analyses of values under each of these three bases require that consideration be given to relative characteristics of power from different sources and that adjustment be made to reflect transmission cost to a common or equivalent delivery point at or near the load center. Delivery to the main transmission system near the load center would appear the most reasonable assumption to make in a comparison of relative values of energy from hydroelectric and steam-electric plants. There is now located near Antioch, Contra Costa County, a main substation, and delivery at this point will be used for comparison of values since it is approximately at the load center of the northern California market. This substation is 200 miles transmission distance from Kennett dam and power plant.

Transmission of Electric Energy to Load Center.—The electric energy that would be produced at Kennett or other proposed plants could be transmitted to the load center, which is assumed in these studies to be Antioch, and there delivered wholesale, or, as an alternative, it could be sold at the power plant. In either case, transmission lines and substations must be constructed adequate to deliver the output at Antioch. In the first instance, the lines would be constructed by the producer and in the second, by the agency purchasing the energy at the power plant. A greater dependability would be obtained by interconnection with existing transmission circuits. The Kennett plant would require a 220,000 volt double circuit tower line, 200 miles long, to deliver its output to Antioch. Other plants of the State Water Plan would require different transmission distances and line capacities.

The capital cost of a transmission system from the Kennett plant to Antioch was previously ** estimated to be $6,000,000 for transmission line and $3,600,000 for terminal substation, or a total of $9,600,000.

* San Joaquin Light and Power Corporation, Midland Counties Public Service Corporation, Turlock and Modesto Irrigation Districts and Merced Irrigation District.

** Bulletin No. 20, "Report on Kennett Reservoir Development," Division of Engineering and Irrigation, 1929.

Some addition would appear advisable to cover the cost of a special river crossing at Antioch and interconnections to existing transmission lines. A revised estimate of capital cost of $10,150,000 is shown in Table 51. In this table, it also is shown that the annual cost of the transmission line from Kennett power plant to Antioch and the necessary substations, if these were constructed and operated by some private agency, would be $1,027,000. The value of the energy to the agency, delivered to it at the Kennett power plant, therefore, would be $1,027,000, annually, less than the value if delivered at Antioch, due to the transmission cost. Based on the average annual amount of electric energy delivered at Antioch from the Kennett power plant alone, for the 40-year period 1889–1929, with the Kennett reservoir operated primarily for the generation of power, this would amount to about 0.88 of a mill per kilowatt hour at the terminal substation. If the transmission line and substation were constructed and operated by the State, and it is assumed that the cost of construction would be the same as shown in Table 51, that interest on investment would be 4.5 per cent per year, and that the cost of the line would be amortized in 40 years with a sinking fund at 4 per cent interest, the total annual cost to the state would be $789,000, and the cost of transmission per kilowatt hour based on the average amount of electric energy delivered at Antioch from the Kennett plant would be 0.68 of a mill.

TABLE 51

COST OF TRANSMISSION OF ELECTRIC ENERGY FROM KENNETT POWER PLANT TO ANTIOCH

INVESTMENT COST.		
Transmission line.		
200 miles, 220,000 volt, double circuit tower line		$6,000,000
Added cost of river crossings (Sacramento and San Joaquin rivers)		350,000
Total		$6,350,000
Substation and interconnections.		
Interconnections to existing transmission lines		200,000
Terminal substation (220,000 kilowatt capacity)		3,600,000
Grand total		$10,150,000
BASIS OF ANNUAL COST.		
Development by private agency	*Per cent of capital cost*	
Interest or return	7.5	
Depreciation annuity	1.0	
Operation, maintenance and general expense—		
Transmission line	.75	
Substation	2.00	
Federal taxes	.40	
ANNUAL COST.		
Transmission line.		
Interest or return		$476,000
Depreciation annuity		64,000
Operation, maintenance and general expense		48,000
Federal taxes		25,000
Subtotal		$613,000
Substation.		
Interest or return		$285,000
Depreciation annuity		38,000
Operation maintenance and general expense		76,000
Federal taxes		15,000
Subtotal		$414,000
Total annual cost		$1,027,000
COST PER KILOWATT HOUR.		
Cost per kilowatt hour of energy from Kennett power plant delivered at terminal substation (1,322,800,000 kilowatt hours x 88 per cent = 1,164,000,000 kilowatt hours)		$.00088

Value Based on Cost of Electric Energy from Other Hydroelectric Plants.—In Table 52, the values of electric energy at the Kennett power plant switchboard are estimated from the costs of electric energy from the existing Pit and Feather river hydroelectric plants. In estimating the values at Kennett, the costs of the electric energy from the Pit and Feather river plants, delivered at Antioch, taking into account transmission losses and costs, were first estimated. The cost of transmission, as shown in Table 51, and costs due to transmission losses, from Kennett power plant to Antioch, deducted from these values gave the value of electric energy at Kennett power plant based on the costs of electric energy from the Pit and Feather river plants. In these estimates, the transmission losses were taken at 6 per cent per 100 miles of transmission distance. This method, although general in application, is considered reasonably accurate for determination of relative values. It is to be noted that when due consideration is given to differences in energy costs and transmission distances, the costs of electric energy delivered at the terminal substation from the Pit and Feather river plants are almost equal. Estimates for future power developments on these rivers indicate costs approximately 0.25 of a mill per kilowatt hour lower than shown in Table 52. The costs, however, are based on preliminary surveys only and may be increased.

TABLE 52

VALUE OF ELECTRIC ENERGY FROM KENNETT RESERVOIR DEVELOPMENT BASED ON COST OF ENERGY FROM EXISTING HYDROELECTRIC PLANTS ON PIT AND FEATHER RIVERS

	Pit River plants	Feather River plants
Estimated cost at plant switchboard, per kilowatt hour[1]	$.00261	$.00314
Transmission distance, in miles	240	150
Transmission losses at 6 per cent per 100 miles, in per cent	14.4	9.0
Production cost, per kilowatt hour of terminal substation delivery	$.00305	$.00345
Transmission cost, per kilowatt hour delivered to substation	.00109	.00061
Cost, per kilowatt hour, of substation delivery from existing hydroelectric plants on Pit and Feather rivers	.00414	.00406
Transmission cost from Kennett plant, per kilowatt hour	.00088	.00088
Cost of substation delivery less transmission cost, per kilowatt hour	.00326	.00318
Resultant value at Kennett plant switchboard, per kilowatt hour, with transmission losses at 12 per cent	.00287	.00280

[1]Bulletin No. 20, "Report on Kennett Reservoir Development," Division of Engineering and Irrigation, 1929, page 41.

It, therefore, may be concluded that the value of electric energy from the Kennett power plant with the Kennett reservoir operated primarily for power so that the output would have characteristics comparable to those of the outputs of the existing plants on the Pit and Feather rivers, would be $0.00280 to $0.00287 per kilowatt hour at Kennett, based on the costs of electric energy from these latter plants. With the reservoir operated primarily for irrigation or irrigation and other uses, the power characteristics would be poorer and lower values would result.

Value Based on Wholesale Price of Electric Energy as Indicated by Existing Contracts.—The market price of electric energy as determined from existing contracts has been quite fully covered in a previous report.* Little change has occurred in the prices paid under these contracts as they are to run for long terms and the prices are not subject to revision. Only one important new contract has been entered into recently. This a five-year agreement between the East Bay Municipal Utility District and the Great Western Power Company. The contract provides for the sale of approximately 100,000,000 kilowatt hours of electric energy per year from the power plant at the Pardee Reservoir of the district at a price varying throughout the year, but averaging approximately 3.7 mills per kilowatt hour. The load factor of operation is relatively high and the power characteristics somewhat better than where reservoirs are operated primarily for irrigation.

If consideration is given to the relative cost of energy from other hydroelectric and steam-electric plants at the time the contracts were entered into and also at present, it appears that the average of contract prices as indicated in the previous report referred to above is approximately 0.5 of a mill per kilowatt hour higher than would be obtained at present, other conditions being the same. This reduction would result in an indicated value of approximately three mills per kilowatt hour at Kennett power plant.

Value Based on Cost of Electric Energy from Steam-electric Plants.—An important element affecting present and future value of electric energy is the cost of steam produced electric energy. The economic changes in steam-electric power production during the last several years have caused practically a cessation of development of water power in both northern and southern California. The only recent water power development of importance in northern California is that of the Pacific Gas and Electric Company on the Mokelumne River. In the south, no hydroelectric plants are being constructed in this state but a large hydroelectric plant will be built at Hoover Dam on the Colorado River, just outside of the state, which will generate electric energy for delivery into southern California.

During the past few years, extensive developments of natural gas have occurred in the Kettleman Hills district. Gas transmission lines were constructed and natural gas made available in the San Francisco Bay area and several other sections of northern California. Owing to the extent of the Kettleman Hills fields, the large sizes of the holdings and the method of development, it appears that a relatively large amount of natural gas will be available as a by-product of oil production in northern California for some time to come. The effect of this development has been to reduce the price of fuel oil, or its gas equivalent, for steam-electric plants in northern California and to assure for a considerable period the continuance of the lower cost of fuel. The permanence of the supply is not subject to accurate estimate. The fact that the Pacific Gas and Electric Company and the Standard Oil Company have expended large sums in pipe lines is proof of their confidence of an available supply for a relatively long period.

The question of the cost of steam-electric energy involves probable future price of fuel and the efficiencies of, investments in, and operating costs of steam plants.

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* Bulletin No. 20, "Report on Kennett Reservoir Development" Division of Engineering and Irrigation, 1929.

Price of Fuel Oil.—The fuel used in steam-electric production for a number of years in the future probably will be natural gas. However, for clarity of analysis, costs on a basis of equivalent price per barrel for fuel oil will be used. To give some idea of the past history of fuel production and price, Table 53 and Plate XIX, "Petroleum Production and Unit Values, 1895–1929" and Plate XX, "Petroleum Production, Storage and Unit Values in California, 1895–1929," are included in this report. Plate XIX shows the annual production of crude petroleum in California, mid-continent, United States and the world through 1929, together with the estimated values of crude petroleum for the United States and California. Plate XX shows the comparison of the crude petroleum production with pipe line and tank farm stocks in California, and the average prices of fuel oil per barrel at San Francisco and crude petroleum values at wells in California. These data were obtained mainly from the United States Bureau of Mines.

The quoted price of fuel oil in 1930 was $0.89 per barrel barge delivery on San Francisco Bay. Natural gas for large plants was being sold at the same time at a price equivalent to $0.77 to $0.80 per barrel of fuel oil. Attempts have been made with some success to control wastage of gas and indirectly, oil production. This should tend to stabilize both production and price. It does not appear possible to make any definite estimate of future fuel prices. It would be reasonable, however, in any consideration of power values for the next ten or fifteen years to base estimates on fuel prices of from $0.80 per barrel (approximate present oil equivalent of natural gas price) to $1.00 per barrel.

Steam-electric Plant Efficiencies.—Efficiency in steam-electric plant operation has been increased fairly rapidly in the last fifteen years. The efficiency of Long Beach No. 1 plant, constructed prior to 1916 by the Southern California Edison Company, was approximately one barrel of oil per kilowatt per year for standby and 265 kilowatt hours of output per additional barrel of oil used. The efficiency of Long Beach No. 2 plant, constructed in 1924–25, is approximately one barrel per kilowatt per year for standby and 433 kilowatt hours of output per additional barrel of oil used. Long Beach No. 3 plant, one of the more recently constructed steam-electric plants in California, is operated on a basis of approximately .55 barrel per kilowatt per year for standby and 500 kilowatt hours of output per additional barrel of oil used.

For plants operating at 400 pounds boiler pressure, an efficiency, based on net plant output, of approximately .55 barrel of oil per kilowatt per year for standby and 500 kilowatt hours of output, switchboard delivery, per additional barrel, may be considered reasonable. For future steam-electric plants at 1200 pounds boiler pressure, an efficiency of .55 barrel of oil per kilowatt per year for standby and 540 kilowatt hours of output per additional barrel appears obtainable. The above figures assume installations at tidewater or points where adequate condensing water would be available.

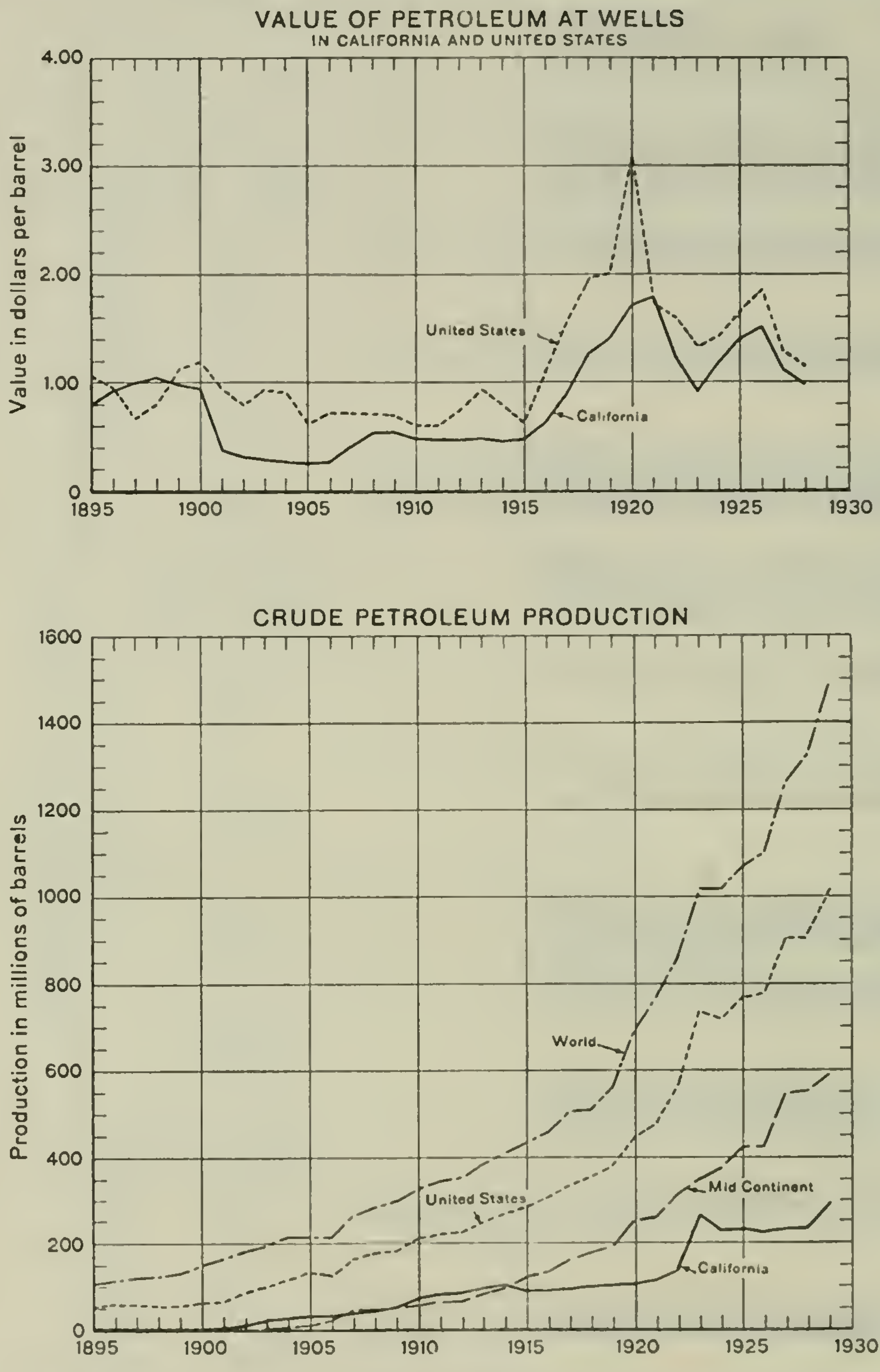
TABLE 53

PETROLEUM STATISTICS, 1880-1929

Year	California crude oil production					Mid-continent crude oil production				United States crude oil production					World crude oil production, in thousands of barrels
	Thousands of barrels	Per cent of United States total	Value per barrel at wells	Pipe line and tank farm stocks, in thousands of barrels, Dec. 31st	Average price of fuel oil per barrel at San Francisco	Thousands of barrels	Per cent of United States total	Value per barrel at wells	Pipe line and tank farm stocks, in thousands of barrels, Dec. 31st	Thousands of barrels	Per cent of world total	Value per barrel at wells	Domestic stocks in thousands of barrels, Dec. 31st: Pipe line and tank farm	Domestic stocks in thousands of barrels, Dec. 31st: Producers	
1880	41	0.2	$1.50							26,286	88	$0.94			30,018
1881	100	0.4	1.25							27,661	86	.92			31,993
1882	129	0.4	2.00							30,350	85	.78			35,704
1883	143	0.6	2.00							23,450	78	1.10			30,255
1884	262	1.1	2.50							24,218	67	.85			35,969
1885	325	1.5	2.31							21,859	59	.88			36,765
1886	377	1.3	2.31							28,065	59	.71			47,243
1887	679	2.4	2.00							28,283	59	.67			47,807
1888	690	2.5	2.00							27,612	53	.65			52,165
1889	303	0.9	1.21			.5				35,164	57	.77			61,507
1890	307	0.7	1.25			1.2				45,824	60	.77			76,633
1891	324	0.6	1.24			1.4				54,293	60	.56			91,100
1892	385	0.8	1.46			5.1				50,515	57	.51			88,739
1893	470	1.0	1.29			18				48,431	53	.60			92,038
1894	783	1.6	1.36			40	0.1			49,344	55	.72			89,337
1895	1,245	2.4	.80			44	0.1			52,892	51	1.06			103,692
1896	1,258	2.1	.94			115	0.2			60,960	53	.96			114,199
1897	1,912	3.2	1.00			148	0.3			60,476	50	.68			121,993
1898	2,249	4.1	1.06			617	1.1			55,364	44	.80			124,979
1899	2,678	4.7	.99			738	1.3			57,071	44	1.13			131,147
1900	4,330	6.8	.96			917	1.4			63,621	43	1.19			149,137
1901	7,710	11.1	.38			990	1.4			69,389	41	.96			167,440
1902	14,357	16.2	.33		$0.688	987	1.1			88,767	49	.80			181,809
1903	24,341	24.2	.30		.648	1,573	1.6			100,461	52	.94			194,879
1904	29,736	25.4	.28		.584	6,187	5.3	$0.95		117,081	54	.86			217,048
1905	34,276	25.4	.26		.497	12,534	9.3	.55		134,717	63	.62			215,091
1906	32,624	25.8	.28		.455	22,840	18.1	.45		126,494	59	.73			213,263
1907	40,311	24.3	.42		.823	46,896	28.2	.41		166,095	63	.72			263,957
1908	48,307	27.1	.55		1.000	48,824	27.3	.39		178,527	63	.72			285,287

1909	58,192	31.8	.56	18,000	.991	50,834	27.8	.37	53,542	183,171	61	.70	116,687	....	298,709
1910	77,698	37.1	.49	33,085	.887	59,218	28.3	.39	54,179	209,557	64	.61	131,030	....	327,763
1911	84,648	38.4	.48	44,240	.601	66,595	30.2	.48	57,680	220,449	64	.61	137,233	....	344,361
1912	89,689	40.2	.47	47,552	.717	65,473	29.4	.69	51,538	222,935	63	.74	122,870	....	352,443
1913	98,495	39.6	.49	48,302	.786	84,920	34.2	.95	57,392	248,446	64	.95	122,803	....	385,345
1914	102,882	38.7	.46	55,661	.797	97,995	36.9	.80	60,818	265,763	65	.81	141,550	....	407,544
1915	91,147	32.4	.48	44,588	.693	123,294	43.8	.59	74,230	281,104	65	.64	146,254	47,931	432,033
1916	90,263	30.0	.64	39,398	.958	136,934	45.5	1.19	77,307	300,767	66	1.10	139,303	40,069	457,500
1917	95,396	28.4	.91	32,450	1.341	163,506	48.8	1.73	99,426	335,316	67	1.56	150,063	9,389	502,891
1918	99,731	28.0	1.28	32,043	1.551	179,383	50.4	2.19	79,094	355,928	71	1.98	126,553	2,033	503,515
1919	101,183	26.7	1.41	30,480	1.600	193,147	51.0	2.16	76,712	378,367	68	2.01	129,205	4,089	555,875
1920	103,377	23.3	1.73	22,240	1.869	250,111	56.5	3.36	75,690	442,929	64	3.07	117,159	3,586	688,884
1921	112,600	23.8	1.80	35,022	1.734	258,461	54.7	1.65	102,401	472,183	62	1.73	172,083	5,139	766,002
1922	138,468	24.8	1.25	49,375	1.284	310,992	55.8	1.71	152,573	557,531	65	1.61	248,413	8,428	858,898
1923	262,876	35.9	.92	62,162	1.000	348,460	47.6	1.54	202,904	732,407	72	1.34	330,020	9,850	1,015,736
1924	228,933	32.1	1.20	96,505	1.371	375,479	52.6	1.46	210,558	713,940	70	1.43	377,312	8,389	1,014,318
1925	232,492	30.5	1.42	130,234	1.423	424,331	55.6	1.73	195,941	763,743	71	1.68	394,479	7,560	1,068,933
1926	224,673	29.1	1.54	119,170	1.040	423,867	55.0	2.01	173,848	770,874	70	1.88	361,350	5,904	1,096,823
1927	231,196	25.7	1.13	113,805	1.040	547,003	60.7	1.30	246,839	901,129	71	1.30	426,442	7,536	1,262,582
1928	231,811	25.7	.99	115,914	1.040	553,125	61.4	1.15	265,748	901,474	68	1.17	443,479	6,521	1,324,734
1929	292,037	29.0	....	153,135	.896	584,751	58.1	....	274,072	1,005,598	68	....	488,219	6,050	1,488,604

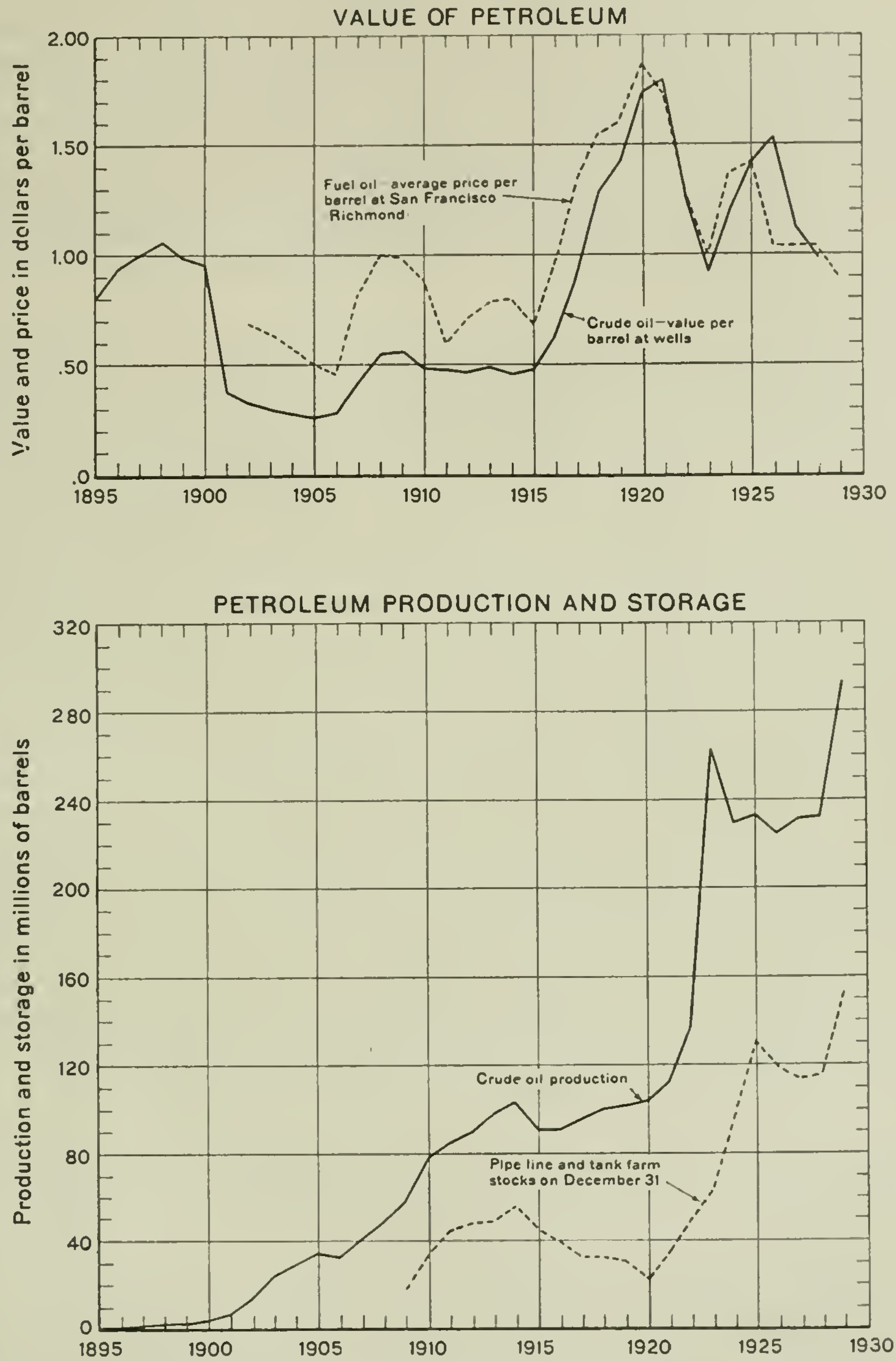
PLATE XIX



PETROLEUM PRODUCTION AND UNIT VALUES

1895-1929

PLATE XX



PETROLEUM PRODUCTION,
STORAGE AND UNIT VALUES
IN CALIFORNIA
1895-1929

Estimated Capital Cost of Steam-electric Power Plant.—The cost of a steam-electric power plant, including connecting transmission lines, was estimated in a previous report* to be $110 per kilowatt of plant capacity. This included approximately $90 for steam-electric power plant and $20 for substation and transmission line connection. Analysis of costs of plants recently constructed indicate that the cost per kilowatt varies within wide limits, depending upon size, local conditions, the extent to which the plant was completed to ultimate capacity, and the efficiency desired. For an entirely new plant, future prices for the plant alone of $85 per kilowatt at tidewater on the basis of 400-pound boiler pressure and $90 for 1200-pound pressure appear reasonable.

Capital Cost of Connecting Transmission Line to Steam-electric Plant.—An important cost involved in determining the comparative value of hydroelectric and steam-electric energy is that of necessary transmission from steam-electric, as well as hydroelectric plants, to the main system supplying the market. It has been held by some that conditions in northern California require a minimum of transmission lines from steam plants, the main load being concentrated near the San Francisco Bay area where the steam plants are located. The 220,000-volt transmission lines from the mountains concentrate at points near Antioch and Newark, with 110,000-volt lines running into the bay area. Approximately 56 per cent of the electric energy requirements of northern California, excluding the market served by the San Joaquin system,** or 46 per cent including that system, are located in San Francisco, San Mateo, Alameda and Contra Costa counties. The effect of supplying the present growth of power load requirements of northern California by adding steam-electric plants at San Francisco will be to release hydro-generated electric energy for supply of upcountry loads. This will tend to reverse flow of energy on incoming transmission lines. Supply for load growth will thus be obtained without proportionate addition of transmission lines. The conditions existing at present lend themselves especially well to this method of added service without important increase in transmission lines.

In the study of the electric energy from Hoover Dam power plant for southern California, it was generally agreed that transmission line capacity would be required for delivery of energy from a comparable steam-electric plant to the market. The report of engineers of the United States Bureau of Reclamation provides for a terminal substation and transmission line from a steam-electric plant to a transmission terminal costing $18.80 per kilowatt. Engineers representing the city of Los Angeles include $22.50 per kilowatt for these features. The Southern California Edison Company's estimates include a total of approximately $16.57 to $17.25 per kilowatt for transmission. These costs cover 25 miles of transmission line and a terminal substation.

* Bulletin No. 20, "Report on Kennett Reservoir Development," Division of Engineering and Irrigation, 1929.

** San Joaquin Light and Power Corporation, Midland Counties Public Service Corporation, Turlock and Modesto Irrigation Districts, and Merced Irrigation District.

In northern California, some additional electric energy from steam-electric plants could be absorbed, as noted above, without much additional connecting transmission line. However, when consideration is given to the supply that would be available in amounts of 100,000 to 200,000 kilowatts or more from Kennett power plant or other units of the State Water Plan, allowance must be made for transmission circuits and substations necessary to deliver the output of comparative steam-electric plants to the main transmission network. This is necessary in order that the cost of steam-electric energy delivered will be on a basis comparable with that from hydroelectric plants delivered to Antioch, the approximate load center.

An allowance of $20.00 per kilowatt of steam-electric plant capacity, for transmission circuits and substation, has been made in the following estimates. On this basis the total cost of steam-electric plant and transmission to be used in estimating the value of the hydroelectric energy delivered to the general system would be approximately $105 to $110 per kilowatt.

Annual Costs of Steam-electric Power Plants.—In all of the studies made for this report to estimate the value of hydroelectric energy based on the cost of producing an equivalent amount of electric energy of the same characteristics with a steam plant located in the area of consumption, taking into account the cost of transmission from point of generation to load center, it was assumed that the steam-electric plant would be constructed and operated by a private agency. In all computations of annual costs, therefore, a return of 7.5 per cent per annum on the capital investment was assumed.,

From a study of recent developments, it would appear that on account of the advances in design and construction, longer lives and lower rates of depreciation than those formerly used would be justified. Therefore, for estimating annual steam-electric plant costs, a depreciation annuity of two per cent was allowed.

The tendency of the last ten years has been toward a reduction in operating costs per kilowatt with increasing size of steam-electric plants and units. Recent studies indicate that operation and maintenance expense, including general costs, should be taken at this time at $2.65 per kilowatt of capacity.

An allowance of 0.4 per cent of capital cost for federal taxes also was made.

Annual Cost of Connecting Transmission Line to Steam-electric Plant.—The rate of return on transmission line investment would be the same as on steam-electric plants. Depreciation on long transmission lines is estimated for private development to be 1 per cent of the capital investment. Allowance for a short transmission line and substation, owing to a higher rate on the latter, should be 1.25 per cent, for private development. A reasonable amount for maintenance and operation of transmission facilities from an equivalent steam-electric plant in determining the value of hydroelectric energy would be $0.25 per kilowatt of plant capacity, per year.

Cost of Steam-electric Energy Delivered from Terminal Substation.—Based on the estimated capital costs, operating efficiencies and annual costs for a steam-electric plant and connecting transmission line heretofore set forth, Table 54 shows the cost of steam-electric energy delivered from the terminal substation. Estimates are presented on two bases; first, under present conditions and efficiencies with oil at $0.80 per barrel, and second, with probable future conditions with higher efficiencies and using a price of $1.00 per barrel for oil.

TABLE 54

COST OF STEAM-ELECTRIC ENERGY DELIVERED FROM TERMINAL SUBSTATION

	Present conditions	Probable future conditions
Investment per kilowatt of capacity:		
Steam-electric plant	$85 00	$90.00
Transmission line and substation	20 00	20 00
Total	$105.00	$110.00
Estimated efficiency:		
Standby oil in barrels per kilowatt per year	.55	.55
Output in kilowatt hours per additional barrel of oil	500	540
Price assumed per barrel for fuel oil	$0 80	$1 00
Cost of energy:		
Fixed costs per kilowatt per year:		
Steam plant—		
Return or interest at 7.5 per cent	$6 375	$6 750
Depreciation at 2.0 per cent	1 700	1.800
Operating expenses at $2.65 per kilowatt	2.650	2.650
Standby oil	.440	.550
Federal taxes at 0.4 per cent	.340	.360
Subtotal	$11.505	$12 110
Transmission—		
Return or interest at 7.5 per cent	$1 50	$1 50
Depreciation at 1.25 per cent	25	.25
Operating expenses at $0.25 per kilowatt	.25	.25
Federal taxes at 0.4 per cent	.08	.08
Subtotal	$2 08	$2.08
Total fixed costs of steam plant and transmission, per kilowatt per year	$13 585	$14.190
Output cost per kilowatt hour of plant delivery	$0 00160	$0.00185
Total costs of substation delivery on basis of 2.5 per cent loss in transmission:		
Fixed costs per kilowatt per year	$13.933	$14.554
Output cost per kilowatt hour	.00164	.00190
Recommended unit costs of substation delivery:		
Fixed costs per kilowatt per year	$13 95	$14 55
Output cost per kilowatt hour	00165	.00190
Average cost per kilowatt hour at 60 per cent annual load factor	$0 00430	$0.00467

For estimating the values of the energy outputs of hydroelectric plants, the fuel prices, efficiencies and recommended unit costs of substation delivery for steam-electric plants given in Table 54, were used.

Computed Value of Hydroelectric Energy Based on Steam-electric Energy Costs.—In estimating the value of hydroelectric energy based on the cost of steam generated electric energy, the electric energy requirements having characteristics of the market supplied by System 1 and sufficient to utilize the full output of the hydroelectric plant in question in a maximum year were first determined. This load would require some steam produced electric energy to supply the energy in excess of the hydroelectric plant output in months when the market demand exceeded the hydroelectric plant output. Second, the average annual amount of steam produced electric energy necessary to make up the full requirements was estimated and also the monthly maximum auxiliary steam plant output for the year of lowest hydroelectric energy output.

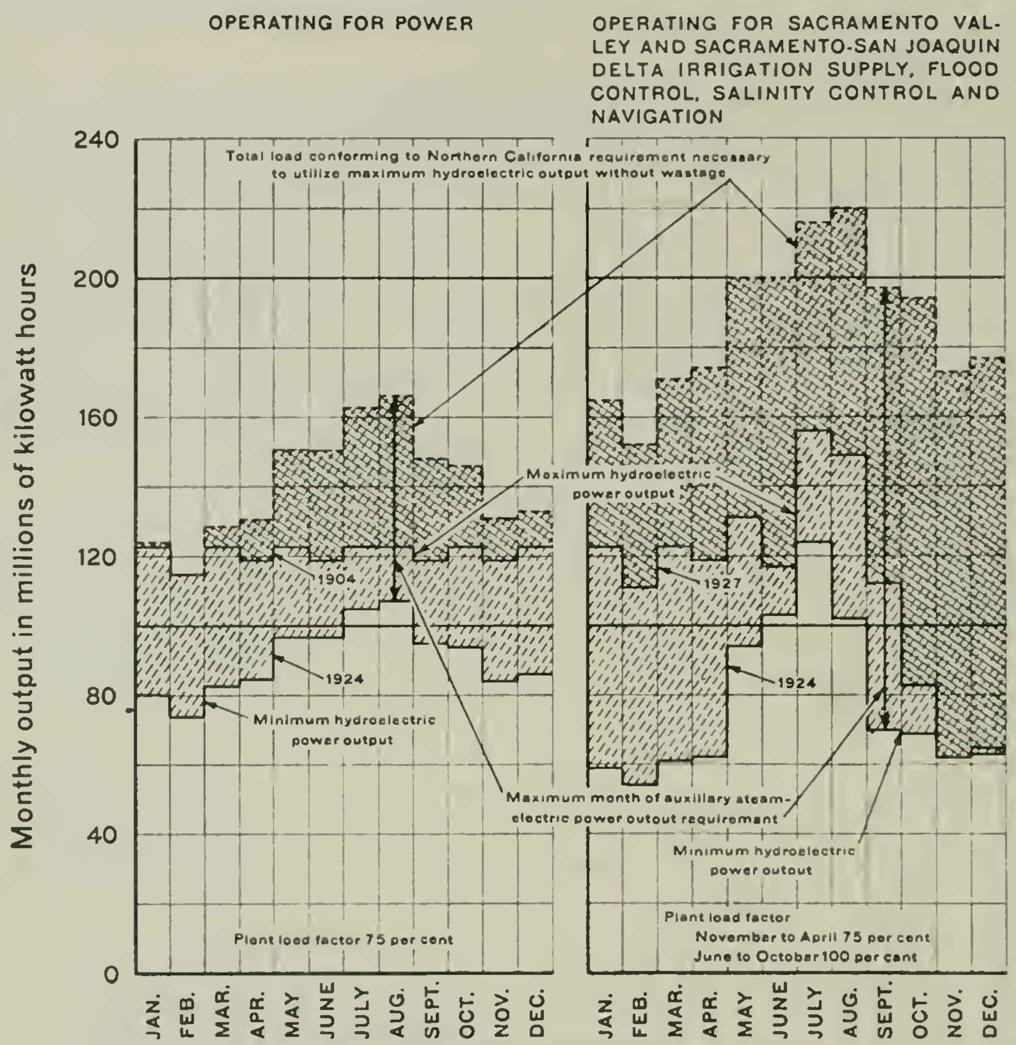
Plate XXI, "Analysis of Steam-electric Power Required to Utilize the Hydroelectric Power Output of Kennett Reservoir," sets forth graphically the monthly relation of total load and steam-electric and hydroelectric output for maximum and minimum hydroelectric output years. This is set up for Kennett reservoir operating primarily for the generation of power and also operating for the combined uses of flood control; supplying water for the irrigation requirements of lands along the Sacramento River and in the Sacramento-San Joaquin Delta, for salinity control and for the improvement of navigation on the Sacramento River; and the generation of electric energy incidental to the other uses. The former operation is that designated as Method I and the latter as Method II, in Chapter XI.

It may be noted from the graphs that the total load with the reservoir operating primarily for the generation of power would have been much less than when operating for the combined uses outlined above, indicating that the annual steam produced electric energy necessary to utilize the maximum hydroelectric energy output would be less when the plant is operated in the former manner. This extra amount of steam produced electric energy in the second case would be necessary to absorb the hydroelectric output when hydroelectric plant load factor was unity. Based on these data and on the effective capacity characteristics of the hydroelectric plant, the size of an independent steam-electric plant, located near the load center, necessary to supply the entire load, and the auxiliary steam-electric plant capacity required to supply the kilowatts and kilowatt hours in excess of those from the hydroelectric plant during critical months, were calculated.

The annual cost of supplying the total load from an independent steam-electric plant was estimated, and from this was deducted the average annual cost of the auxiliary steam-electric plant necessary in conjunction with the hydroelectric plant. The amount remaining represented the value of the hydroelectric energy delivered at Antioch substation. Deduction of the annual cost of the transmission system from the hydroelectric plant to Antioch gave the value of the average annual output of the hydroelectric plant delivered direct from the plant.

Table 55 sets forth the monthly energy outputs of Kennett power plant in the years of maximum and minimum production with the reservoir operated under Methods I and II, as above described, together with the kilowatt hours of the total load required to absorb these outputs. The data in the table are shown graphically on Plate XXI.

PLATE XXI



ANALYSIS OF STEAM-ELECTRIC POWER REQUIRED TO UTILIZE THE HYDROELECTRIC POWER OUTPUT OF KENNETT RESERVOIR

Steam-electric power required in maximum year of hydroelectric power output

Steam-electric power required in minimum year of hydroelectric power output

TABLE 55

ANALYSIS OF STEAM-ELECTRIC ENERGY REQUIRED TO UTILIZE MAXIMUM ELECTRIC ENERGY OUTPUT OF KENNETT POWER PLANT

Installed capacity, 275,000 kilovolt amperes or 220,000 kilowatts
Reservoir operated primarily for generation of power (Method I, Chapter XI)

Month	Energy output of Kennett hydroelectric plant in maximum year, in millions of kilowatt hours	Northern California load, in per cent of annual total	Total load on hydroelectric and steam-electric plants required to utilize maximum hydroelectric plant output, in millions of kilowatt hours	Energy output of hydroelectric plant in minimum year, 1924, in millions of kilowatt hours	Maximum output required from steam-electric auxiliary plant, in millions of kilowatt hours
January	122.7	7.36	124.2	79.9	44.3
February	114.7	6.79	114.7	73.7	41.0
March	122.7	7.63	128.7	82.9	45.8
April	118.7	7.79	131.4	84.6	46.8
May	122.7	8.93	150.7	97.0	53.7
June	118.7	8.95	151.0	97.2	53.8
July	122.7	9.65	162.8	104.8	58.0
August	122.7	9.84	166.0	106.8	59.2
September	118.7	8.78	148.1	95.3	52.8
October	122.7	8.65	145.9	93.9	52.0
November	118.7	7.74	130.6	84.0	46.6
December	122.7	7.89	133.1	85.7	47.4
Totals	1,448.4	100.00	1,687.2	1,085.8	601.4

Average annual output of Kennett power plant alone=1,322,800,000 kilowatt hours.

Reservoir operated to control floods and to supply water for irrigation demands along Sacramento River and in Sacramento-San Joaquin Delta, navigation and salinity control, with incidental power (Method II, Chapter XI)

Month	Energy output of Kennett hydroelectric plant in maximum year, in millions of kilowatt hours	Northern California load, in per cent of annual total	Total load on hydroelectric and steam-electric plants required to utilize maximum hydroelectric plant output, in millions of kilowatt hours	Energy output of hydroelectric plant in minimum year, 1924, in millions of kilowatt hours	Maximum output required from steam-electric auxiliary plant, in millions of kilowatt hours
January	122.7	7.36	164.9	58.9	106.0
February	110.8	6.79	152.1	54.3	97.8
March	122.7	7.63	170.9	61.1	109.8
April	118.7	7.79	174.5	62.3	112.2
May	130.9	8.93	200.0	94.4	105.6
June	117.2	8.95	200.5	103.4	97.1
July	155.8	9.65	216.2	122.3	93.9
August	148.5	9.84	220.4	101.7	118.7
September	112.0	8.78	196.6	70.3	126.3
October	83.4	8.65	193.8	69.2	124.6
November	61.9	7.74	173.4	61.9	111.5
December	65.2	7.89	176.7	63.1	113.6
Totals	1,349.8	100.00	2,240.0	922.9	1,317.1

Average annual output of Kennett power plant alone=1,297,600,000 kilowatt hours.

Table 56 sets forth the computation of the value of electric energy output from Kennett power plant on the basis of cost of steam generated electric energy from a modern steam-electric plant. The value is set in two ways: first, with present price of oil and steam-electric plant efficiency and, second, with probable future conditions of oil price and plant efficiency, as shown in Table 54. The value of the electric energy has been computed for the reservoir operating under the two methods previously mentioned, that is, primarily for the generation of power, and primarily for the combined uses of irrigation, salinity control, flood control and navigation. Under both methods of operation, the reservoir would have been drawn down to approximately half head at the end of 1924, a condition reducing the plant capacity materially. In the case of operation primarily for power, the draft on the reservoir could be adjusted to eliminate this effect or added generator capacity installed. In the case of the operation for the combined uses, some loss in net capacity must be experienced under conditions similar to those of 1924.

TABLE 56

VALUE OF HYDROELECTRIC ENERGY FROM KENNETT POWER PLANT, BASED ON PRODUCTION BY STEAM-ELECTRIC PLANT

Reservoir operated primarily for the generation of power (Method I, Chapter XI)

Plant capacity	220,000 kilowatts
Transmission distance	200 miles
Energy output measured at Kennett hydroelectric plant:	
Total load to utilize hydroelectric output in maximum year	1,687,200,000 kilowatt hours
Hydroelectric plant output—average year	1,322,800,000 kilowatt hours
Steam-electric plant output required—average	364,400,000 kilowatt hours
Energy output—terminal substation measurement:	
Total	1,484,700,000 kilowatt hours
Hydroelectric plant output—average year	1,164,100,000 kilowatt hours
Steam-electric plant output required—average	320,600,000 kilowatt hours
Maximum month—auxiliary steam-electric plant output reduced to terminal substation measurement	52,100,000 kilowatt hours
All-steam-electric plant peak to serve load at 60 per cent annual load factor	282,500 kilowatts
Auxiliary steam-electric plant peak required to supply demand in maximum month	89,000 kilowatts

Value of Hydroelectric Energy

	Present conditions		*Probable future conditions*	
Fuel oil—price per barrel	$0.80		$1.00	
All-steam-electric plant cost				
Fixed cost	3,941,000		4,110,000	
Output cost	2,450,000		2,821,000	
Total	6,391,000		6,931,000	
Auxiliary steam-electric plant cost				
Fixed cost	1,242,000		1,295,000	
Output cost	529,000		609,000	
Total	1,771,000		1,904,000	
Resultant value of hydroelectric energy at terminal substation				
Total	4,620,000		5,027,000	
Per kilowatt hour		.00397		.00432
Transmission cost	1,027,000		1,027,000	
Resultant value of hydroelectric energy at power plant switchboard				
Total	3,593,000		4,000,000	
Per kilowatt hour		.00272		.00302

TABLE 56—Continued

Reservoir operated to control floods and to supply water for irrigation demands along Sacramento River and in Sacramento-San Joaquin Delta, navigation and salinity control, with incidental power (Method II, Chapter XI)

Plant capacity	220,000 kilowatts
Transmission distance	200 miles
Energy output measured at Kennett hydroelectric plant:	
Total load to utilize hydroelectric plant output in maximum year	2,240,000,000 kilowatt hours
Hydroelectric plant output—average year	1,297,600,000 kilowatt hours
Steam-electric plant output required—average	942,400,000 kilowatt hours
Energy output—terminal substation measurement:	
Total	1,971,200,000 kilowatt hours
Hydroelectric plant output—average year	1,141,900,000 kilowatt hours
Steam-electric plant output required—average	829,300,000 kilowatt hours
Maximum month—auxiliary steam-electric plant output reduced to terminal substation measurement	111,100,000 kilowatt hours
All-steam-electric plant peak to serve load at 60 per cent annual load factor	375,000 kilowatts
Auxiliary steam-electric plant peak required to supply demand in maximum month	190,000 kilowatts

Value of Hydroelectric Energy

	Present conditions		*Probable future conditions*	
Fuel oil—price per barrel	$0.80		$1.00	
All-steam-electric plant cost				
Fixed cost	5,231,000		5,456,000	
Output cost	3,252,000		3,745,000	
Total	8,483,000		9,201,000	
Auxiliary steam-electric plant cost				
Fixed cost	2,650,000		2,764,000	
Output cost	1,368,000		1,576,000	
Total	4,018,000		4,340,000	
Resultant value of hydroelectric energy at terminal substation				
Total	4,465,000		4,861,000	
Per kilowatt hour		.00391		.00426
Transmission cost	1,027,000		1,027,000	
Resultant value of hydroelectric energy at power plant switchboard				
Total	3,438,000		3,834,000	
Per kilowatt hour		.00265		.00295

Transmission cost from the Kennett plant to Antioch has been included as indicated in Table 51. If the transmission line and substation were constructed and operated by the State, the transmission cost per kilowatt hour would be less on account of financing with money at a lower interest rate. This would increase the value of the energy at the power plant. In this report, however, values have been used which are based on the sale of electric energy to private carriers at the plant, which results in a lower and more conservative annual return from the sale of the energy in estimating the total revenue from the Kennett project.

It may be noted from Table 56 that a decrease in value of output would occur if operation primarily for the production of power were modified in order to make water available for irrigation demand, navigation and salinity control and to control floods. As requirements for irrigation and other uses would increase and the operations of the respective developments would be modified to meet these requirements, the value of the energy output would be reduced. The value of the energy output, therefore, would depend quite definitely upon conditions imposed by water requirements of the Great Central Valley.

Table 57 shows the electric energy outputs and their values with several methods of operation of the Kennett reservoir. The basis of estimating the values was steam-electric energy costs under present conditions. The table also shows the changes in the characteristics of power plant output under the different methods of reservoir operation.

TABLE 57

COMPARISON OF VALUES OF ELECTRIC ENERGY OUTPUT FROM KENNETT POWER PLANT UNDER DIFFERENT METHODS OF OPERATION, BASED ON THE COST OF STEAM-ELECTRIC ENERGY UNDER PRESENT CONDITIONS

Plant capacity of Kennett power plant, in kilovolt amperes, 275,000; in kilowatts, 220,000.
Plant capacity of Keswick power plant in kilovolt amperes, 50,000; in kilowatts, 40,000.
Transmission line length in miles, 200; capital cost, $10,150,000.

	Method of operation			
	I[1]	II[2]	III[3]	IV[4]
Energy output, hydroelectric plant measurement:				
Total load to utilize hydroelectric output, in kilowatt hours	1,687,200,000	2,240,000,000	2,826,000,000	2,657,000,000
Hydroelectric output in average year, in kilowatt hours	1,322,800,000	1,297,600,000	1,289,000,000	1,055,400,000
Steam-electric output required, average in kilowatt hours	364,400,000	942,400,000	1,537,000,000	1,601,600,000
Energy output, terminal substation measurement:				
Total load to utilize hydroelectric output, in kilowatt hours	1,484,700,000	1,971,200,000	2,486,900,000	2,338,200,000
Hydroelectric output in average year, in kilowatt hours	1,164,100,000	1,141,900,000	1,134,300,000	928,800,000
Steam-electric output required, average in kilowatt hours	320,600,000	829,300,000	1,352,600,000	1,409,400,000
Maximum month—auxiliary steam-electric energy output equated to terminal substation measurement, in kilowatt hours	52,100,000	111,100,000	182,200,000	-------------
All-steam-electric plant peak to serve load at 60 per cent annual load factor, in kilowatts	282,500	375,000	473,000	455,000
Auxiliary steam-electric plant peak required to supply demand in maximum month, in kilowatts	89,000	190,000	310,000	345,000
All-steam-electric plant peak minus auxiliary steam-electric plant peak or resultant steam-electric kilowatt value of hydroelectric plant, in kilowatts	193,500	185,000	163,000	110,000
Annual cost of above resultant capacity:				
Fixed cost	$2,699,000	$2,581,000	$2,274,000	$1,534,000
Output cost	1,921,000	1,884,000	1,872,000	1,533,000
Value of hydroelectric energy output at substation terminals	4,620,000	4,465,000	4,146,000	3,067,000
Annual cost of transmission	1,027,000	1,027,000	1,027,000	1,027,000
Value of hydroelectric energy at power plant switchboard	3,593,000	3,438,000	3,119,000	2,040,000
Value of hydroelectric energy per kilowatt hour of plant output	$0.00272	$0.00265	$0.00242	$0.00193
Combined average annual hydroelectric energy output of Kennett and Keswick power plants, in kilowatt hours	1,622,800,000	1,591,800,000	1,581,100,000	1,285,000,000
Resultant value of combined Kennett and Keswick hydroelectric energy at power plant switchboards	$4,414,000	$4,218,000	$3,826,000	$2,480,000

[1] Method I is described on page 382, Chapter XI.
[2] Method II is described on page 382, Chapter XI.
[3] Method III is described on page 383, Chapter XI.
[4] Method IV is described on page 384, Chapter XI.

Under irrigation operation for maximum irrigation yield, Method IV, no water would be released from the reservoir from November to February except when spilling, resulting in no power production in these months in many years. Under these conditions, the value of the electric energy produced would approach practically that of fuel cost for steam-electric energy less transmission cost. In the computations for this operation, it was assumed that sufficient water would be released to operate the plant to one-half of its capacity to supply the peak demands of the power market during the winter months. Such operation would require limited water withdrawals which would affect the irrigation yield only in critical years such as 1920 and 1924. The last two lines of items at the bottom of the table show the combined hydroelectric energy outputs, and the values of these outputs, respectively, from the Kennett power plant and the Keswick afterbay power plant. In making the estimates of value, it was assumed that the electric energy from both plants would have the same unit values.

Summary.—In the foregoing paragraphs, estimates of the value of the electric energy output from the Kennett power plant, delivered at the plant switchboard, with the reservoir operated primarily for the generation of power, are given for three bases of estimating. These bases, and the value obtained by each, are summarized as follows:

Basis of valuation	*Value of electric energy, in mills per kilowatt hour*
Cost of hydroelectric energy from other developments	2.80 to 2.87
Prices in existing contracts, discounted for economic changes	3.00
Cost of steam-electric energy	2.72

A comparison of these figures shows that the lowest value is that resulting from the basis of the cost of steam produced electric energy. This basis, therefore, since it gives the most conservative values, has been used in estimating the revenue from the electric energy generated at the Kennett power plant.

The values of the electric energy generated at the Kennett power plant with the other methods of operation of the Kennett reservoir also were estimated on the basis of the cost of steam-produced electric energy using present prices of oil and present efficiencies of steam-electric plants.

Values of Electric Energy from Units of State Water Plan for Sacramento River Basin.—In the foregoing discussion, details have been given of the methods used in estimating the value of electric energy from the Kennett power plant. The values of the electric energy from the other major units of the State Water Plan in the Sacramento Basin, for which power plants are proposed, also were estimated on the basis of the cost of producing an equivalent amount of electric energy of the same characteristics with a steam-electric plant located in the area of consumption, taking into account the cost of transmission from point of generation to the load center.

For the American River unit, values of electric energy were estimated for four methods of operation which are similar to the four methods for the Kennett reservoir. Values also were estimated for two methods for the coordinated operation of the Folsom, Auburn and Pilot Creek reservoirs and Folsom afterbay, with their power plants, called the "Partial American River unit." These four methods of operation for the complete American River unit and the two methods for the partial American River unit are described in detail in Chapter XI.

For the Trinity River diversion, values of electric energy were estimated only for the system operated primarily for the generation of power. For the Oroville reservoir and afterbay and for the Narrows reservoir, values were estimated for the reservoirs operated primarily for the generation of power and primarily for supplying irrigation water with the incidental generation of power.

The average annual amounts of electric energy generated and the values of this energy from all of the power plants of the State Water Plan in the Sacramento River Basin, are shown in Table 58.

TABLE 58

VALUE OF ELECTRIC ENERGY FROM UNITS OF STATE WATER PLAN IN SACRAMENTO RIVER BASIN

Unit	Method of operation	Average annual electric energy output, in kilowatt hours	Value of electric energy per kilowatt hour, at plant switchboard	Average annual revenue from electric energy
Kennett reservoir and Keswick afterbay	I [1]	1,622,800,000	$0 00272	$4,414,000
	II [2]	1,591,800,000	.00265	4,218,000
	III [3]	1,581,100,000	.00242	3,826,000
	IV [4]	1,285,000,000	00193	2,480,000
Oroville reservoir and afterbay	I [5]	1 409,100,000	.00310	4,368,000
	IV [6]	1,172,200,000	.00225	2,637,000
Narrows reservoir	I [5]	570,300,000	.00298	1,699,000
	IV [7]	528,100,000	.00235	1,241,000
Trinity River diversion	I [5]	1,063,900,000	.00250	2,660,000
Complete American River unit	I [8]	1,052,400,000	.00327	3,441,000
	II [9]	972,500,000	.00331	3,219,000
	III [10]	951,700,000	.00292	2,779,000
	IV [11]	898,800,000	.00256	2,301,000
Partial American River unit	I [12]	762,500,000	.00327	2,493,000
	II [13]	730,000,000	00250	1,828,000

[1] Method I is described on page 382, Chapter XI.
[2] Method II is described on page 382, Chapter XI.
[3] Method III is described on page 383, Chapter XI.
[4] Method IV is described on page 384, Chapter XI.
[5] The reservoir would be operated in such a manner as to obtain the greatest possible revenue from the production of electric energy, all other uses of the water being incidental.
[6] The reservoir would be operated in such a manner as to make available a maximum possible irrigation supply at Oroville dam site.
[7] The reservoir would be operated in such a manner as to make available a maximum possible irrigation supply at Smartsville.
[8] Method I is described on page 384, Chapter XI.
[9] Method II is described on page 384, Chapter XI.
[10] Method III is described on page 385, Chapter XI.
[11] Method IV is described on page 3°6, Chapter XI.
[12] Method I is described on page 386, Chapter XI.
[13] Method II is described on page 388, Chapter XI.

Effect of Operation of Power Reservoirs on Irrigation Yield.

Upstream from the sites for some of the reservoirs of the State Water Plan in the Sacramento River Basin, there are reservoirs now constructed and in operation for the development of hydroelectric energy. In addition to these, there are many favorable reservoir sites which could be developed in the future for the same purpose. In the studies of the yields of the reservoirs of the State Water Plan, account was taken of the modification of the regimen of the streams, in each instance, due to the existing power reservoirs. However, no account was taken of any modification for possible future development of other reservoir sites suitable for power purposes. Therefore, it was deemed desirable to ascertain, at least relatively, the additional irrigation yield, if any, which would be obtainable through such upstream development.

A general inquiry was made of the entire situation and a rather detailed study was made on one particular stream, the Feather River. The value of any power development reservoir located in the mountains, in improving the irrigation conditions at lower elevations on the stream on which it is located, is dependent upon the size of the drainage area tributary to it, the size of the reservoir, and the method of its operation, that is, whether the storage is cyclic or annual. An examination of the records of the existing power reservoirs in the basin discloses that the drafts from storage to meet the power demands usually begin in the summer months and extend into the late fall, and early winter months in some years. The drafts, therefore, synchronize only in part with the irrigation demand because the irrigation season in the Sacramento Valley practically terminates in October, whereas power released from storage may extend into January in years of subnormal precipitation. Such late releases would not be utilizable directly for irrigation purposes. With the exception of Lake Almanor on the Feather River, a Great Western Power Company development, most existing power reservoirs are filled, if possible, and emptied each year. No cyclic operation is attempted. On the other hand, Lake Almanor, having a capacity of 1,300,000 acre-feet and capable of storing nearly two years normal run-off from above its dam, is operated cyclically, storing water in years of abundant run-off for years of scant supply.

The existing reservoirs which are used primarily for the storage of water for the generation of power, and the storage capacity of each reservoir, are shown in Table 59.

TABLE 59

EXISTING POWER DEVELOPMENT RESERVOIRS IN THE SACRAMENTO RIVER BASIN

Stream	Reservoir	Storage capacity, in acre-feet
Upper Sacramento River Basin—		
Pit River	Britton	32,200
Feather River Basin—		
West Branch	Round Valley	1,280
	Philbrook	5,060
North Fork	Almanor	1,300,000
Hamilton Branch	Mountain Meadow	36,000
Butt Creek	Butt Valley	50,000
Bucks Creek	Bucks Creek	103,000
Yuba River Basin—		
North Fork	Bullards Bar	[1]14,080
Dobbins Creek	Lake Francis	2,400
South Fork	Lake Van Norden	5,870
	Lake Spaulding	74,450
Fordyce Creek	Lake Fordyce	46,660
American River Basin—		
North Fork	Lake Valley	8,130
South Fork	Medley Lakes	5,400
	Echo Lake	2,000
Silver Fork	Twin Lakes	21,400
	Silver Lake	6,200

[1] Effective storage.

The results of studies made to estimate the effect of certain present and future power development reservoirs on the North Fork of the

Feather River, on the irrigation yield of the entire Feather River at Oroville, are summarized in Table 60. These studies were made for the period 1909–1926, and the irrigation yields are based on this period. The monthly distribution of the seasonal irrigation draft was assumed to be the same as that for the Sacramento Valley floor. There are other reservoirs on the West Branch of the North Fork which are used for the storage of water for power development purposes, but this water is diverted from the watershed above Oroville and the releases from these reservoirs do not affect the flow at this point. A list of the existing power reservoirs on both the North Fork and the West Branch is given in Table 59. The Indian Valley reservoir site is situated on Indian Creek, a tributary of Spanish Creek which flows into the North Fork.

TABLE 60

INCREASED IRRIGATION YIELD AT OROVILLE DUE TO POWER RESERVOIRS ON FEATHER RIVER

Storage development	Capacity of reservoir, in acre-feet	Aggregate capacity of reservoirs, in acre-feet	Method of operation	Seasonal irrigation yield[1] for period 1909-1926, in acre-feet	Increased irrigation yield, in acre-feet, with reservoirs operated primarily for generation of power
None				336,000	
Lake Almanor[2]	1,300,000				
Butt Valley	50,000	1,453,000	Power	574,000	238,000
Bucks Creek	103,000				
Lake Almanor[2]	1,300,000				
Butt Valley	50,000				
Bucks Creek	103,000	2,141,000	Power	702,000	366,000
Indian Valley	688,000				

[1] Yield would have an average seasonal deficiency for the period of two per cent.
[2] Mountain Meadows reservoir lies above Lake Almanor and its releases are reregulated by the latter reservoir.

The seasonal irrigation yield of 336,000 acre-feet from the Feather River unregulated by any storage, for the period 1909–1926, is only about 7.8 per cent of the average and 25.9 per cent of the minimum annual full natural run-off for the same period, at Oroville. The added annual yield with the existing power development reservoirs is 238,000 acre-feet or 71 per cent of the yield without any storage. If the Indian Valley reservoir also were constructed and operated primarily for the generation of power, the irrigation yield at Oroville would be increased 366,000 acre-feet, or 109 per cent, over the yield without any storage. The power development reservoirs, therefore, cause a considerable increase in the irrigation yield available from unregulated stream flow.

The operation of a reservoir to supply water primarily for the generation of power may cause annual, monthly, weekly and diurnal modifications in the natural flow of the stream on which it is located.

The annual and monthly modifications are usually beneficial to the irrigation uses of the stream flow since water stored in seasons or months of ample run-off is released for power development in the dry years or months and increases the amounts of water available for irrigation at these times. In most cases, the effect of the power reservoirs in changing the total annual flow is very limited since very few reservoirs are operated for cyclic storage. The largest reservoir which is operated in this way is Lake Almanor, and it has been very effective in improving stream flow conditions in the Feather River in several recent dry years by releasing water stored in previous years of ample run-off. This same effect would be obtained from other power reservoirs in the mountains if large enough to be operated for cyclic storage.

The most economic operation of hydroelectric developments having reservoirs requires the releases of stored water at varying rates throughout the week and the day. This is due to most systems having light power loads from Saturday to Monday, and during the night hours, and heavy peak loads during other hours of the day. During the days and hours of light load, the amounts of water passed through the power plants are small, or nothing, and these amounts gradually increase as the load increases until they reach a maximum at the peak load. These varying rates of release of water from the reservoir would naturally cause a changing rate of stream flow if some means were not available for its reregulation. This reregulation can be very effectively obtained by an afterbay installed downstream from the power plant. In this afterbay, flows in excess of a uniform rate can be stored and so released that there will be uniform flow, which is best suited to irrigation use, in the stream below it. The major reservoir units of the State Water Plan would act as afterbays for the power developments in the mountains above them and would regulate the stream flows for irrigation uses on the Sacramento Valley floor.

It is concluded, therefore, that power reservoirs, and especially the larger ones, located on a stream or its tributaries in the mountains above the major reservoir units of the State Water Plan, would be effective in increasing the irrigation yield that could be obtained from the stream either with or without the major reservoir unit. The calculated yields from these reservoirs, which are given in Chapter IX, therefore, probably would be somewhat increased by the future construction of power reservoirs.

CHAPTER IX

MAJOR UNITS OF STATE WATER PLAN IN SACRAMENTO RIVER BASIN

Under present conditions of stream flow and regulation in the Sacramento River Basin, practically all of the water in the streams during the summer months is used for irrigation. A study of these flows and present demands indicates that with the present monthly and seasonal distribution of these flows, a dependable supply is not available for the present uses and appropriations and that further development dependent upon the present stream flows would be impracticable without storage facilities.

A review of the data contained in Chapter II reveals the wide variation of stream flow from one season to another, from month to month, and even from day to day. In some years, large amounts of water waste to the ocean and in nearly all years some water is wasted which, with proper storage facilities, could be put to a beneficial use.

Any project to utilize the water resources of the Sacramento River Basin to the greatest degree would require a much more dependable supply than one having these wide variations. To regulate the water supplies so that approximately the same amounts would be available in each season, would require adequate reservoir capacity to store the excess flows in seasons having more run-off than can be economically used, for use in seasons having run-off insufficient for the requirements. Even if the run-off had an equal seasonal distribution, the greater part of that in each season occurs in the winter when practically no water is required for irrigation and the streams reach their lowest flows in the late summer when there is the greatest demand for water for irrigation, power development, navigation and salinity control. Reservoirs, therefore, also are needed to store the winter and spring flows and make them available to meet the demands for use in the summer and fall months.

A comparison of the water supply available in different sections of the Great Central Valley of California with the irrigation requirements for ultimate development of the land in those sections shows that there is an unequal geographic distribution of water supply as related to irrigation requirements. In order to overcome this unequal distribution of water supply with relation to its needs, both as to the time of occurrence and as to locality, so that all parts of the Great Central Valley would receive a supply dependable in time and adequate in amount, physical works must be provided. The necessary works to accomplish this are designated as the State Water Plan. They comprise storage reservoirs to equalize the seasonal run-offs of the streams and to give them the proper monthly distribution, and conduits to carry the stored water from areas of surplus to areas of deficient supply. The entire plan is described in another bulletin* and that for

* Bulletin No. 25, "Report to Legislature of 1931 on State Water Plan," Division of Water Resources, 1930.

the San Joaquin River Basin portion of the Great Central Valley is described in more detail in the report * on that basin. The units of the plan in the Sacramento River Basin are described in this chapter.

Reservoirs constructed on the major streams for the conservation of water for irrigation and other purposes also could be used to reduce the maximum mean daily or flood flows to certain specified amounts, if the reservoirs were operated specifically for that purpose.

There are in the mountains and foothills of the Sacramento River Basin a large number of reservoir sites, many of which are now fully or partially developed. The development of storage began many years ago when reservoirs were built to store water for use in hydraulic mining operations. Other reservoirs were later developed for irrigation or power use, or a combination of the two, and some of the old mining reservoirs have been converted to these uses.

With the beginning of the State's present water resources investigations in 1921, it was realized that large storage reservoirs would be necessary in the Sacramento River Basin to fully, or even partially, develop its water resources. Surveys were started, therefore, to determine all available sites, their capacities, the character of dam most suitable for each site and the approximate cost of each reservoir. This information has been added to in succeeding years until at the present time a large amount of information is available covering practically every site in the basin. As stated above, many of these sites have been developed and in these cases information was obtained from the owners. Other sites had been investigated by public or private agencies, and data are available from their investigations. A reconnaissance was made by the State directed toward finding other sites and especially those at strategic locations at which large storage could be obtained at reasonable cost. Preliminary topographic surveys were made of a large number of reservoir and dam sites and, in many cases, preliminary geological investigations of the dam sites were made to determine the suitability of the formations for the foundation for a dam of some standard type. During the investigations, several sites have been found on the major streams near the edge of the valley floor, in addition to those which were already known to exist, in which large storage could be developed.

In general, the reservoir sites in the mountains are of small capacity as compared to the foothill sites and are suitable primarily for power development and irrigation in the mountain and foothill areas and should be reserved for these purposes. Some sites, however, such as Big Valley and Fall River Valley on the Pit River and Big Meadows or Lake Almanor on the North Fork of the Feather River have storage capacity in excess of a million acre-feet. Other sites range in size from this capacity down to a few hundred acre-feet. The smaller sites are usually relatively expensive. Some of the mountain reservoirs have been constructed for power development purposes but in most cases the water, after passing through the power plants, is used for irrigation in the low mountains or foothills or on the valley floor.

* Bulletin No. 29, "San Joaquin River Basin," Division of Water Resources, 1931.

TABLE 61

RESERVOIR SITES IN SACRAMENTO RIVER BASIN

Stream	Name of reservoir site	Location			Drainage area, in square miles
		Section	Township	Range	
Sacramento River	Wagon Valley	29	40 N.	4 W.	117
Sacramento River	Sims	18	37 N.	4 W.	287
Sacramento River	Delta	35	36 N.	5 W.	390
Sacramento River	Gregory	35	35 N.	5 W.	....
McCloud River	Old Bartle	36	40 N.	1 W.	58
McCloud River	Upper Falls	7	39 N.	1 W.	309
McCloud River	Rinckle	15	38 N.	2 W.	415
McCloud River	Whittier	5 and 8	37 N.	2 W.	435
McCloud River	Squaw Valley	27	37 N.	3 W.	577
McCloud River	Ellery	29	35 N.	3 W.	619
McCloud River	Lower McCloud	27	34 N.	4 W.	....
Squaw Creek	Modin	4	35 N.	2 W.	39
Squaw Creek	Winni Bulli	1	34 N.	3 W.	85
North Fork Pit River	Joseph Creek	36	44 N.	13 E.	73
North Fork Pit River	Cubalo	5	42 N.	13 E.	193
Between Pine and Parker Creeks	Dorris*	17 and 8	42 N.	13 E.	6
South Fork of Pit River	Jess Valley	11	39 N.	14 E.	91
Tributary to South Fork of Pit River	West Valley	18	39 N.	14 E.	142
Tributary to Rattlesnake Creek	Big Dobe North*	22	44 N.	12 E.	17
Rattlesnake Creek	Big Sage*	7	43 N.	12 E.	104
Crooks Canyon	Crooks Canyon	32	40 N.	12 E.	34
Clover Swale	Essex*	6	42 N.	11 E.	12
Pit River	Warm Springs Valley	9, 10, 15	41 N.	9 E.	1,500
Pit River	Stone Coal Valley	25	41 N.	7 E.	1,461
Ash Creek	Ash Valley	18 and 19	38 N.	11 E.	134
Ash Creek	Round Valley	21	39 N.	9 E.	265
Pit River	Big Valley	27	37 N.	7 E.	3,086
Coyote Creek	Coyote Flat*	31	36 N.	9 E.	30
Horse Creek	Dixie Valley	18	35 N.	8 E.	91
Pit River	Fall River	31	37 N.	5 E.	4,151
Hat Creek	Big Springs	12	32 N.	4 E.	98
Hat Creek	Lake Logan	2	32 N.	4 E.	6
Hat Creek	Cassel	5	35 N.	4 E.	....
Burney Creek	Tamarack	1	33 N.	2 E.	62
Pit River	Lake Britton*	30	37 N.	3 E.	4,821
Pit River	Baird	33	34 N.	4 W.	6,037
Sacramento River	Kennett	15	33 N.	5 W.	6,649
Sacramento River	Coram	29	33 N.	5 W.	6,660
Sacramento River	Keswick	17	32 N.	5 W.	6,690
Little Cow Creek	Ingot	1	33 N.	2 W.	54
South Cow Creek	Wagoner Canyon	33	32 N.	1 W.	67
South Cow Creek	Millville	9 and 16	31 N.	2 W.	94
Cow Creek	Palo Cedro	6, 7, 8	30 N.	3 W.	443
Stillwater Creek	Stillwater	2	31 N.	4 W.	41
South Fork Bear Creek	Thatchers Mill	4	31 N.	2 E.	6
Cottonwood Creek	Misselbeck*	31	31 N.	7 W.	12
Cottonwood Creek	Cottonwood	16 and 17	30 N.	6 W.	97
South Fork Battle Creek	Battle Creek Meadows	23 and 26	29 N.	3 E.	25
Antelope Creek	Antelope Creek	8	27 N.	2 W.	129
Red Bank Creek	Red Bank	16	26 N.	6 W.	14
Elder Creek	Gallatin	14	25 N.	6 W.	146
Mill Creek	Morgan Springs	22	29 N.	4 E.	21
Thomas Creek	Thomas Creek	5	23 N.	6 W.	211
Deer Creek	Wilson Lake	33	29 N.	5 E.	2
Deer Creek	Deer Creek Meadows	21	28 N.	5 E.	58
Butte Creek	Butte Creek House	21 and 28	26 N.	5 E.	29
Butte Creek	Grizzly Gulch	1	25 N.	3 E.	44
Tributary to Butte Creek	Clear Lake	7	24 N.	4 E.	....
Little Butte Creek	De Sabla Ranch	11	23 N.	3 E.	67
Little West Branch Feather	Long Gulch	31	24 N.	4 E.	....
Butte Creek	Magalia*	25	23 N.	3 E.	11
Little Stony Creek	East Park*	3	17 N.	6 W.	102
Stony Creek	Stonyford	16	18 N.	6 W.	....
Stony Creek	Rockville	10	18 N.	6 W.	....
Briscoe Creek	Briscoe	31	20 N.	6 W.	43
Stony Creek	Stony Gorge*	16	20 N.	6 W.	275
Stony Creek	Millsite	1	21 N.	6 W.	597
Stony Creek	Newville	3	22 N.	6 W.	53
West Branch Feather River	Round Valley*	30	26 N.	5 E.	....
Philbrook Creek	Philbrook*	13	25 N.	4 E.	5
Crane Valley	Kimshaw	7	24 N.	5 E.	....
West Branch Feather River	Retzen	22	24 N.	4 E.	....
North Valley Creek	Rock Creek	....	24 N.	5 E.	12
Concow Creek	Lake Wilenor*	16	22 N.	4 E.	15
Butte Creek	Dry Creek	9	20 N.	3 E.	49

*Constructed.

TABLE 61—Continued

RESERVOIR SITES IN SACRAMENTO RIVER BASIN

Stream	Name of reservoir site	Location			Drainage area, in square miles
		Section	Township	Range	
Yellow Creek	Humbug Valley	18	26 N.	7 E.	34
Butt Creek	Butt Valley*	13	26 N.	7 E.	79
Hamilton Branch	Mountain Meadows*	13	28 N.	8 E.	152
North Fork of Feather	Lake Almanor*	28	27 N.	8 E.	497
North Canyon	Round Valley*	15	26 N.	9 E.	15
Last Chance Creek	Last Chance	9	26 N.	13 E.	
Clover Creek	Clover Valley	10	24 N.	13 E.	109
Indian Creek	Indian Valley	34	26 N.	9 E.	740
Spanish Creek	American Valley	6	24 N.	10 E.	
Spanish Creek	Spanish Ranch	13	24 N.	8 E.	
Bucks Creek	Bucks Creek Diversion*	29	24 N.	7 E.	31
Bucks Creek	Bucks Creek*	33	24 N.	7 E.	28
French Creek	French Creek		22 N.	5 E.	
Berry Creek	Berry	27	21 N.	5 E.	
Little Last Chance Creek	Last Chance	33	24 N.	16 E.	93
Middle Fork Feather River	Portola	17	23 N.	14 E.	597
Grizzly Creek	Grizzly Valley	2	23 N.	13 E.	45
Middle Fork Feather River	Clio	26	22 N.	12 E.	694
Frazier Creek	Gold Lake	16	21 N.	12 E.	9
Gray Eagle Creek	Long Lake	6	21 N.	12 E.	
Middle Fork Feather River	Nelson Point	16	23 N.	10 E.	905
Middle Fork Feather River	Bald Rock				1,113
Middle Fork Feather River	Indian Bar	11	21 N.	6 E.	
Middle Fork Feather River	Bidwell Bar	32	20 N.	5 E.	1,352
South Fork Feather River	Little Grass Valley	31	22 N.	9 E.	23
Lost Creek	Lost Creek*	24	20 N.	7 E.	31
Lost Creek	Lost and Sly Creek	20	20 N.	8 E.	
Feather River	Oroville	1 and 2	19 N.	4 E.	3,613
Feather River	Afterbay No. 1	8	19 N.	4 E.	
South Fork Feather River	Palermo	33	19 N.	4 E.	
Wyandotte Creek	Wyandotte Creek	22	18 N.	4 E.	
South Honcut Creek	Browns Valley I. D.	18	18 N.	6 E.	
South Fork Honcut Creek	Jones Flat	25	18 N.	5 E.	23
Dry Creek	New York Flat	25	19 N.	6 E.	
Indian Creek	New York House	30	19 N.	7 E.	
Tributary to Dry Creek	Oregon House	2 and 10	17 N.	6 E.	
Dry Creek	Virginia Ranch	21	17 N.	6 E.	71
Tributary to Dry Creek	Long Bar	13	16 N.	5 E.	
Tributary to Dry Creek	California	24	16 N.	5 E.	
Slate Creek	Slate Creek	11	21 N.	9 E.	
Canyon Creek	Canyon Creek	17	21 N.	10 E.	
East Fork of North Fork Yuba River	Gold Valley	26	21 N.	11 E.	4
Sardine Creek	Sardine Flat	3 and 10	20 N.	12 E.	17
North Fork of North Fork of Yuba River	Bassett	11	20 N.	12 E.	
North Fork of West Fork Yuba River	Lincoln Valley	15	20 N.	13 E.	
South Fork of West Fork Yuba River	Hay Press Valley	4	19 N.	13 E.	8
North Fork Yuba River	Sierra City	28	20 N.	12 E.	130
North Fork Yuba River	Shady Flat	32	20 N.	11 E.	
North Fork Yuba River	Indian Valley	18	19 N.	9 E.	314
North Fork Yuba River	Bullards Bar*	24	18 N.	7 E.	484
Middle Fork Yuba River	English Dam	32	19 N.	13 E.	
Middle Fork Yuba River	Jackson Meadows	18	19 N.	13 E.	39
Middle Fork Yuba River	Milton	12 and 13	19 N.	13 E.	44
Middle Fork Yuba River	Freemans Crossing	32	18 N.	8 E.	180
Canyon Creek	Dead Horse Flat	25	18 N.	11 E.	20
Canyon Creek	Bowman Lake*	5 and 8	18 N.	12 E.	29
Canyon Creek	French Lake*	17	18 N.	13 E.	55
Fordyce Creek	Lake Fordyce*	35	18 N.	13 E.	30
South Fork Yuba River	Lake Van Norden*	23	17 N.	14 E.	12
South Fork Yuba River	Rattlesnake	17 and 30	17 N.	13 E.	57
South Fork Yuba River	Lake Spaulding*	20	17 N.	12 E.	120
South Fork Yuba River	Washington	11	17 N.	10 E.	150
South Fork Yuba River	Gov. Stephens Lake	8	17 N.	11 E.	140
South Fork Yuba River	Norton Canyon	13	17 N.	9 E.	
South Fork Yuba River	Jones Bar	31	17 N.	8 E.	
Yuba River	Narrows	14 and 23	16 N.	6 E.	1,108
Deer Creek	Scotts Flat	2	16 N.	9 E.	
Clear Creek	Gassaway	2	15 N.	7 E.	
Deer Creek	Anthony House	20	16 N.	7 E.	58
Reeds Creek	Indian Springs	22	15 N.	7 E.	
Dry Creek	Cabbage Patch	33	15 N.	6 E.	80
South Wolf Creek	South Wolf Creek	25	15 N.	8 E.	13
Bear River	Bear River	22 and 23	15 N.	9 E.	102
Bear River	Parker	30	14 N.	9 E.	130
Bear River	Van Giesen*	2	13 N.	8 E.	134
Bear River	Combie Crossing		13 N.	8 E.	132

* Constructed.

TABLE 61—Continued

RESERVOIR SITES IN SACRAMENTO RIVER BASIN

Stream	Name of reservoir site	Location			Drainage area, in square miles
		Section	Township	Range	
Bear River	Camp Far West†	21	14 N.	6 E.	282
Coon Creek	Coon Creek	7	13 N.	7 E.	42
Tributary North Fork of North Fork American River	Lake Valley*	35	17 N.	12 E.	5
Palisade Creek	High Sierras	33	17 N.	14 E.	4
Shirt Tail Canyon	Brimstone	25	15 N.	10 E.	
North Fork American River	Clipper Creek	31	13 N.	9 E.	339
Middle Fork American River	French Meadows	25 and 36	15 N.	13 E.	47
South Fork American River	Medley Lakes*	30	12 N.	17 E.	28
Tributary Rubicon River	Rockbound Lake	6	13 N.	16 E.	
Tributary Rubicon River	Lower Hell Hole	16	14 N.	14 E.	115
Gerle Creek	Loon Lake	4	13 N.	15 E.	12
Middle Fork American River	Ox Bow	33	14 N.	11 E.	525
Middle Fork American River	Poverty Bar	33	13 N.	9 E.	609
North Fork American River	Auburn	11	12 N.	8 E.	965
North Fork American River	Pilot Creek	34	12 N.	8 E.	
North Fork American River	Whiskey Bar	20	11 N.	8 E.	983
Greenwood Creek	Greenwood	13	12 N.	9 E.	8
South Fork American River	Slab Creek	19	11 N.	12 E.	
North Fork Silver Creek	Silver Creek No. 3	1	11 N.	14 E.	34
Silver Creek	Silver Creek No. 2	20 and 29	12 N.	14 E.	82
South Fork Silver Creek	Silver Creek No. 1	15	12 N.	14 E.	29
Cables Creek	Twin Lakes*	19	10 N.	18 E.	13
Tributary Silver Fork	Silver Lake*	32	10 N.	17 E.	15
South Fork American River	Slippery Ford	29	11 N.	15 E.	196
Alder Creek	Alder Creek	8 and 17	10 N.	15 E.	18
South Fork American River	Coloma	28	11 N.	9 E.	708
South Fork American River	Webber Creek	30	11 N.	9 E.	
American River	Folsom	24	10 N.	7 E.	1,875
American River	Folsom Afterbay	35	10 N.	7 E.	
Webber Creek	Webber Creek	18	10 N.	12 E.	9
Webber Creek	Webber Creek*	19	10 N.	11 E.	
Tributary to Willow Creek	Oat Valley	15	11 N.	1 W.	
Cache Creek	Little Indian Valley	4	14 N.	6 W.	120
Cache Creek	Clear Lake*	6	12 N.	6 W.	470
Cache Creek	Capay	5 and 6	10 N.	2 W.	996
Putah Creek	Guenoc	21	11 N.	6 W.	120
Putah Creek	Devils Head	3	10 N.	5 W.	
Putah Creek	Monticello	29	8 N.	2 W.	620

* Constructed.
† Existing reservoir to be enlarged in State Water Plan.

There is given in Table 61 a list of known reservoir sites in the Sacramento River Basin which could be developed to capacities in excess of five thousand acre-feet. These sites are considered part of the State Water Plan for the maximum use of the water resources for the development of power; furnishing an adequate supply of water for domestic, industrial and irrigation uses; the improvement of navigation; the prevention of the invasion of saline water into the Sacramento-San Joaquin Delta; and for the prevention of damage from excessive flood flows. Ten of these sites, however, strategically located near the edge of the valley floor, are of major importance. These sites are Kennett on Sacramento River, Oroville on Feather River, Narrows on Yuba River, Camp Far West on Bear River, Folsom, Auburn and Coloma on American River, Millsite on Stony Creek, Capay on Cache Creek, and Monticello on Putah Creek. They lie below practically the entire mountain watershed of the streams on which they are located. They are in positions to control the natural run-off, to reregulate water released from the higher reservoirs for power and the return water from irrigation in the mountains and foothills, and to make the maximum amount of all water from the mountainous areas available for irrigation use on the valley floor. Also, being situated at the points where the floods originating in the mountains debouch onto the valley floor, they are ideally located to control these flows to such amounts as can be safely cared for by the existing flood control works or new works which could be constructed to protect additional lands, at reasonable cost. These reservoirs, being the lowest sites for storage on the streams, can properly function without any interference with power development in the mountains.

The area tributary to these ten sites contains 15,740 square miles. This is 60 per cent of the total Sacramento River Basin and 74 per cent of the mountain and foothill area, which is the principal source of the basin's run-off. The drainage area tributary to these ten sites yields, on an average, 76.5 per cent of the total run-off from the entire foothill and mountain area of the basin. An additional 12.9 per cent originates between the proposed reservoir site on the Sacramento River near Kennett and the foothill line at Red Bluff. Considerable beneficial use of this water would be made possible by the proper operation of the Kennett reservoir.

In addition to the waters of the Sacramento River Basin which may be regulated for all uses by means of reservoirs, other waters could be imported into the basin from watersheds in which there is a surplus over the ultimate future water requirements in those watersheds. The streams from which it is physically possible to divert a part of the flow into the Sacramento River Basin are the Eel River; the upper Klamath River; and the Trinity River, a branch of the Klamath River.

The Eel River water could be diverted into Clear Lake which is on Cache Creek, a Sacramento River Basin stream. Two plans for this diversion are physically feasible. One plan would be to convey surplus water to the Snow Mountain Water and Power Company power plant in Potter Valley by means of existing works and to construct a canal and tunnel to convey it from the power house to Clear Lake. The other plan would be to develop a larger supply by diverting some of the run-offs of the Middle Fork of Eel River, Black Butte River, and numerous small creeks into Lake Pillsbury by means of a collecting canal and tunnel to Salmon Creek. From Lake Pillsbury a tunnel would convey the water to Middle Creek, a tributary of Clear Lake. The water from either diversion could be stored in Clear Lake or in the Capay reservoir of the State Water Plan.

There are three possible routes for the diversion of the Klamath River water to the Sacramento River Basin. Under two of the plans water would be diverted from the river just below Upper Klamath Lake which would be used as a storage reservoir. One route for the diversion would be by way of Tule Lake and the Modoc Lava Beds with a discharge into Fall River in the Sacramento River watershed. The other route for the diversion would be by way of the rim of Shasta Valley and through a tunnel into the headwaters of the Sacramento River near Mount Shasta. Under the third plan of diversion, water would be diverted from the Klamath River about seven miles upstream from Fall Creek at an elevation about 1000 feet lower than with the first two plans. The route of this conduit also would be by way of the rim of Shasta Valley and thence through a tunnel into the headwaters of the upper Sacramento River. The conduit for each plan would have considerable length and several miles would be in tunnel.

The Trinity River diversion is the most feasible of all the diversions into the Sacramento River Basin and water from it will be required to furnish a supply to lands on the western side of the upper Sacramento Valley which it is not feasible to serve from any other source. It, therefore, was adopted as one of the major units of the State Water Plan. This diversion, in addition to furnishing a large and dependable supply of new water which may, with adequate storage on the Trinity River, be drawn upon as desired, has large power possibilities. The diversion is described in some detail near the end of this chapter.

The major units of the State Water Plan in the Sacramento River Basin are surface storage reservoirs and the Trinity River diversion conduit. Distribution conduits from the reservoirs within the basin are not included as they are considered to be features for local development. In connection with some of the reservoirs, power plants and afterbays are proposed where the generation of electric energy would be economically feasible.

The eleven reservoir units considered to be of major importance in making the water supply of the Sacramento River Basin and a portion of the Trinity River available for use in the Great Central Valley of California are shown in Table 62 and are delineated on Plate XXII, "Major Units of State Plan for Development of Water Resources of California." This table also shows the area of the drainage basin and the full natural run-off tributary to each of the major reservoir units in the basin.

TABLE 62

MAJOR RESERVOIR UNITS OF STATE WATER PLAN IN SACRAMENTO RIVER BASIN

Reservoir	Stream	Tributary drainage area		Full natural run-off, 40-year mean, 1889-1929		
		In square miles	In per cent of mountain and foothill area of Sacramento River Basin	In acre-feet	In per cent of run-off of mountain and foothill area of Sacramento River Basin	In per cent of run-off of Sacramento River Basin plus Trinity River diversion
Kennett	Sacramento River	6,649	31.1	6,149,000	24.8	24.0
Oroville	Feather River	3,613	16.9	5,201,000	21.0	20.3
Narrows	Yuba River	1,108	5.2	2,553,000	10.3	10.0
Camp Far West	Bear River	282	1.3	402,000	1.6	1.6
Folsom	American River	1,875	8.8	3,049,000	12.3	11.9
Auburn[1]	American River	[1]965	[1]4.5	[1]1,830,000	[1]7.4	[1]7.1
Coloma[1]	American River	[1]708	[1]3.3	[1]1,054,000	[1]4.2	[1]4.1
Millsite	Stony Creek	597	2.8	432,000	1.7	1.7
Capay	Cache Creek	996	4.7	762,000	3.1	3.0
Monticello	Putah Creek	620	2.9	420,000	1.7	1.6
Totals		15,740	73.7	18,968,000	76.5	74.1
Totals for mountain and foothill area of Sacramento River Basin		21,369	100.0	24,800,700	100.0	96.9
Fairview reservoir on Trinity River		667		[2]796,000		3.1
Totals for mountain and foothill area of Sacramento River Basin plus Trinity River diversion		22,036		25,596,700		100.0

[1] Amounts for Auburn and Coloma reservoirs are included in those for Folsom reservoir.

[2] The amount which would have been diverted from the Trinity River to the Sacramento River Basin was 796,000 acre-feet per year. The mean annual full natural run-off at Fairview dam site was 1,201,000 acre-feet.

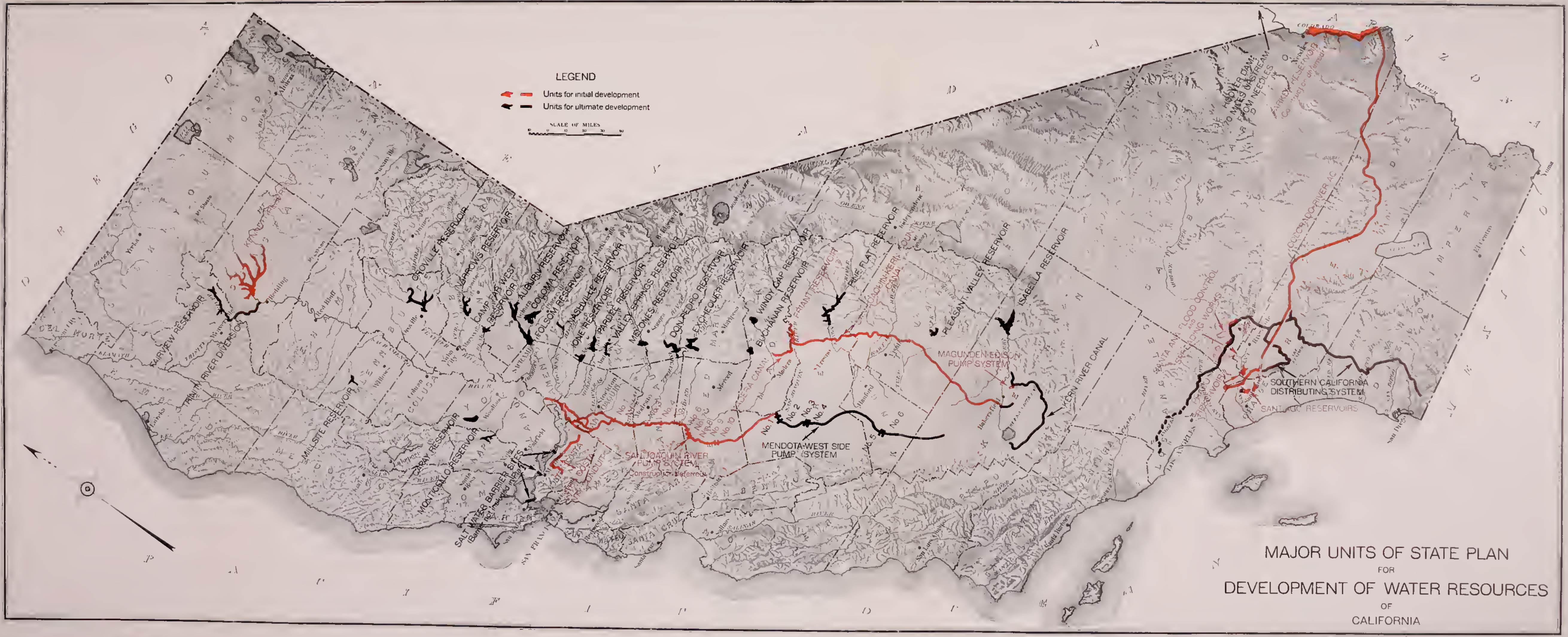
MAJOR UNITS OF STATE PLAN

FOR

ELOPMENT OF WATER RESOURCES

OF

CALIFORNIA



MAJOR UNITS OF STATE PLAN FOR DEVELOPMENT OF WATER RESOURCES OF CALIFORNIA

In order to estimate the yield of a reservoir, it is first necessary to know the amount of the water supply available at the dam, and the rate of losses by evaporation from the reservoir surface. The full natural, present net and ultimate net run-offs at the dam site for each major reservoir unit, therefore, were estimated by the methods described in Chapter II. The net evaporation from the surfaces of the major reservoir units were estimated from the best data available. The total annual net amounts in feet and the distribution by months are shown in Table 63. It is estimated that during the months in which no evaporation is shown the rainfall would compensate for the evaporation losses.

TABLE 63

NET EVAPORATION FROM RESERVOIRS

Month	Reservoir					
	Kennett, Oroville, Narrows, Camp Far West, Folsom, Auburn, Coloma		Fairview		Millsite, Monticello, Capay	
	Depth in feet	Per cent of seasonal total	Depth in feet	Per cent of seasonal total	Depth in feet	Per cent of seasonal total
January	0	0	0	0	0	0
February	0	0	0	0	0	0
March	0	0	0	0	0	0
April	0.32	9.2	0.23	9.2	0.37	9.3
May	0.44	12.6	0.32	12.8	0.51	12.7
June	0.52	15.0	0.37	14.8	0.60	15.0
July	0.62	17.8	0.44	17.6	0.71	17.8
August	0.58	16.6	0.42	16.8	0.66	16.5
September	0.45	12.7	0.32	12.8	0.51	12.7
October	0.34	9.6	0.24	9.6	0.38	9.5
November	0.23	6.5	0.16	6.4	0.26	6.5
December	0	0	0	0	0	0
Totals	3.50	100.0	2.50	100.0	4.00	100.0

Studies were made to estimate the seasonal irrigation yield that would have been available from each unit during the 40-year period 1889–1929. In making these studies the reservoir was assumed to have been full at the end of the extremely wet winter season of 1889–90 and the reservoir operation was carried by months through the entire 40-year period. The water supply to the reservoir was taken as the ultimate net run-off. The seasonal irrigation yields determined were those that would have been obtained with deficiencies not to exceed 35 per cent in the year of maximum deficiency or an average not to exceed two per cent over the entire 40-year period. The irrigation draft was assumed to be distributed through the season in accordance with the schedule for use on the Sacramento Valley floor as determined by previous studies.* This distribution is shown in the last column of Table 64. Studies also were made to estimate the seasonal irrigation yield that could have been obtained from the unregulated run-off during the 40-year period as it would have been if impaired by ultimate

* Bulletin No. 6, "Irrigation Requirements of California Lands," Division of Irrigation and Engineering, 1923.

In order to estimate the yield of a reservoir, it is first necessary to know the amount of the water supply available at the dam, and the rate of losses by evaporation from the reservoir surface. The full natural, present net and ultimate net run-offs at the dam site for each major reservoir unit, therefore, were estimated by the methods described in Chapter II. The net evaporation from the surfaces of the major reservoir units were estimated from the best data available. The total annual net amounts in feet and the distribution by months are shown in Table 63. It is estimated that during the months in which no evaporation is shown the rainfall would compensate for the evaporation losses.

TABLE 63

NET EVAPORATION FROM RESERVOIRS

Month	Reservoir					
	Kennett Oroville Narrows Camp Far West Folsom Auburn Coloma		Fairview		Millsite Monticello Capay	
	Depth in feet	Per cent of seasonal total	Depth in feet	Per cent of seasonal total	Depth in feet	Per cent of seasonal total
January	0	0	0	0	0	0
February	0	0	0	0	0	0
March	0	0	0	0	0	0
April	0.32	9.2	0.23	9.2	0.37	9.3
May	0.44	12.6	0.32	12.8	0.51	12 7
June	0.52	15.0	0.37	14.8	0.60	15.0
July	0.62	17.8	0.44	17.6	0.71	17.8
August	0.58	16.6	0.42	16.8	0.66	16.5
September	0.45	12.7	0.32	12.8	0.51	12.7
October	0.34	9.6	0.24	9.6	0.38	9 5
November	0.23	6.5	0 16	6.4	0.26	6.5
December	0	0	0	0	0	0
Totals	3.50	100.0	2.50	100.0	4.00	100.0

Studies were made to estimate the seasonal irrigation yield that would have been available from each unit during the 40-year period 1889–1929. In making these studies the reservoir was assumed to have been full at the end of the extremely wet winter season of 1889–90 and the reservoir operation was carried by months through the entire 40-year period. The water supply to the reservoir was taken as the ultimate net run-off. The seasonal irrigation yields determined were those that would have been obtained with deficiencies not to exceed 35 per cent in the year of maximum deficiency or an average not to exceed two per cent over the entire 40-year period. The irrigation draft was assumed to be distributed through the season in accordance with the schedule for use on the Sacramento Valley floor as determined by previous studies.* This distribution is shown in the last column of Table 64. Studies also were made to estimate the seasonal irrigation yield that could have been obtained from the unregulated run-off during the 40-year period as it would have been if impaired by ultimate

* Bulletin No. 6, "Irrigation Requirements of California Lands," Division of Irrigation and Engineering, 1923.

upstream uses. This yield was determined at the same point and with the same monthly distribution and the same limits of deficiencies as that with reservoir regulation. The difference in irrigation yield between that which could be obtained from the unregulated stream and from the stream with reservoir control will be called "new water."

The initial major reservoir unit in the Sacramento River Basin would be operated to control floods; to furnish water for the irrigation of lands along the stream on which it is located and the lands in the Sacramento-San Joaquin Delta; to furnish water for salinity control; to improve navigation, if the stream on which it is located is navigable; to furnish water which is surplus to these uses for exportation to lands having a deficiency in supply; and to generate hydroelectric energy incidental to all of the other uses. As each of the other large major reservoir units of the State Water Plan is built, there would be a certain period before its entire irrigation yield could be absorbed. During this period, the reservoir might be operated primarily for the generation of power or for power development combined with other uses. The water discharged from the reservoir when operated in this manner would furnish considerable new water for irrigation requirements. As the irrigation demands increased, the reservoir would be operated to furnish irrigation water to keep pace with these demands and eventually it would be operated primarily to furnish water for irrigation use or for irrigation combined with other uses. Studies, therefore, were made of the major units having power plants, operated primarily for the generation of power. With the reservoirs operated for this purpose, it was assumed that the minimum head on the plants at the dams would never have been less than 50 per cent of the maximum head obtainable. As in the irrigation studies, the reservoir was assumed to have been full at the end of the 1889–90 winter season. The water supply to the reservoir, however, was taken as the present net run-off. The distribution of the demand for electric energy was assumed to be in accordance with present requirements in northern and central California. This distribution, together with that for water for irrigation use, is given in Table 64.

TABLE 64

MONTHLY DEMAND FOR ELECTRIC ENERGY AND IRRIGATION WATER

Month	Electric energy consumption in northern California, in per cent of annual total	Irrigation water consumption on Sacramento Valley floor, in per cent of annual total
January	7.36	0
February	6.79	0
March	7.63	1.0
April	7.79	5.0
May	8.93	16.0
June	8.95	20.0
July	9.65	22.0
August	9.84	20.0
September	8.78	12.0
October	8.65	4.0
November	7.74	0
December	7.89	0
Totals	100.00	100.0

Studies also were made to estimate the amounts of electric energy that could have been developed by the releases from the reservoirs operated primarily for irrigation use, and the characteristics of this energy. It was assumed that when operated for this use the reservoir would never have been drawn down so that the minimum head on the power plant would have been less than 50 per cent of the maximum head. It also was assumed that the power plant would have had the same installed capacity as with the reservoir operated primarily for the generation of power.

Some of the reservoirs could be operated for controlling flood flows in addition to their use for other purposes. The value of storage in reservoirs in the control of floods has been discussed in Chapter VI. The regulation of floods to certain controlled flows which would not be exceeded oftener than a definite number of times in a specified period would require the reservation of storage space in the top portion of the reservoir, in which run-off in excess of the regulated flow would be stored. The amounts of storage space to be reserved in each reservoir for controlling floods to certain specified amounts are given in Chapter VI. In that chapter, a rule also is given for the determination of the period during which reserve space should be held in the reservoir and the proportionate amount of this space at different times throughout the period.

A somewhat detailed description of each major unit, and estimated capital and annual costs, are given in this chapter. While it is not likely that designs for these units at the time they are constructed would exactly follow the descriptions given, the plans presented were developed after considerable study and are those on which the estimates of cost are based.

Estimates were made of the costs of dams and reservoirs, power plants, afterbays and power drops. These estimates were based on the costs of materials and labor as of 1929 and 1930. The unit costs used for the principal items are given in Table 65. The estimates also were based on the assumption that each unit would be constructed in one step. If based upon the assumption of progressive development, the cost would be substantially greater. Excavation quantities have been based on depths of stripping as determined from explorations by boring and tunneling and where these were not available, from geological reports and field examinations. Field examinations also were made in the vicinity of the dam sites to determine the nearest and best sources of aggregates for concrete. The construction period for each reservoir was estimated by comparison with that on similar projects and interest during this period, based on an interest rate of 4.5 per cent compounded semiannually, was included in the capital cost of the project.

Annual costs including those for interest and amortization on bonds, depreciation, operation and maintenance also were estimated for each unit. The bases for estimating the annual costs are as follows:

Interest, in per cent	4.5
Amortization of capital investment (40-year bonds on 4 per cent sinking fund basis) in per cent of capital cost	1.05

Depreciation—	
Lands and improvements flooded, in per cent of capital cost	0.0
Dam, in per cent of capital cost	0.3
Power plant, spillway gates, flood control gates and appurtenances (40-year sinking fund basis at 4 per cent) in per cent of capital cost	1.05
Operating expenses and maintenance—	
Dam and reservoir, lump sum	$5,000 to $100,000
Power plant	$10,000
plus $0.65 per kilovolt ampere of installed capacity.	

The values of the electric energy outputs from each power plant when operated primarily for the generation of power and also primarily for yield in irrigation water, were estimated by the methods discussed in Chapter VIII. The estimated values at the power plants were based on the cost of producing an equivalent amount of electric energy of the same characteristics with a steam-electric plant located in the area of consumption, taking into account the cost of transmission from the point of generation to the load center, and using the present price of fuel oil and present steam-electric plant efficiencies.

In the following pages, each major unit is briefly described and its cost and accomplishments are given.

Kennett Reservoir on Sacramento River

A major reservoir unit of the State Water Plan on the upper Sacramento River is required in the plan for the development of the water resources of the Sacramento River Basin for the irrigation of the lands lying in the Sacramento River water service area described in Chapter V. Much of this area can be served from no other stream and the remainder can be served more economically from the Sacramento River than any other source of supply. Also, since the Sacramento River has the largest run-off of any stream entering the Sacramento Valley, the major reservoir unit on the stream will be required to regulate the water surplus to the needs for irrigation in the Sacramento River water service area for irrigation supplies for lands in the Sacramento Valley having no local supplies or insufficient supplies of their own for their full development, for salinity control and irrigation in the Sacramento-San Joaquin Delta, for the maintenance of navigation on the Sacramento River, and for exportation to the San Joaquin Valley and San Francisco Bay Basin to supplement local supplies in those areas for irrigation and industrial uses. Studies indicate that all water that can be economically developed in the Sacramento River Basin by the operation of the State Water Plan will ultimately be required and that a considerable portion of the water for the foregoing uses outside of the Sacramento River water service area should be derived from the reservoir on the Sacramento River.

Several dam and reservoir sites on the river above Red Bluff were investigated and the Kennett site was selected as being the most satisfactory. The dam site for the Kennett reservoir is located in Section 15, Township 33 North, Range 5 West, M. D. B. and M., and is the same

TABLE 65

SUMMARY OF UNIT COSTS USED IN ESTIMATES

Item	Unit	Unit cost [1]																			
																	Trinity River diversion				
		Kennett reservoir	Keswick afterbay	Oroville reservoir	Oroville afterbay	Narrows reservoir	Camp Far West reservoir	Auburn reservoir	Pilot Creek power drop	Coloma reservoir	Webber Creek power drop	Folsom reservoir	Folsom afterbay	Millsite reservoir	Capay reservoir	Monticello reservoir	Fairview reservoir and power plant No. 1	Lewiston reservoir	Conduit and power plant No. 2	Conduit and power plant No. 3	Conduit and power plant No. 4
Excavation, gravel	Cubic yard						$1 00			$1 00		$2 00		$1 00		$1 00	$2 00				
Excavation, dry rock	Cubic yard	$1 50	$2 50	$2 50	$2 50	$2 50	2 50	$2 50	$2 50	2 50	$2 50	2 50-3 50	$2 50	2 50		2 50	1 50	$1 50			
Excavation, wet rock	Cubic yard	4 00	5 00	5 00	5 00	5 00	5 00	5 00	5 00	5 00	5 00	5 00	5 00			5 00	5 00	5 00			
Excavation, tunnel	Cubic yard	6 00-8 00	6 50-8 50	6 50-9 50	6 00-7 00	6 50-9 50		7 50-9 50	7 50-9 50	9 50	7 50-9 50	6 50-7 50	7 00		$6 50-$14 50		7 00-10 00		$11 00		$9 00-9 50
Excavation, canals, earth and rock	Cubic yard																		1 20	$1 20	1 00-1 20
Concrete, mass	Cubic yard	7 00	7 00	6 85	6 85	6 35	6 75	6 50	6 50	6 50	6 50	6 30	6 30		6 50	6 50	9 00	8 00			
Concrete, reinforced—																					
Spillway piers	Cubic yard	16 00	16 00	15 50	15 50	15 00	15 50	15 00		15 00		15 00	15 00	21 50		15 00	19 00				
Roadway over spillway	Cubic yard	24 00	24 00	24 00	24 00	23 50	24 00	23 50		23 50		23 50				23 50	27 50				
Parapets	Cubic yard	19 50	19 50	19 50		18 50	19 50	18 50		18 50		18 50				18 50	22 50				
Spillway channel paving	Cubic yard	12 50				12 00								15 00		11 50	16 00				
Inlet structures	Cubic yard	12 50-24 00	12 50-24 00	12 50-24 00	12 50-24 00	12 00-23 50	15 50-24 00	12 00-23 50		12 00-23 50		12 00-23 50	12 00-23 50	9 00	14 50-23 50	15 00-23 50	16 00-27 50				
Deep cut-off walls	Cubic yard																17 50				
Shallow cut-off walls	Cubic yard						9 00					8 50			8 50						
Slope paving	Cubic yard						12 00					11 50			11 50						
Tunnel lining	Cubic yard	20 00	20 00	20 00	20 00	20 00	20 00	20 00	20 00	20 00	20 00	20 00	20 00		20 00		23 50		23 50		23 50
Canal lining	Cubic yard																		17 00	17 00	15 50-16 00
Walls—benched canal section	Cubic yard																		23 50		22 00
Covered conduit	Cubic yard																				22 00
Flume pedestals	Cubic yard																			19 00	17 50-18 00
Penstock cradles	Cubic yard	12 50	12 50	12 50	12 50	12 50		12 00	12 00	12 00	12 00	12 00	12 00				16 00				
Buttress and deck slab	Cubic yard													15 00							
Drilling and grouting foundation	Lineal foot of hole	4 25	4 25	4 25	4 25	4 25	4 25	4 25	4 25	4 25	4 25	4 25	4 25	4 25		4 25	4 25	4 25			
Drainage wells	Lineal foot of hole	3 00	3 00	3 00	3 00	3 00	3 00	3 00	3 00	3 00	3 00	3 00	3 00	3 00		3 00	3 00	3 00			
Earth fill	Cubic yard						50					50			50						
Rockfill in coffer dams	Cubic yard	75	75	75	75	75		75	75	75	75		75			75					
Clay blanket for coffer dams	Cubic yard	1 25	1 25	1 25	1 25	1 25		1 25	1 25	1 25	1 25										
Sheet piling	Ton											75 00	75 00	75 00		75 00	85 00				
Steel in trash racks	Pound	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	105		105	105	105
Reinforcing steel	Pound	05½	05½	05½	05½	05½	05½	05½	05½	05½	05½	05½	05½	05½	05½	05½	06				
Riveted steel pipe	Pound	08½	08½	08½	08½	08½	08½	08½	08½	08½	08½	08½	08½	08½		08½	09		[2]15	[2]15	[2]15
Caterpillar type sluice gates	Pound	22½	22½	22½	22½	22½	22½	22½	22½	22½	22½	22½	22½	13		22½	23				
Slide gates	Pound	13		13		13	13	13		13		13		13		13	135				
Needle valves	Pound	28		28		28	28	28		28		28		28		28	285				
Segmental steel drum gates	Pound	10	10	10	10	10	10	10	10	10	10	10	10		10	10	105				
Tunnel timbering	Thousand board feet	70 00	70 00	70 00	70 00	70 00		70 00	70 00	70 00	70 00	70 00	70 00		70 00		70 00		70 00		70 00
Flume hardware	Pound																			11	11
Flume metal	Pound																			11	11
Lumber	Thousand board feet																			110 00	110 00
Power plant building and equipment	Kilovolt ampere	21 50	35 50	21 50	54 00	23 00		26 00	35 00	32 50	36 00	25 00	54 00				30 00		29 50	36 50	30 00

[1] Unit cost does not include administration, engineering and contingencies or interest during construction. The cost given is for the units in place.
[2] Includes cradles and anchors.

site as that formerly selected* for a dam for a reservoir to develop the water resources of the Sacramento River. It is about 2.1 miles south of the town of Kennett and about 13 miles upstream from the city of Redding.' Water impounded by this dam would back up the Sacramento River, the Pit River, the McCloud River, Squaw Creek and many smaller creeks, giving a reservoir with many long narrow arms and capable of development to large storage capacity.

The watershed above the site has an area of about 6649 square miles which is about 72 per cent of the total Sacramento River drainage area above Red Bluff and about 31 per cent of the total mountain and foothill area of the Sacramento River Basin. The Pit, McCloud and upper Sacramento rivers join within the reservoir area to form the main Sacramento River. The drainage basin above the dam site is bounded on the east and west by mountains which rise to elevations of 9000 feet or more, while to the north this basin is separated from that of the Klamath River by a range which culminates in Mount Shasta having a crest elevation of 14,161 feet. To the east and south of Mount Shasta is an extensive plateau varying from four to five thousand feet in elevation. With the exception of this plateau and some valleys along the Pit River, most of the area is mountainous. Along the Pit and upper Sacramento rivers there are 367,000 acres of agricultural land, much of which is irrigated. Elevations within the basin vary from 14,161 feet on Mount Shasta down to about 600 feet at the dam site. The distribution of the area for three ranges of elevation is given in Table 66.

TABLE 66

DISTRIBUTION OF AREAS BY RANGE OF ELEVATION IN UPPER SACRAMENTO RIVER DRAINAGE BASIN ABOVE KENNETT DAM SITE

Elevation above sea level	Drainage area	
	In square miles	In per cent of total drainage area
Below 2,500 feet	469	7
Between 2,500 feet and 5,000 feet	3,857	58
Above 5, 00 feet	2,323	35
Totals	6,649	100

Water Supply.—The tributary drainage basin above the Kennett dam site is one of the most productive of run-off of any in the state. The rate of run-off from the upper Sacramento and McCloud rivers is exceeded in California by only a few small streams on the north Pacific Coast.

Information on the run-off was obtained from stream measurements at the Jellys Ferry and Red Bluff gaging stations of the United States Geological Survey, over a period of 34 years and at the Kennett station for a period of four years. Precipitation data are available for a number of stations throughout the basin for a longer period and

* Bulletin No. 9, "Supplemental Report on Water Resources of California," Division of Engineering and Irrigation, 1925.

' Bulletin No. 12, "Summary Report on the Water Resources of California and a Coordinated Plan for Their Development," Division of Engineering and Irrigation, 1927.

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were used to determine the probable run-offs for the years prior to the period of stream measurements. Rainfall within the watershed varies from a mean of 15 to 65 inches per year.

The full natural run-offs at the dam site were obtained for the period of record at Kennett gaging station by increasing the full natural run-offs at the gaging station by the estimated run-offs from the area between it and the dam site. The monthly full natural run-offs at Kennett gage for the period of record were obtained by adding the estimated net uses of water on 96.000 to 145,000 acres of irrigated land above the gaging station and by adding or subtracting, respectively, the amounts of water known or estimated to have been stored in or released from reservoirs in the basin above the station. The monthly full natural run-offs for the period from 1889 to 1925 were obtained from curves of relationships of the monthly full natural run-offs at the dam site and at Red Bluff using the monthly full natural run-offs at the latter point as indices.

The monthly ultimate net run-offs were obtained from the monthly full natural run-offs by deducting the estimated ultimate net uses of water for irrigation above the dam site and adding water released from and deducting water stored in reservoirs now in use or required for ultimate development of the irrigated lands in the watershed above the dam site.

The present net run-offs by months were estimated in the same manner as the ultimate net except that present instead of ultimate uses and storage were used.

The seasonal full natural, ultimate net and present net run-offs at the Kennett dam site are shown in Table 67.

The run-off from this basin is more evenly distributed throughout the year than that from most basins on account of the absorptive lava formations lying to the east and south of Mount Shasta, which act as a natural reservoir. Even with these natural conditions favoring the water supply from this basin, there is still a large variation in the run-off from season to season and also within the season. The data in Table 67 show the variations in the full natural, the present net, and the ultimate net seasonal run-offs from the area above the Kennett dam site for the 40-year period 1889–1929. From this table it may be seen that the maximum seasonal full natural run-off was 12,582,000 acre-feet in 1889–90 and the minimum was 2,691,000 acre-feet in 1923–24, a variation of from 205 per cent to 44 per cent of the mean seasonal run-off for the 40-year period.

The average monthly distribution of the run-off as determined from the monthly full natural run-offs at Kennett dam site during the 40-year period 1889–1929 is shown in Table 68.

That there is also a wide variation in the mean daily flows is indicated by the maximum discharge of 254,000 second-feet on February 3, 1909, with a peak of 278,000 second-feet, and a minimum discharge of 2810 second-feet which occurred in August, 1924. Both of these flows occurred at Red Bluff but indicate the variation that may occur at the Kennett dam site.

Since the Kennett reservoir is in a position to control only about two-thirds of the run-off of the Sacramento River drainage basin above Red Bluff, a much larger yield in water for irrigation or other uses could be obtained by releasing water from the reservoir to supplement natural run-off from the area between it and Red Bluff. The run-off from this area, therefore, is an important item in any study of the yield of Kennett reservoir. The seasonal full natural run-offs at the Red Bluff gaging station have been shown in Table 5. The ultimate net and present net run-offs at this station also have been estimated and the seasonal amounts, together with the seasonal full natural run-offs, are shown in Table 69. The run-offs from the area between Kennett dam site and the Red Bluff gaging station are equal to the differences between the amounts shown in Tables 69 and 67, for corresponding seasons and means.

TABLE 67

SEASONAL RUN-OFFS OF SACRAMENTO RIVER AT KENNETT DAM SITE, 1889-1929

Season	Full natural run-off, in acre-feet	Present net run-off, in acre-feet	Ultimate net run-off, in acre-feet
1889-1890	12,582,000	12,396,000	11,823,000
1890-1891	4,637,000	4,451,000	4,397,000
1891-1892	5,118,000	4,932,000	4,687,000
1892-1893	7,891,000	7,706,000	7,225,000
1893-1894	5,895,000	5,709,000	5,595,000
1894-1895	7,837,000	7,651,000	7,332,000
1895-1896	7,247,000	7,061,000	6,698,000
1896-1897	6,858,000	6,672,000	6,406,000
1897-1898	3,871,000	3,685,000	3,690,000
1898-1899	4,340,000	4,154,000	3,976,000
1899-1900	5,896,000	5,710,000	5,341,000
1900-1901	6,073,000	5,887,000	5,559,000
1901-1902	7,122,000	6,936,000	6,748,000
1902-1903	6,586,000	6,400,000	6,222,000
1903-1904	9,523,000	9,337,000	8,982,000
1904-1905	7,038,000	6,852,000	6,670,000
1905-1906	7,259,000	7,073,000	6,687,000
1906-1907	8,486,000	8,300,000	7,942,000
1907-1908	5,494,000	5,308,000	5,258,000
1908-1909	8,605,000	8,419,000	8,016,000
1909-1910	6,156,000	5,970,000	5,860,000
1910-1911	6,668,000	6,482,000	6,023,000
1911-1912	4,726,000	4,540,000	4,558,000
1912-1913	5,001,000	4,815,000	4,560,000
1913-1914	8,361,000	8,174,000	7,835,000
1914-1915	7,849,000	7,663,000	7,653,000
1915-1916	6,924,000	6,738,000	6,413,000
1916-1917	5,039,000	4,853,000	4,565,000
1917-1918	4,028,000	3,842,000	3,830,000
1918-1919	5,389,000	5,203,000	5,058,000
1919-1920	3,294,000	3,108,000	3,030,000
1920-1921	7,396,000	7,209,000	6,771,000
1921-1922	4,769,000	4,583,000	4,347,000
1922-1923	3,994,000	3,808,000	3,661,000
1923-1924	2,691,000	2,505,000	2,342,000
1924-1925	5,427,000	5,241,000	5,021,000
1925-1926	3,921,000	3,735,000	3,550,000
1926-1927	7,222,000	7,036,000	6,679,000
1927-1928	5,331,000	5,145,000	4,924,000
1928-1929	3,400,000	3,214,000	3,068,000
40-year means, 1889-1929	6,149,000	5,963,000	5,725,000
20-year means, 1909-1929	5,379,000	5,193,000	4,987,000
10-year means, 1919-1929	4,745,000	4,558,000	4,339,000
5-year means, 1924-1929	5,060,000	4,874,000	4,648,000

TABLE 68

AVERAGE MONTHLY DISTRIBUTION OF RUN-OFF OF SACRAMENTO RIVER AT KENNETT DAM SITE

Month	Average full natural run-off	
	In acre-feet	In per cent of mean seasonal
January	754,000	12.26
February	906,000	14.74
March	883,000	14.36
April	744,000	12.10
May	570,000	9.27
June	394,000	6.41
July	300,000	4.88
August	249,000	4.05
September	235,000	3.82
October	243,000	3.95
November	368,000	5.98
December	503,000	8.18
Totals	6,149,000	100.00

TABLE 69

SEASONAL RUN-OFFS OF SACRAMENTO RIVER AT RED BLUFF, 1889-1929

Season	Full natural run-off, in acre-feet	Present net run-off, in acre-feet	Ultimate net run-off, in acre-feet
1889-1890	22,700,000	22,422,000	21,221,000
1890-1891	6,460,000	6,182,000	5,993,000
1891-1892	7,250,000	6,972,000	6,435,000
1892-1893	12,400,000	12,122,000	11,305,000
1893-1894	8,640,000	8,362,000	7,988,000
1894-1895	12,300,000	12,022,000	11,366,000
1895-1896	11,351,000	11,073,000	10,406,000
1896-1897	10,387,000	10,109,000	9,606,000
1897-1898	5,138,000	4,860,000	4,784,000
1898-1899	5,980,000	5,702,000	5,349,000
1899-1900	8,711,000	8,433,000	7,576,000
1900-1901	9,023,000	8,745,000	8,121,000
1901-1902	11,379,000	11,101,000	10,576,000
1902-1903	9,942,000	9,664,000	9,256,000
1903-1904	16,104,000	15,826,000	15,083,000
1904-1905	10,782,000	10,504,000	10,103,000
1905-1906	11,292,000	11,014,000	10,243,000
1906-1907	13,881,000	13,603,000	12,996,000
1907-1908	7,916,000	7,638,000	7,382,000
1908-1909	14,571,000	14,293,000	13,555,000
1909-1910	9,109,000	8,831,000	8,502,000
1910-1911	10,108,000	9,830,000	9,013,000
1911-1912	6,574,000	6,296,000	6,093,000
1912-1913	7,044,000	6,766,000	6,242,000
1913-1914	13,716,000	13,438,000	12,735,000
1914-1915	12,568,000	12,290,000	11,981,000
1915-1916	10,697,000	10,419,000	9,863,000
1916-1917	7,134,000	6,856,000	6,289,000
1917-1918	5,441,000	5,163,000	5,039,000
1918-1919	7,824,000	7,546,000	7,033,000
1919-1920	4,217,000	3,939,000	3,831,000
1920-1921	11,476,000	11,198,000	10,243,000
1921-1922	6,666,000	6,388,000	5,919,000
1922-1923	5,347,000	5,069,000	4,825,000
1923-1924	3,294,000	3,016,000	2,809,000
1924-1925	8,078,000	7,800,000	7,126,000
1925-1926	5,674,000	5,396,000	5,014,000
1926-1927	10,971,000	10,693,000	9,952,000
1927-1928	7,634,000	7,356,000	6,876,000
1928-1929	4,399,000	4,121,000	3,938,000
40-year means, 1889-1929	9,354,000	9,076,000	8,567,000
20-year means, 1909-1929	7,898,000	7,620,000	7,166,000
10-year means, 1919-1929	6,775,000	6,498,000	6,053,000
5-year means, 1924-1929	7,351,000	7,073,000	6,581,000

Reservoir Site.—The lands that would have to be acquired for the Kennett reservoir are mostly steep, rough and mountainous with very little agricultural value. Some of them are suitable for grazing and a few small areas could be cultivated. The assessed values over the entire area are low, ranging from $0.50 to $10 per acre and averaging $3.75 per acre.

There are a few small towns or settlements within the area none of which are of any importance. Kennett, the largest town, was, during the operation of the Mammoth mine, a place of considerable size. Since the closing of that mine in 1925, however, its population and property values have rapidly decreased. The other towns are Antler, Pollock, Copper City, and Delta. The latter would not be flooded by a dam less than 520 feet in height.

Several mines and smelters would at one time have been affected by the construction of the reservoir. These are the Bully Hill, Herault, Mammoth and Arps mines and the Bully Hill, Herault and Mammoth smelters. Of these, only the Arps mine would be flooded by any height of dam built at the Kennett site. The Mammoth mine has been worked out and abandoned and the smelter has been dismantled. The Herault mine is several hundred feet above the highest flow line of any reservoir considered in this report. The Bully Hill mine and smelter are on Squaw Creek, a tributary of the Pit River. This was originally a copper producing property but after remaining idle for several years was reopened in 1924 for the production of zinc oxide. This mine was connected to the Afterthought mine, several miles away on the south side of the Pit River near Ingot, by an aerial tram, and ore from the latter mine was conveyed to Bully Hill where, with the ore from the Bully Hill mine, it was shipped to the main line of the Southern Pacific Railroad in the Sacramento Canyon over a standard gage track located along the right bank of the Pit River. No ore is now being shipped and the smelter is inactive but is kept in repair, as is the branch railroad line. This railroad would be partially flooded with a dam over 103 feet in height and would be entirely flooded by a dam 300 feet in height. The smelter would be flooded by a dam 600 feet in height and the mine would be cut off from transportation. In 1925, the Bully Hill mine, smelter and railroad were sold at public auction for $788,827.24 in foreclosure proceedings.

The principal improvements that would be affected by the construction of the reservoir are the main line of the Southern Pacific Railroad and the State highway. Both of these can be moved to new locations but the expense would be large and would constitute a substantial part of the entire cost of the reservoir. Proposed relocations of the railroad were made for dams 420 feet and 520 feet in height. Both of these relocated lines would be shorter than the existing line but would require greater lengths of tunnels and bridges. The relocation of the railroad for the 520-foot height of dam was surveyed and estimates of its cost prepared by the United States Army engineers. This relocation was used for estimating the cost of the reservoir with both the 420-foot and 520-foot dams since it is believed that the dam would be built ultimately to the latter height and no further relocation of the railroad would then be necessary. The relocated line would leave the present line near Redding and run northerly on the west side of the

Sacramento River and rejoin the present line near Delta. The line would be 32.6 miles long and would require 26.3 miles of open track, 30,340 feet of tunnel and seven bridges aggregating 2960 feet in length. The State highway along the Pit and McCloud rivers, Salt Creek and the Sacramento River near Pollock would have to be relocated. This would involve heavy grading and the construction of large bridges over the Pit and Sacramento rivers. The estimated cost of this work was based on data furnished by the Division of Highways, Department of Public Works.

There are also a few other roads and other improvements that would be flooded including the United States fish hatchery at Baird on the McCloud River.

A topographic survey of the Kennett reservoir site for a depth of water of 615 feet at the dam site was made by the State in 1924 and a map was drawn from this survey at a scale of one inch equals 1000 feet, with a contour interval of 25 feet. The water surface areas measured from this map and the capacities of the reservoir computed from them are shown in Table 70.

TABLE 70

AREAS AND CAPACITIES OF KENNETT RESERVOIR

Height of dam, in feet (5-foot freeboard,	[1]Water surface elevation of reservoir, in feet	Area of water surface, in acres	Capacity of reservoir, in acre-feet
100	680	900	30,000
120	700	1,260	52,000
140	720	1,800	82,000
160	740	2,460	124,000
180	760	3,250	181,000
200	780	4,200	257,000
220	800	5,490	353,000
240	820	6,590	471,000
260	840	7,780	618,000
280	860	9,060	785,000
300	880	10,500	983,000
320	900	12,370	1,209,000
340	920	14,150	1,476,000
360	940	16,110	1,774,000
380	960	18,230	2,122,000
400	980	20,500	2,510,000
420	1,000	23,030	2,940,000
440	1,020	25,810	3,430,000
460	1,040	28,700	3,980,000
480	1,060	31,650	4,578,000
500	1,080	34,700	5,242,000
520	1,100	37,820	5,967,000
540	1,120	40,920	6,759,000
560	1,140	44,080	7,600,000
580	1,160	47,390	8,516,000
600	1,180	50,800	9,501,000
620	1,200	54,430	10,555,000

[1] Southern Pacific Railroad datum.

Dam and Power Plant.—A survey of the dam site was made by the State in 1924. A topographic map drawn from this survey at a scale of one inch equals 400 feet, with a contour interval of 25 feet, was used in laying out and estimating the cost of the Kennett dam and power plant. The site for the dam is topographically favorable for a dam somewhat over 600 feet in height. The stream channel is about 150 feet wide and at 615 feet above low water surface, the canyon width is 3600 feet. Preliminary explorations of the site to determine the foundation conditions were made by means of core drillings and exploration tunnels. A total of 4299 feet of holes were drilled and 1415 feet of tunnels were excavated. These drill holes and tunnels, as well as the surface exposures, indicated the character of the foundation rock, the depth to which it has been weathered and oxidized, and the amount of surface material that it would be necessary to remove to obtain a good firm rock foundation. The site was studied by two eminent geologists, Drs. George D. Louderback and Frederick L. Ransome, whose report may be found in Appendix A. The foundation rock is described by the geologists as a metaandesite or "greenstone" and is declared by them to be a suitable foundation for a high dam of any type.

PLATE XXIII

Kennett Dam Site on Sacramento River

Only the gravity concrete and rock-fill types of dam were considered. A sufficient quantity of suitable rock for the latter type can be obtained in the vicinity but comparative estimates indicate that on account of the additional cost of the outlet works and spillways for this type of dam, it would cost about the same as a gravity concrete dam. The latter type was used in making the estimates for this report. Sand and gravel for use in the construction of a concrete dam are available in the vicinity of Redding.

Estimates were made for the Kennett dam and reservoir for five heights of dam from 220 to 620 feet at hundred foot intervals. The detailed estimate and layout for only one of these heights, 420 feet, are shown in this report. The features for this height are typical of those for other heights and are described herein for illustration. The layout for the 420-foot dam is shown on Plate XXIV, "Kennett Reservoir on Sacramento River."

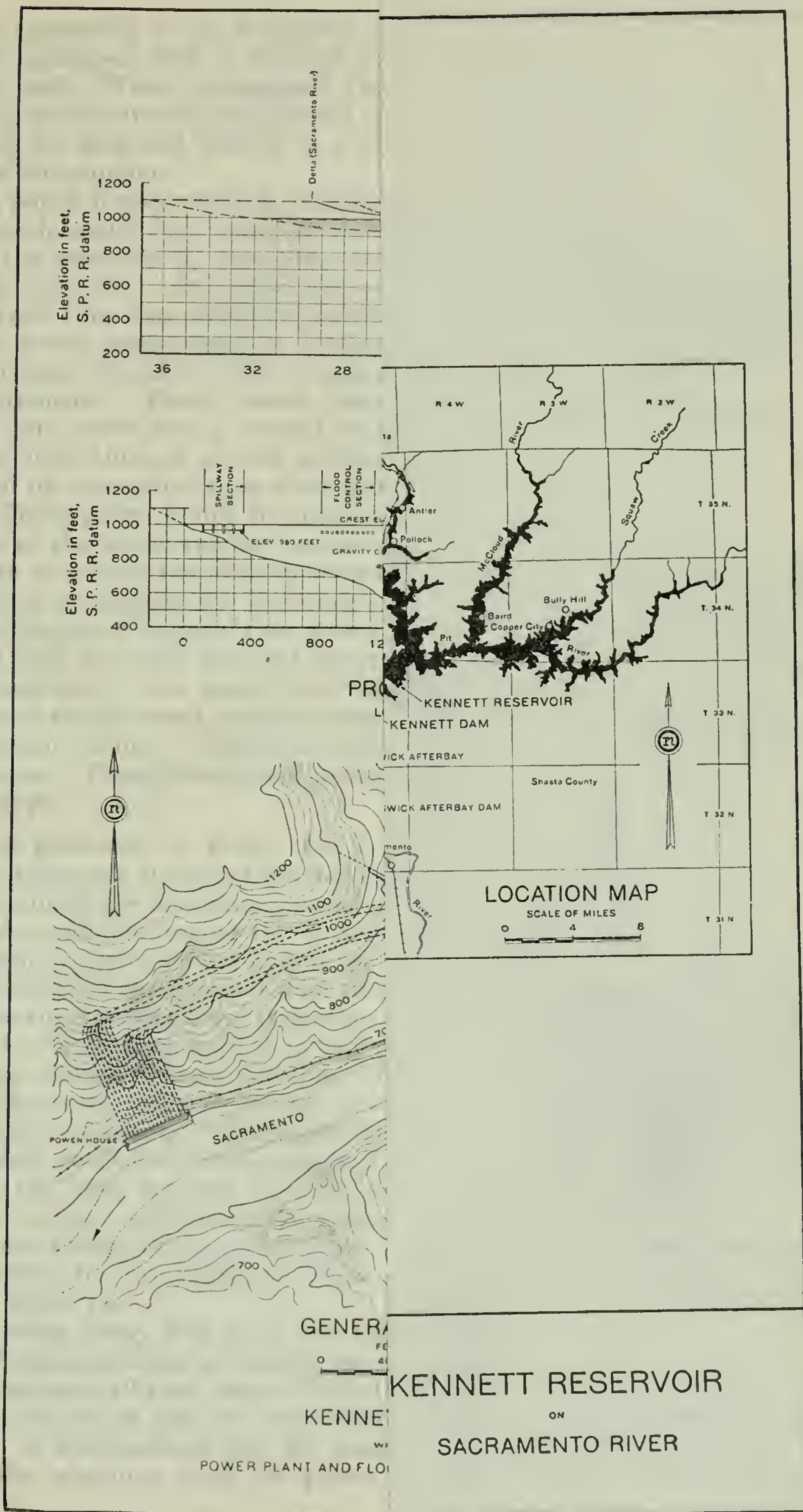
The dam would be of the gravity concrete type, slightly arched in plan so as to better fit the topography of the site. It would rest on good firm rock which would require the removal of considerable amounts of decomposed surface rock to obtain a suitable foundation. There would be a cut-off wall at the upstream toe, beneath which the rock would be sealed by grouting. The foundation also would be drained by a row of drainage wells, just downstream from the upper cut-off wall, which would be connected to a gallery in the dam.

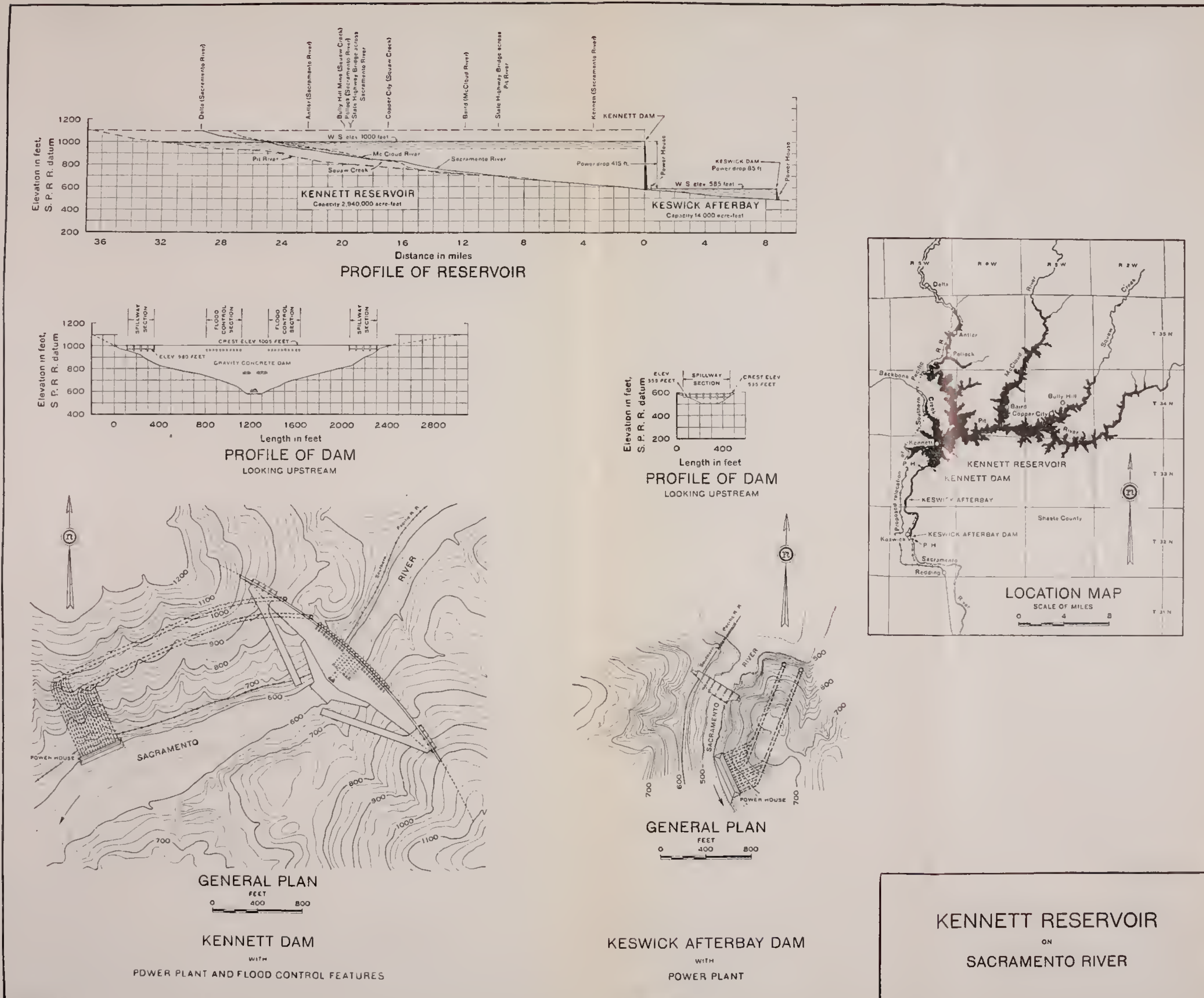
Diversion of the stream flow during the excavation for the foundation and the construction of the lower portion of the dam would be accomplished by means of rockfill coffer dams with earth blankets, placed above and below the excavation in the stream bed. The diverted water would be conveyed around the excavation by a concrete lined horseshoe shaped tunnel which would have a capacity of 15.000 second-feet. This tunnel would be plugged and backfilled after it was no longer required for diversion purposes.

The spillway would have a capacity of 125,000 second-feet and would be divided into two equal parts with one at each end of the dam. Each section would have 200 feet of clear opening with the fixed crest 20 feet below the flow line of the reservoir and 25 feet below the top of the dam. The flow over the spillway would be controlled by eight hydraulically operated steel segmental drum gates 20 feet in height set in the crest. These gates would be 50 feet in length and would be separated by 10-foot piers in which the operating mechanism would be located. The overflow water from the spillways would be intercepted in reinforced-concrete lined spillway channels which would convey it to the stream channel about 250 feet downstream from the dam. An ample freeboard would be allowed on these channels to care for entrained air and turbulent flow.

Twenty-eight outlets would be provided through the dam for the release of water for flood control and irrigation. The flood control outlets would have a capacity of 125,000 second-feet with the water in the reservoir drawn down a sufficient depth to give the reserve storage space required for controlling floods to this amount. These outlets would be fourteen feet square, would be spaced at thirty foot intervals, and would be located at a distance of 45 feet below the top of the dam. Flow through each opening would be controlled by a caterpillar type self-closing sluice gate at the upstream face of the dam, operated from the top of the dam and protected by steel trash racks set in semicircular concrete structures extending to the top of the dam.

The outlets to serve as sluiceways and for the release of irrigation water would be located in the section of the dam over the stream channel. These outlets would be steel lined and 130 inches in diameter. Five of these outlets would be placed 235 feet below the top of the dam and the other two would be 150 feet lower. Flow through each outlet would be controlled by a caterpillar type self-closing sluice gate at the upstream face of the dam, which would be protected by steel trash racks set in a semicircular concrete structure and would be operated from the top of the dam, in a concrete enclosed gate well extending to the top of the dam. Further control on each outlet would be provided by an auxiliary slide valve operated from a chamber inside of the dam a short distance below its upstream face. Also, in order to obtain a more


Elevation in feet, S. P. R. R. datum
Delta (Sacramento River)
1200
1000
800
600
400
200
36
32
28
SPILLWAY SECTION
FLOOD CONTROL SECTION
CREST EL
ELEV 980 FEET
GRAVITY C
0
400
800
PR
KENNETT RESERVOIR
KENNETT DAM
ICK AFTERBAY
WICK AFTERBAY DAM
R 4 W
R 3 W
R 2 W
River
Creek
Squaw
McCloud
Antler
Pollock
Bully Hill
Baird
Copper City
Pit
River
T. 35 N.
T. 34 N.
T. 33 N.
T. 32 N
T. 31 N
Shasta County
LOCATION MAP
SCALE OF MILES
0 4 8
1200
1100
1000
900
800
700
POWER HOUSE
SACRAMENTO
GENER
KENNE
POWER PLANT AND FLO
KENNETT RESERVOIR
ON
SACRAMENTO RIVER



KENNETT RESERVOIR
ON
SACRAMENTO RIVER

accurate regulation of the irrigation releases, one of the lower outlets would be equipped with a 130-inch balanced needle valve at its discharging end. Water discharged from both the flood control and irrigation outlets would be collected in concrete lined channels along the toe of the dam and carried to a concrete lined stilling pool in the bottom of the canyon.

The power house would be located on the right bank of the stream about two thousand feet below the dam. Water would be conveyed to it from the reservoir by two concrete lined horseshoe shaped tunnels 20 feet in diameter. At a point opposite the power house, each tunnel would divide into four steel pipe penstocks, 10.5 feet in diameter, each of which would carry water to a turbine in the power house. These steel penstocks would be laid in separate concrete lined tunnels 14.5 feet in diameter. Water would enter each main tunnel through a concrete gate tower over a vertical concrete lined shaft. Water would enter the tower through several openings, flow through which would be controlled by caterpillar type sluice gates operated from the top of the tower. These gates would be located 220 feet below the maximum elevation of the water surface in the reservoir, would be protected by steel trash racks and would be operated in concrete enclosed gate wells.

Studies to estimate the economic installation of generating equipment for this plant indicate that with a load factor of 0.75 and a power factor of 0.80, the total installed generator capacity should be 275,000 kilovolt amperes. This would be divided equally among eight generators, each of which would be direct connected to a vertical shaft variable head reaction turbine. The power house would be of steel and concrete construction. Transformers and protective equipment would be of the outdoor type.

Yields of Reservoir in Water for Irrigation and in Hydroelectric Energy—Reservoir Operated Primarily for Irrigation.—Analyses were made to estimate the maximum annual amounts of water that would have been made available during the 40-year period 1889–1929, at the Red Bluff gaging station, for irrigation use, by the construction of dams of several heights at the Kennett dam site and the operation of the reservoir primarily for supplying irrigation water, and the amounts of these yields that would have been new water. These studies were made by the method described in the fore part of this chapter. In making these studies, the entire capacity of the reservoir was utilized in the years of deficiency in supply. The drafts from the Kennett reservoir were those which would have been necessary to supplement the natural run-off from the area between Kennett dam and Red Bluff to give an irrigation supply, distributed in accordance with the demand in the Sacramento Valley, at the latter point. The total yields, and the yields in new water for five heights of dam, as shown by these studies, are given in Table 74.

A similar study was made for the reservoir having the 420-foot height of dam operating primarily for irrigation with incidental power during the same 40-year period 1889–1929. This study differed from the previous one in that the entire capacity of the reservoir was not utilized. It was assumed that the reservoir would have been operated so that the minimum head for power development would have been

accurate regulation of the irrigation releases, one of the lower outlets would be equipped with a 130-inch balanced needle valve at its discharging end. Water discharged from both the flood control and irrigation outlets would be collected in concrete lined channels along the toe of the dam and carried to a concrete lined stilling pool in the bottom of the canyon.

The power house would be located on the right bank of the stream about two thousand feet below the dam. Water would be conveyed to it from the reservoir by two concrete lined horseshoe shaped tunnels 20 feet in diameter. At a point opposite the power house, each tunnel would divide into four steel pipe penstocks, 10.5 feet in diameter, each of which would carry water to a turbine in the power house. These steel penstocks would be laid in separate concrete lined tunnels 14.5 feet in diameter. Water would enter each main tunnel through a concrete gate tower over a vertical concrete lined shaft. Water would enter the tower through several openings, flow through which would be controlled by caterpillar type sluice gates operated from the top of the tower. These gates would be located 220 feet below the maximum elevation of the water surface in the reservoir, would be protected by steel trash racks and would be operated in concrete enclosed gate wells.

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Yields of Reservoir in Water for Irrigation and in Hydroelectric Energy—Reservoir Operated Primarily for Irrigation.—Analyses were made to estimate the maximum annual amounts of water that would have been made available during the 40-year period 1889–1929, at the Red Bluff gaging station, for irrigation use, by the construction of dams of several heights at the Kennett dam site and the operation of the reservoir primarily for supplying irrigation water, and the amounts of these yields that would have been new water. These studies were made by the method described in the fore part of this chapter. In making these studies, the entire capacity of the reservoir was utilized in the years of deficiency in supply. The drafts from the Kennett reservoir were those which would have been necessary to supplement the natural run-off from the area between Kennett dam and Red Bluff to give an irrigation supply, distributed in accordance with the demand in the Sacramento Valley, at the latter point. The total yields, and the yields in new water for five heights of dam, as shown by these studies, are given in Table 74.

A similar study was made for the reservoir having the 420-foot height of dam operating primarily for irrigation with incidental power during the same 40-year period 1889–1929. This study differed from the previous one in that the entire capacity of the reservoir was not utilized. It was assumed that the reservoir would have been operated so that the minimum head for power development would have been

50 per cent of the maximum obtainable. It also was assumed that the power plant would have had the same installed capacity as if it had been installed primarily for the generation of power. With this method of operation, the seasonal yield in irrigation water, with deficiencies corresponding to those for the reservoir operated primarily for irrigation without power, would have been 4,340,000 acre-feet, of which 2,850,000 acre-feet would have been new water. The electric energy would have had a low value on account of there being some months in each year when none would have been generated. However, by a slight modification of releases so that some water would have been available for power development in the months when none was released for irrigation uses, the irrigation yield would have been practically the same as with the former method of operation and the power value would have been substantially increased. The average annual electric energy output with this modified operation would have been 1,055,400,000 kilowatt hours. The value of this energy at the power plant based on the cost of producing an equivalent amount of electric energy of the same characteristics with a steam-electric plant in the area of consumption, taking into account the cost of transmission from point of generation to load center, as shown in Chapter VIII, was estimated to be $.00193 per kilowatt hour. The average annual revenue at this value would have been $2,037,000.

A similar study for a reservoir having a 520-foot dam, shows that with this size reservoir the seasonal yield in irrigation water would have been 5,386,000 acre-feet of which 3,896,000 acre-feet would have been new water. The average annual electric energy output would have been 1,277,500,000 kilowatt hours. The average annual revenue from this energy, if it had been sold at the same rate as the energy developed by the power plant with a 420-foot dam, would have been $2,466,000.

Yields of Reservoir in Hydroelectric Energy and in Water for Irrigation—Reservoir Operated Primarily for Generation of Power.—A study also was made to estimate the amount of power that would have been developed in the 40-year period 1889–1929 with the reservoir having a 420 foot dam operated primarily for this purpose, and the amount of new water that would have been made available with this method of operation of the reservoir. The power plant would have had an installed capacity of 275,000 kilovolt amperes. This plant operated on a load factor of 0.75 and with a power factor of 0.80 would have produced an average annual output of 1,322,800,000 kilowatt hours. The output in the minimum year would have been 1,085,800,000 kilowatt hours and in the maximum year 1,448,400,000 kilowatt hours. The value of this electric energy was estimated to be $0.00272 per kilowatt hour. The average annual return at this value would have been $3,598,000.

The reservoir while operating primarily for the generation of power would have made available an annual yield of 2,085,000 acre-feet of water which would have been available for irrigation, diverted in accordance with the demand for irrigation water. This yield would have had a maximum seasonal deficiency of 9.6 per cent and an average for the 40-year period 1889–1929, of two per cent. This yield amounts to 46 per cent of that with the reservoir operated primarily for irrigation. Of this yield, 595,000 acre-feet would have been new water. This is nineteen per cent of the yield in new water with the reservoir operated primarily for irrigation.

Flood Control.—The value of the Kennett reservoir for controlling flood flows at the point where the river debouches into the Sacramento Valley near Red Bluff is not as great as if it were located nearer this point. Curves on Plate VIII and data in Table 32 in Chapter VI show the probable frequency of occurrence of flood flows at Red Bluff and from the area between Red Bluff and the Kennett dam site. These curves and data show that a flood may originate between Kennett dam site and Red Bluff which may exceed 187,000 second-feet mean daily flow on an average of once in 100 years. A mean daily flow of 125,000 second-feet from this area may be exceeded on an average of once in fourteen years. The curves on Plate X and data in Table 35 in Chapter VI show the reservoir space required to control floods at Red Bluff, both from the total area above that point and from the area between Kennett dam site and Red Bluff, to certain controlled flows which would be exceeded with different frequencies. These curves and data indicate that 512,000 acre-feet of space would be needed at Red Bluff to control the total flow to 125,000 second-feet exceeded once in 100 years on the average and that 123,000 acre-feet would be required at the same point to give the same degree of control for floods from the area between Kennett dam site and Red Bluff. This would indicate that 389,000 acre-feet of reserve space in Kennett reservoir would be required to control flows to 125,000 second-feet exceeded once in 100 years on the average if 123,000 acre-feet more space could be provided on the river near Red Bluff. If, however, the latter space is not provided, flows would exceed 125,000 second-feet mean daily flow on an average of once in fourteen years and would exceed 187,000 second-feet mean daily flow on an average of once in 100 years.

Since no reservoir is now proposed on the river near Red Bluff, the 512,000 acre-feet of space would be reserved in the Kennett reservoir and the entire flow from above Kennett would be stored as long as the run-off from the area between the reservoir and Red Bluff was exceeding 125,000 second-feet. As soon as the run-off from the area between Kennett dam site and Red Bluff no longer exceeded 125,000 second-feet, or at any time the flow from this area did not equal this amount, water would be released from the Kennett reservoir in such amounts that the flow would not exceed 125,000 second-feet at Red Bluff. The reservoir would be operatetd and space reserved in accordance with the rule given in Chapter VI.

The control of floods with the Kennett reservoir would considerably reduce those that might be expected without control. The effect of this control is shown by Table 71 which shows the reduction in flows at Red Bluff and Colusa with Kennett reservoir operated for flood control. The effect of the control of floods by the Kennett reservoir on the Sacramento Flood Control Project, and its effect in reducing the cost of the protection of Butte Basin, have been discussed in Chapter VI

TABLE 71

FLOOD FLOWS AT RED BLUFF AND COLUSA WITHOUT AND WITH FLOOD CONTROL BY KENNETT RESERVOIR

Point of flow	Maximum mean daily flow, in second feet		Number of times flow would be exceeded on the average
	Without reservoir control	With reservoir control	
Red Bluff	303,000	[1]187,000	Once in 100 years
Red Bluff	218,000	[1]125,000	Once in 14 years
Colusa	370,000	250,000	Once in 100 years
Colusa	254,000	170,000	Once in 14 years

[1] Floods would be controlled to 125,000 second-feet maximum flow exceeded once in 100 years on the average except when this amount is exceeded by the uncontrolled run-off between Kennett reservoir and Red Bluff. Flows greater than 125,000 second-feet would continue for only a short time.

Cost of Reservoir and Power Plant.—Estimates of the cost of the Kennett reservoir were prepared for the five heights of dam previously mentioned. These estimates were made as generally outlined in the fore part of this chapter and include all of the items, except the power plant, which have been briefly described in the foregoing paragraphs. The costs are listed in Table 74. In estimating the cost of the reservoir for each height of dam, the costs of relocating the Southern Pacific Railroad and the State highway to clear the maximum water surface in that reservoir were estimated for, and included in, the cost of that reservoir.

A somewhat detailed estimate is given for the reservoir having a 420-foot dam in Table 72. In this estimate, however, the cost of relocating the railroad to a height sufficient to clear a 520-foot dam is included since it is assumed that the dam would eventually be raised to that height and no other relocation would then be necessary. The items included under miscellaneous in the cost estimates are a short railroad spur to the gravel pit, a permanent camp, and cleaning up after construction. The same items and similar unit prices were used in estimating the costs for reservoirs with other heights of dam.

TABLE 72

COST OF KENNETT RESERVOIR WITH FLOOD CONTROL FEATURES

Height of dam, 420 feet. Capacity of reservoir, 2,940,000 acre-feet.
Capacity of spillway, 125,000 second-feet.
Capacity of flood-control outlets, 125,000 second-feet.

Diversion of river during construction		$270,000
Clearing reservoir site		460,000
Excavation for dam, 1,433,000 cu. yds. at $1.50 to $4.00	$2,309,000	
Mass concrete, 3,139,000 cu. yds. at $7	21,973,000	
Reinforced concrete, 4,000 cu. yds. at $16 to $24	74,000	
Spillway gates	250,000	
Spillway channel	583,000	
Irrigation outlets and sluiceways	632,000	
Flood control features	797,000	
Drilling and grouting foundation	61,000	
		26,679,000
Lands and improvements flooded		17,680,000
Miscellaneous		100,000
Subtotal		$45,189,000
Administration and engineering, 10 per cent		4,519,000
Contingencies, 15 per cent		6,778,000
Interest during construction based on a rate of 4.5 per cent per annum		8,514,000
Total cost of dam and reservoir		$65,000,000

The estimated cost of the Kennett reservoir with a 520-foot dam, the estimated ultimate height, is $100,500,000.

The estimated cost for the 275,000 kilovolt ampere power plant previously described in connection with the 420-foot dam is shown in Table 73. It is estimated that the cost of a 400,000 kilovolt ampere power plant to be constructed in connection with a 520-foot dam would be $16,500,000.

TABLE 73

COST OF POWER PLANT FOR KENNETT RESERVOIR WITH 420-FOOT DAM

Installed capacity, 275,000 kilovolt amperes.
Power factor = 0.80. Load factor = 0.75.

Intake structures	$424,000
Penstocks	3,676,000
Building and equipment	5,984,000
Subtotal	$10,084,000
Administration and engineering, 10 per cent	1,008,000
Contingencies, 15 per cent	1,513,000
Interest during construction based on a rate of 4.5 per cent per annum	895,000
Total cost of power plant	$13,500,000

The total estimated capital cost of the Kennett reservoir, with a 420-foot dam, and its power plant would be $78,500,000. The estimated cost for the same features for the reservoir with a 520-foot dam would be $117.000,000.

The annual cost for each of the five sizes of reservoir previously referred to, without a power plant, was estimated on the bases shown in the fore part of this chapter and is given in Table 74. The annual costs of the Kennett reservoir with a 420-foot dam, and its 275,000 kilovolt ampere power plant, based on the capital costs given in Tables 72 and 73 were estimated to be $3,820,000 and $1,081,000 respectively, or a total of $4,901,000. The annual costs of the reservoir with a 520-foot dam, and its 400,000 kilovolt ampere power plant. were estimated to be $5,877,000 and $1,359,000 respectively, or a total of $7,236,000.

Comparison of Sizes of Reservoir.—Many considerations must enter into the selection of the capacity of a reservoir to be constructed at the Kennett site. The reservoir should have an ultimate capacity large enough to yield at least sufficient water for the irrigation of the area dependent entirely upon the Sacramento River for its supply. It also should develop sufficient additional supply to improve and maintain navigation on the upper Sacramento River and, together with the other major reservoirs of the State Water Plan, should furnish water for the control of salinity and for an irrigation supply in the Sacramento-San Joaquin Delta and additional water supplies for exportation to supplement the water supplies of areas in the Great Central Valley and the San Francisco Bay basin having insufficient local water supplies for their ultimate needs.

Since the upper Sacramento River has the largest run-off of any stream entering the Sacramento Valley, a large storage capacity on this stream would be desirable ultimately for as complete utilization of this water as is economically justified.

Although the demands for navigation and salinity control would vary somewhat from those for irrigation use and the costs per acre-foot of water for these purposes would be slightly different, they are comparable as to relative costs of regulated water from the reservoir. Reservoirs of different capacities, therefore, may be compared on the basis of the cost of irrigation yield when operated primarily for that purpose. Comparisons of reservoirs of different capacities at the Kennett site, were made on the bases of the cost of storage, the cost of the total seasonal irrigation yield and yield in new water, the cost of the reservoir per acre-foot increase in each of these items, and the annual cost for irrigation water for both the total yield and the yield in new water. These items are given in tabular form in Table 74 and are shown graphically on Plate XXV, "Cost of Reservoir Capacity and Unit Yield of Water for Irrigation from Kennett Reservoir." The capital costs do not include the costs of power features and the annual costs are gross costs from which no deductions were made for revenue from the sale of electric energy. The average annual revenue from the sale of electric energy generated at the Kennett reservoirs with the 420-foot and 520-foot dams and the Keswick afterbay, when operated primarily for irrigation with incidental power, and the average net annual costs not covered by revenue from the sale of this electric energy, are set forth in Table 136. That table shows that the average net annual costs per acre-foot of total seasonal irrigation yield and yield in new water are considerably reduced by the revenue from the sale of electric energy.

The data in Table 74 and the curves on Plate XXV show that with the reservoir operated primarily for irrigation, the cheapest water could be obtained with a dam 320 to 350 feet in height. A reservoir with this height of dam, however, would not yield sufficient water for the ultimate requirements for irrigation in the Sacramento River service area, shown on Plate VI, which amount to 4,172,000 acre-feet per season, the yield of a reservoir with a 320-foot dam being only 3,386,000 acre-feet per season. This yield also is only 39.5 per cent of the average seasonal ultimate net run-off of the Sacramento River above Red Bluff, which is a small degree of control of the water available from the stream.

Heights of dam up to 520 feet would give reasonable capital and annual costs per acre-foot of irrigation yield. The cost of yield in new water at this height would be $1.47 per acre-foot per season and the annual cost of the total yield would be only $1.07 per acre-foot.

In the following pages of this chapter, estimates of cost and yield are given for the other major reservoir units of the State Water Plan in the Sacramento River Basin. Tables similar to Table 74 and plates similar to Plate XXV are given for the Oroville, Auburn and Coloma reservoirs and the estimated yields and costs are given for one height of dam for the Narrows, Camp Far West, Folsom, Millsite, Capay and Monticello reservoirs.

Near the end of this chapter, comparisons are made of all of the major reservoir units of the State Water Plan in the Sacramento River Basin. Two plates, Nos. LII and LIII, also are given, which show the comparisons graphically.

TABLE 74

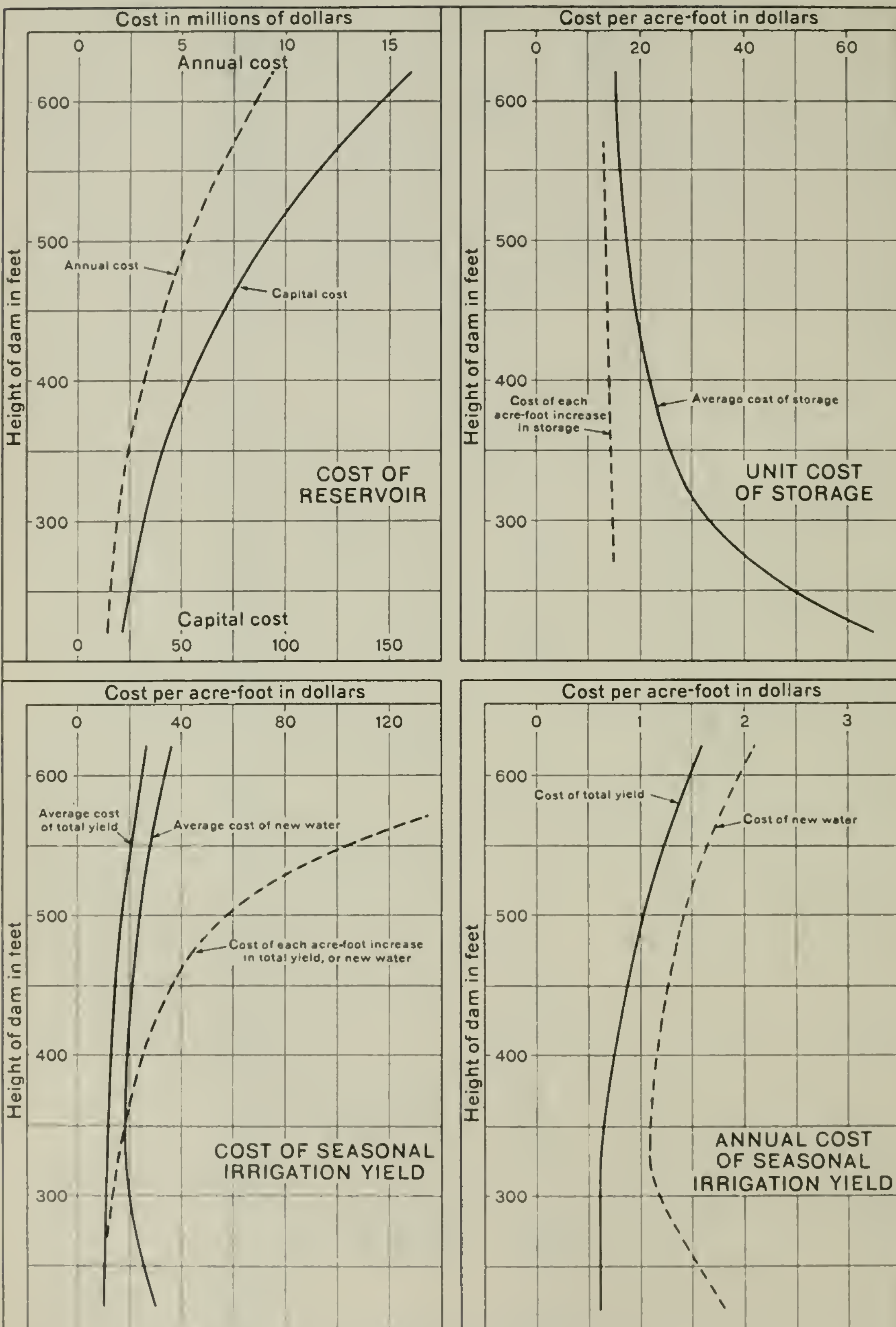
COST OF RESERVOIR CAPACITY AND UNIT YIELD OF WATER FOR IRRIGATION FROM KENNETT RESERVOIR

With Flood Control Features and Without Power Plant

Height of dam, in feet	Elevation of water surface, in feet	Capacity of reservoir, in acre-feet	Seasonal irrigation yield[1]		Cost of reservoir		Capital cost, per acre-foot						Annual cost per acre-foot of irrigation yield	
							Total storage	Increase in storage	Irrigation yield		Increase in irrigation yield			
			Total yield, in acre-feet	New water, in acre-feet	Capital	Annual			Total yield	New water	Total yield	New water	Total yield	New water
220	800	353,000	2,260,000	770,000	$22,900,000	$1,396,000	$64 90	----------	$10 10	$29 70	----------	----------	$0 62	$1 81
320	900	1,209,000	3,386,000	1,896,000	35,600,000	2,133,000	29 40	$14 80	10 50	18 80	$11 30	$11 30	0 63	1 12
420	1000	2,940,000	4,555,000	3,065,000	61,000,000	3,598,000	20 70	14 70	13 40	19 90	21 70	21 70	0 79	1 17
520	1100	5,967,000	5,481,000	3,991,000	100,500,000	5,877,000	16 80	13 00	18 30	25 20	42 70	42 70	1 07	1 47
620	1200	10,555,000	5,925,000	4,435,000	160,500,000	9,363,000	15 20	13 10	27 10	36 20	135 10	135 10	1 58	2 11

[1] Entire capacity of reservoir utilized in years of deficiency in supply. Yields shown are based on run-off for the 40-year period 1889-1929 and are those which would have been available at Red Bluff from natural stream flow supplemented by releases from Kennett reservoir. Each yield would have had a maximum seasonal deficiency not exceeding 35 per cent and an average deficiency for the 40-year period not exceeding two per cent.

PLATE XXV



COST OF RESERVOIR CAPACITY AND UNIT YIELD OF WATER FOR IRRIGATION FROM KENNETT RESERVOIR

Selection of Capacity of Reservoir.—It may be noted from Plate LII that the capital cost per acre-foot of seasonal yield in new water for irrigation from Kennett reservoir with a 2,940,000 acre-foot capacity (420-foot dam) is less than the cost of water from any reservoir except the Kennett reservoir with smaller capacities, and the Folsom reservoir. The Kennett reservoir with a 320-foot dam yields water at a lower capital cost per acre-foot but its seasonal yield is only 1,896,000 acre-feet of new water per season and that from the Folsom reservoir is only 666.000 acre-feet, as compared to 3,065,000 acre-feet from the Kennett reservoir with the 420-foot dam.

Plate LIII shows that the same relation holds true when gross and net annual unit costs instead of capital costs are compared.

Capacity of Unit for Initial Development.—The most important immediate water problem in the Sacramento River Basin in need of solution is the invasion of saline water into the Sacramento-San Joaquin Delta. In months of low water flow from the Sacramento and San Joaquin rivers, saline water from the lower bay has, due to tidal action, invaded the upper reaches of Suisun Bay and far up into the many channels of the delta. Attendant with this situation, the flow in the Sacramento River during the summer months of subnormal years has been so low that navigation has been greatly hampered and distance of navigability has been much reduced. Also, during several of the past dry years, particularly in 1920 and 1924, there was insufficient flow in the river to supply the present rights of the irrigators along the river and increased pumping costs resulted from the low level of the water in the stream. All of these problems—salinity in the delta and upper San Francisco Bay regions, navigation, and insufficient irrigation supply along the Sacramento River, are closely allied.

Although salinity control is the immediate primary function of a reservoir in the Sacramento River Basin and the two allied problems are important, other requirements also should have consideration. Attendant with the control of salinity, a dependable water supply is needed for the present irrigation requirements in the Sacramento-San Joaquin Delta and for a fresh water supply for the developed agricultural and industrial areas along the south shore of Suisun Bay in Contra Costa County. It also would be desirable to reduce the floods in the Sacramento Flood Control Project thereby increasing the degree of protection of lands in this project.

Also, it is most important to furnish water for the relief of areas in the San Joaquin Valley having insufficient supplies for their needs. Under the plan for immediate initial development, described in Chapter XI, it is contemplated that water for the relief of the upper San Joaquin Valley would be obtained by purchase of the water now used on the "grass lands" along the San Joaquin River, and from the surplus waters of that stream. In the plans for the complete initial development, however, the diversion of practically the entire flow of the San Joaquin River at Friant is contemplated. This would necessitate the importation of water from the Sacramento River Basin to supply the "crop lands" along the San Joaquin River above the Merced River now being served from the former river at Mendota. Therefore it is assumed that in selecting the capacity of a reservoir in the Sacramento

River Basin for an initial development, provision would be made for meeting the irrigation demands of the lower San Joaquin Valley under conditions of complete initial development. These demands would require making 896,000 acre-feet of water per year available in the delta for exportation to the San Joaquin Valley.

The desirable accomplishments of an initial unit on the Sacramento River, therefore, would be to control floods to a maximum flow of 125,000 second-feet at Red Bluff, except when this amount is exceeded by the run-off from the area between Red Bluff and the Kennett dam site, and to furnish water to supplement unregulated flows from the Sacramento River Basin and inflows to the San Joaquin Delta from the San Joaquin Valley streams, to:

1. Supply the irrigation demands along the Sacramento River above Sacramento, in accordance with the monthly distribution of requirements in the Sacramento Valley, up to 6000 second-feet maximum draft in July.
2. Supply the full present irrigation requirements of the lands in the entire Sacramento-San Joaquin Delta.
3. Furnish sufficient water to maintain a fresh water flow of not less than 3300 second-feet past Antioch into Suisun Bay to control salinity to the lower end of the Sacramento-San Joaquin Delta.
4. Maintain a navigable depth of five to six feet in the Sacramento River from the city of Sacramento to Chico Landing and substantially improve the depths from that point to Red Bluff.
5. Make available in the Sacramento-San Joaquin Delta a water supply for the developed agricultural and industrial area along the south shore of Suisun Bay in Contra Costa County.
6. Make available in the Sacramento-San Joaquin Delta an irrigation supply sufficient in amount to fully supply the "crop lands" now being served from the San Joaquin River above the mouth of the Merced River. This water would be conveyed to these lands by the San Joaquin River pumping system and would make possible the exportation of all the available supply in the San Joaquin River at Friant if the "grass land" rights on the San Joaquin River above the mouth of the Merced River were purchased.

The smallest reservoir which would have met these requirements without deficiency in supply through the period 1919-1929 would have a capacity of 2,940,000 acre-feet. The height of dam would be 420 feet. With a combined installed capacity of 325,000 kilovolt amperes at the Kennett and Keswick power plants, the yield in power output would have been 1,581,100,000 kilowatt hours annually, on the average, during the period 1889–1929, with an estimated value at the power plant of 2.42 mills per kilowatt hour.

Many factors in addition to the accomplishment of the foregoing requirements enter into the selection of the size of reservoir. These include, among others, financing and the rate of absorption of the water and electric energy yields. A larger reservoir than one with a 420-foot dam would have a larger capital cost and would produce more water and power, requiring longer periods for utilization. It therefore is concluded at this time, after consideration of all factors, that the 420-foot dam is the economic and practical one for initial construction.

Ultimate Capacity.—In selecting the ultimate capacity of the Kennett reservoir, several factors controlled. The minimum ultimate capacity would be that which would supply the ultimate water requirements of the Sacramento River service area, as this area is described and these requirements are shown in Chapter V. The maximum ultimate capacity would be fixed by many factors, namely, the ultimate requirements of its own service area, requirements for a supplemental supply for other service areas in the Sacramento River Basin having insufficient supplies from their local streams, requirements for irrigation and salinity control in the Sacramento-San Joaquin Delta, the ultimate requirements for a supplemental supply for the San Joaquin Valley and San Francisco Bay Basin, and the relative cost of the yield in water from the reservoir as compared with the cost of yield from the other major reservoir units.

It is shown in Table 28 in Chapter V that the gross allowance of water for the ultimate irrigation of the net irrigable acreage of the Sacramento River service area, which is dependent upon the run-off of the Sacramento River above Red Bluff for a supply, is 4,172,000 acre-feet per season. The water for this area would be obtained by regulating the run-off of the Sacramento River with the Kennett reservoir. A small amount of water would be available from the Trinity River diversion in some months but during the months of June, July and August no water would be available from this source under conditions of ultimate development, as it would all be used on the Trinity River service area. The return water from the Sacramento River service area also would be largely unavailable for reuse in this service area as it would not return to the river within the area.

It is shown in Table 74 that the Kennett reservoir with a 420-foot dam would have yielded during the 40-year period 1889–1929, a total seasonal irrigation supply of 4,555,000 acre-feet available at Red Bluff, with a maximum seasonal deficiency of 35 per cent, if the reservoir had been operated for irrigation yield only. The minimum seasonal yield would have been about 2,960,000 acre-feet and if the Sacramento River service area could endure a maximum deficiency of about 29 per cent, this reservoir would have sufficient yield to supply that area. The minimum ultimate capacity of reservoir for the Kennett site therefore would be one with a 420-foot dam if the 29 per cent deficiency were permissible, and one somewhat larger if it were not.

For the ultimate development of the Great Central Valley, surplus water from the Sacramento River Basin reservoirs is required for the uses outlined in the third preceding paragraph. Since the upper Sacramento River above Red Bluff has the largest run-off of any stream entering the Sacramento Valley, as large a portion of this surplus as is economically justified should be developed on that stream. The run-off in itself is sufficient to justify the development of a reservoir at Kennett larger than one having a 420-foot dam since the yield of 4,555,000 acre-feet at Red Bluff from the upper Sacramento River regulated by this reservoir is only 53.2 per cent of the mean seasonal ultimate net run-off of 8,567,000 acre-feet for the period 1889–1929, at the same point.

The data in Table 74 and on Plate XXV show that by increasing the capacity of the Kennett reservoir from 2,940,000 acre-feet (420-foot dam) to 5,967,000 acre-feet (520-foot dam) the yield of the reservoir would have been increased 926,000 acre-feet per season during the 40-year period 1889–1929, and that on this basis the average capital cost per acre-foot of increase in yield would have been $42.70. Compared to this cost, water in excess of the requirements for its own service area from the Feather River regulated by the Oroville reservoir would have a capital cost of more than $56 per acre-foot and the surplus water from the Yuba River regulated by the Narrows reservoir would have an average capital cost of more than $47. It therefore would be more economical to develop surplus water with a dam 520 feet high at Kennett than to develop it in either the Oroville or Narrows reservoir. From Plate LIII, it also may be seen that the average annual cost, either gross or net, per acre-foot of irrigation yield in new water from the 5,967,000 acre-foot (520-foot dam) Kennett reservoir would be less than from the American River unit or any of the other major reservoir units in the Sacramento River Basin.

The yield of the Kennett reservoir would have been increased about 444,000 acre-feet per season during the 40-year period 1889–1929, by increasing the height of dam from 520 feet to 620 feet. The average capital cost of each acre-foot of this increased yield, however, as shown in Table 74, would have been $135.10. This cost, as shown by Plate LII, would be greater than the average capital cost per acre-foot of yield or increase in yield from any other major reservoir unit in the Sacramento River Basin. This increase in height of dam at Kennett, therefore, would not be justified unless more water would ultimately be needed from the Kennett reservoir, irrespective of cost.

That the Kennett reservoir with a capacity of 5,967,000 acre-feet (520-foot dam), as well as the other major reservoir units with the capacity selected for each, would be required for the regulation of the water required for the ultimate development of the Great Central Valley is shown by studies made of the coordinated operation of all units of the State Water Plan in this valley. The other reservoirs and their selected capacities used in making these studies are shown in Table 138. The studies which were carried through the period 1918–1929 show that during this period the following accomplishments, which are given in greater detail under Method II in Chapter X, could have been obtained:

1. The irrigation of every acre of irrigable land in the Sacramento Valley and Sacramento-San Joaquin Delta *without deficiency* in supply.
2. A fresh water flow of 3300 second-feet, *without deficiency*, past Antioch into Suisun Bay for the control of Salinity to the lower end of the Sacramento-San Joaquin Delta.
3. The irrigation of 2,350,000 acres of land on the eastern and southern slopes of the upper San Joaquin Valley, *without deficiency* in supply.

4. The irrigation of 1,810,000 acres of irrigable land in the lower San Joaquin Valley; 785,000 acres of class 1 and 2 lands lying on the western slope of the upper San Joaquin Valley; and a water supply of 323,000 acre-feet for the irrigation of lands in the San Francisco Bay Basin. The water supplies for these three areas, however, would have had a *maximum seasonal deficiency of 35 per cent in one year during the period studied.*

While the above accomplishments could have been obtained with the 5,967,000 acre-foot (520-foot dam) Kennett reservoir and the other reservoirs having the capacities shown in Table 138, a smaller reservoir at Kennett, or at any of the other sites, would have caused deficiencies in the Sacramento River Basin or delta supplies or a deficiency beyond the endurable 35 per cent per season in the San Joaquin Valley or San Francisco Bay Basin supplies.

The conclusion, therefore, is drawn that, since 926,000 acre-feet more water, most of which would be surplus to the requirements for the Sacramento River water service area, could be obtained each season for other requirements in the ultimate development of the Great Central Valley by raising the dam for the Kennett reservoir from 420 feet to 520 feet; since this supply could be obtained at less cost from the Kennett reservoir than from the Oroville or Narrows reservoirs, both of which as well as the Kennett reservoir are required for ultimate development; since the average cost of each acre-foot of the 444,000 acre-foot increase in irrigation yield from the Kennett reservoir obtained by increasing the height of dam from 520 feet to 620 feet would be greater than the average cost of irrigation yield from the other major reservoir units in the Sacramento River Basin; and since a reservoir at Kennett with a dam lower than 520 feet would cause deficiencies in the water supplies for the ultimate developments in the Sacramento River Basin or Sacramento-San Joaquin Delta, or increase the deficiencies in supplies for the ultimate development in the San Joaquin Valley beyond the endurable 35 per cent per season, the ultimate height for the Kennett dam should be 520 feet.

Keswick Afterbay on Sacramento River.

During the search for dam sites on the Sacramento River, one was found near the old town of Keswick about five miles above Redding and 8.7 miles below Kennett dam site. This site was not considered to be as suitable for a high dam as the Kennett site. It is, however, an excellent site for a low dam to create an afterbay for the Kennett power plant and also an additional power drop.

The reservoir would not be used for storage, except for the small amount required to regulate the irregular releases from the the Kennett power plant to a uniform flow so that there would be no large daily fluctuations in the river below this site. The capacity required for this would be only a portion of that of the reservoir contemplated, however, as additional capacity would be created by the construction of a dam high enough to develop the full available power drop. The construction of the higher dam for power development purposes was shown by studies to be economically justified.

Reservoir Site.—The dam would be constructed high enough to back water up to the tail race of the Kennett power plant. The reservoir therefore would be 8.7 miles long but only about 600 feet wide as the flooded area would nearly all lie in the bottom of the Sacramento River canyon. A survey of the reservoir site was made by the State in 1921 and a map of it was drawn at a scale of one inch equals 1000 feet, with a 25-foot contour interval. The lands that would be flooded are rough, rock canyon of little value. The Southern Pacific railroad now runs along the bottom of the canyon through the entire length of the reservoir site. The relocation of the railroad for the construction of the Kennett reservoir would entirely remove it from this site, however, and there are no other improvements of any value within the flooded area.

Dam and Power Plant.—A survey of the dam site also was made by the State in 1921. A topographic map drawn from this survey at a scale of one inch equals 100 feet, with a contour interval of 25 feet was used in laying out and estimating the costs of the dam and power plant. The site for the dam is topographically favorable for a dam higher than the one proposed. The stream channel is about 150 feet wide and at elevation 590 feet, the top of the proposed 95-foot dam, the canyon is only 500 feet wide. A geological examination of the site was made and the foundation conditions were found suitable for a gravity concrete dam. The rock is exposed over practically the entire foundation area of the dam and is similar to that found at the Kennett dam site. It is weathered in some places and it would be necessary to remove this material to obtain a good firm foundation rock.

PLATE XXVI

Keswick Dam Site on Sacramento River

The dam would be of the gravity concrete overflow type with spillway gates on the crest for practically its entire length. The foundation would be sealed by grouting and would be drained by wells drilled just downstream from the upstream toe of the dam and connected with drainage tunnels in the dam.

The stream flow would be diverted during construction in a manner similar to that described for the Kennett dam. The diversion tunnels at this site, however, would be used after the completion of the dam in connection with the power plant.

The spillway would have a capacity of 225,000 second-feet. The flow over it would be controlled by seven hydraulically operated steel segmental drum gates 50 feet long and 30 feet deep set in the crest. These gates would be separated by 10-foot piers in which the operating mechanism would be located. The water passing through the spillway gates would flow over the downstream face of the dam into the bedrock channel which would require no protection.

As the spillway capacity of 225,000 second-feet would not be sufficient to care for flows which might pass the Kennett dam, additional outlets would be required. These would be provided for a capacity of 25,000 second-feet. There would be five openings eight feet wide and fifteen feet high with the centers located 80 feet below the top of the dam. Flow through these outlets would be controlled by caterpillar type self-closing sluice gates operating in wells built within the piers of the spillway structure. Each opening would be protected by a steel trash rack. The outlets could be used also to pass the regulated flows from the Kennett reservoir if the power plant were not in operation.

The layout for the dam and power plant is shown on Plate XXIV. The power house would be located on the left bank of the river about 800 feet below the dam. A rocky point at the left abutment of the dam offers an opportunity for a power plant well protected from the water passing over the dam and connected with the reservoir by short tunnel penstocks. The two main tunnels would be 21 feet in diameter, horseshoe shaped and concrete lined. At a point near the power house they would divide into eight steel penstocks laid in horseshoe shaped tunnels. Water would enter each main tunnel through a concrete gate tower over a concrete lined shaft. Water would enter the tower through openings which would be closed by caterpillar type sluice gates operated from the top of the tower and protected by steel trash racks.

The power house would be a steel and concrete structure housing eight generators of 6250 kilovolt ampere capacity, each direct connected to vertical shaft reaction turbines. This plant, on account of the use of the reservoir for reregulating power releases from Kennett power plant to uniform flow, would operate on a unity load factor.

Power Output.—The only yield of this afterbay would be in power output from the reregulated water. The seasonal and monthly variations of this power would be dependent upon the Kennett reservoir releases since water from this afterbay would be used for the generation of power without holdover storage of more than one or two days.

With the Kennett reservoir, 420-foot dam, operated primarily for the generation of power, the Keswick power plant would have produced an average annual output during the 40-year period 1889–1929, of 300,000,000 kilowatt hours. The value of energy at Kennett power plant was estimated to be $.00272 per kilowatt hour and it is believed that energy from the Keswick plant would have the same value. This would have yielded an average annual return of $816,000.

With the same size reservoir at Kennett operated primarily for irrigation yield, the Keswick power plant would have produced an average annual output in the 40-year period of 229,600,000 kilowatt hours. This energy at a value of $.00193, which is the value of energy from Kennett power plant with the same method of operation, would have yielded an average annual return of $443,000.

Cost of Reservoir and Power Plant.—The costs of the Keswick afterbay and power plant were estimated by the methods generally outlined in the fore part of this chapter and are shown in Table 75.

TABLE 75

COST OF KESWICK AFTERBAY AND POWER PLANT

Height of dam, 95 feet. Installed capacity of power plant, 50,000 kilovolt amperes. Power factor = 0.80. Load factor = 1.00.

Dam and Reservoir		
Exploration and core drilling		$10,000
Diversion of river during construction		150,000
Clearing reservoir site		10,000
Excavation for dam, 74,000 cu. yds. at $2.50 to $5	$267,000	
Mass concrete, 62,500 cu. yds. at $7	438,000	
Reinforced concrete, 3700 cu. yds. at $15 to $24	62,000	
Spillway gates	385,000	
Sluiceways	150,000	
Drilling and grouting foundation	12,000	
		$1,314,000
Lands		13,000
Permanent camp and clean-up after construction		50,000
Subtotal		$1,547,000
Administration and engineering, 10 per cent		155,000
Contingencies, 15 per cent		232,000
Interest during construction based on a rate of 4.5 per cent per annum		66,000
Total cost of dam and reservoir		$2,000,000
Power Plant		
Intake structures		$187,000
Penstocks		650,000
Building and equipment		1,870,000
Subtotal		$2,707,000
Administration and engineering, 10 per cent		271,000
Contingencies, 15 per cent		406,000
Interest during construction based on rate of 4.5 per cent per annum		116,000
Total cost of power plant		$3,500,000
Total cost dam, reservoir and power plant		$5,500,000

The annual cost of Keswick dam and power plant computed on the bases outlined in the fore part of this chapter would be $396,000. Of this total amount, the annual cost for the dam and reservoir would be $122,000 and for the power plant $274,000.

Kennett Reservoir Unit.

The Kennett reservoir unit would comprise the Kennett reservoir and power plant and the Keswick afterbay and power plant.

The capital costs of the unit with 420 and 520-foot dams for Kennett reservoir would be:

	With 420-foot Kennett dam	*With 520 foot Kennett dam*
Kennett reservoir	$65,000,000	$100,500,000
Kennett power plant	13,500,000	16,500,000
Keswick afterbay	2,000,000	2,000,000
Keswick power plant	3,500,000	3,500,000
Total	$84,000,000	$122,500,000

The annual costs of the unit with the same heights of dam for Kennett reservoir would be:

Kennett reservoir	$3,820,000	$5,877,000
Kennett power plant	1,081,000	1,359,000
Keswick afterbay	122,000	122,000
Keswick power plant	274,000	274,000
Total	$5,297,000	$7,632,000

Other Reservoir Sites in the Upper Sacramento River Basin.

No reservoir in the lower canyon of the upper Sacramento River near Red Bluff is included in the State Water Plan. The value of a reservoir in this location has long been recognized as it would be in a position to control the entire run-off of the upper Sacramento River, about one-third of which originates below Kennett reservoir. Diligent search for a favorable dam site was made prior to and during the present investigation by both Federal and State agencies. Four sites, including three at Iron Canyon immediately above Red Bluff and one at Table Mountain about ten miles further upstream, were explored by drifts, shafts and core drilling. Information developed at the sites thus far explored indicates that the foundation conditions are unsatisfactory for a masonry dam and doubtful for an earth fill or rock fill dam. Furthermore, the desirability of a large earth or rock fill dam impounding 1,000,000 to 3,000,000 acre-feet of water on the main Sacramento River above the entire Sacramento Valley is open to serious question.

Iron Canyon Site.—The three dam sites in Iron Canyon which were studied are located between points 4.5 miles and 7.75 miles above the Sacramento River bridge at Red Bluff. A preliminary investigation was made in 1904–1905 by the United States Reclamation Service. In 1913, the Reclamation Service, in cooperation with local interests, made a further investigation of Iron Canyon, a report* on which was rendered in October, 1914. The dam site investigated and reported upon is located at the upper end of the canyon above the mouth of Paynes Creek.

In 1919 a more thorough investigation was made by the Reclamation Service. The Paynes Creek site and two other sites below Paynes Creek were investigated. Exploration work was carried out and reported upon by geologists and a board of engineers in 1919 and 1920. The locations are known as I, II and III. The original dam site above Paynes Creek is known as Location I, the intermediate site as Location II and the lowest site, about one-half mile below the United States Geological Survey gaging station, is known as Location III. The geological investigations were made by Andrew C. Lawson and Homer Hamlin. The conclusions of these two geologists are published in another report.** On May 7, 1920, a board of engineers and geologists, the personnel of which was D. C. Henny, A. J. Wiley, Homer Hamlin, W. F. McClure, J. L. Savage and H. J. Gault, reported** on the Iron

* "Report on Iron Canyon Project" by the office of the U. S. Reclamation Service at Portland, Oregon, October, 1914.

** "Report on Iron Canyon Project, California" by Homer J. Gault and W. F. McClure, Department of the Interior and State of California, 1920.

Canyon dam sites. This board selected Location III as the most favorable of the three sites investigated for the construction of a dam.

In the water resources investigations of 1929 to 1931, further study was made of the Iron Canyon dam sites, particularly Location III. Investigations were made by two geologists, Drs. George D. Louderback and Frederick L. Ransome, and the Engineering Advisory Committee for the Sacramento River Basin Investigation. The report of the geologists may be found in Appendix A and that of the Engineering Advisory Committee in Appendix B. With reference to the site at Location III, which is the best one in Iron Canyon, the geologists concluded that the site is unfavorable for the construction of a concrete dam and also that the doubt whether leakage around and under a dam at this locality could effectively be prevented or controlled makes it unsatisfactory for any type of dam. The Engineering Advisory Committee expressed the opinions that a masonry dam built at Location III would be dangerously unsafe and that it would be dangerous to build any form of earth or rock fill dam at the site.

Table Mountain Site.—When it became apparent that a satisfactory dam site could not be found in Iron Canyon, attention was turned to finding one at some other point in the lower Sacramento River Canyon. The section of the stream from Location III in Iron Canyon to a point near the mouth of Cottonwood Creek was reconnoitered and geologized. The most satisfactory sites discovered were in the vicinity of Table Mountain between the Bend and Jellys ferries. After a preliminary geological investigation of the canyon between these two ferries, one site was selected as being the most favorable both topographically and geologically and was given further study.

The selected site is located in Sections 2, 4, 5, 9, 10 and 11, Township 28 North, Range 3 West, M. D. B. and M., at a point about sixteen miles by river above the Red Bluff bridge, and has been designated the Table Mountain site. A dam 175 feet high at this site would create a reservoir of 3,000,000 acre-feet capacity. Such a reservoir would flood the towns of Anderson and Cottonwood, the greater portion of the Anderson-Cottonwood Irrigation District and parts of the State highway and Southern Pacific railroad.

The foundations at the dam site were explored by drill holes, tunnels and shafts. Nine vertical holes with a total length of 1000 feet were drilled. Two of these holes, each 150 feet deep, were located on either side of the stream bed on the line of the dam. One tunnel, 40 feet in length, was excavated in the agglomerate on the left bank of the stream and another tunnel was excavated 20 feet into the tuff on the right abutment. Seven pits also were sunk, one on each abutment adjacent to the stream channel, four others on the left abutment and one at the base of the steep slope on the right abutment. The results of the explorations, and the general geology in the vicinity of the dam site, were studied by the same geologists who studied and reported upon the Iron Canyon site and their report on this site also is given in Appendix A. They found that the formations were much the same as at Iron Canyon, that there is irregular variation in the cementation of the agglomerate, that there are weak and permeable masses in the agglomerate, and that very pervious layers occur above and below the agglomerate which make it doubtful whether leakage could be cut off around and under a dam. On account of these conditions, they concluded that the site is unfavorable for the construction of a concrete dam and also that the doubt whether leakage around and under a dam at this locality could effectively be prevented or controlled, makes it unsatisfactory for any type of dam.

This site was studied also by the Engineering Advisory Committee for the Sacramento River Basin Investigation and their report and conclusions may be found in Appendix B. The Committee expressed the opinions that a masonry dam built at this site would be dangerously unsafe and that it would be dangerous to build any form of earth or rock fill dam at this site.

Before the exploration work was completed, an estimate of cost for a 3,000,000 acre-foot reservoir (175-foot dam) at this site was made. The cost of this reservoir including the cost of relocating the highway and railroad was estimated at $36,800,000. The total estimated cost of the reservoir and dam, a power plant at the dam and an afterbay at Iron Canyon is $45,000,000. It should be noted, however, that this estimate was prepared on the assumption that the foundations were capable of supporting safely a concrete dam of the height proposed and it was prepared for the purpose only of making a financial comparison with Kennett reservoir.

This reservoir would meet the requirements of an initial unit in the Sacramento River Basin, as set forth in Chapter XI. The amount of electric energy which could be generated at a power plant at the dam would be about one-half of that for a 420-foot dam at Kennett reservoir. Although the capital cost, so estimated, of the Table Mountain reservoir is only slightly more than one-half that of the Kennett reservoir, the net annual cost is practically the same as that for Kennett because of the lesser power revenue obtainable. If it were possible to construct a safe dam at Table Mountain, there would be two advantages over Kennett, first, the financing of the project might be simplified because of the lesser capital investment required and, second, the power absorption problem would be less because of the smaller amount of electric energy which could be produced at the dam. However, since the foundation conditions at the Table Mountain site are found by both the geologists and the advisory engineers to be unsatisfactory for the construction of a safe dam, no dam at this site is included in the State Water Plan.

Following the rejection of the Table Mountain site a further geological reconnaissance of the lower Sacramento River Canyon was made to determine whether any other more promising site might exist. The report on this investigation is given in Appendix C, together with an areal geological map of the canyon from the lowest Iron Canyon site to Cottonwood Creek. This investigation showed that the formations throughout the entire area are similar in character to those in Iron Canyon and at the Table Mountain dam site, and no site better than the Table Mountain was revealed.

Baird Site.—Another reservoir site investigated in the upper Sacramento River Basin is one whose dam site is on the Pit River below the mouth of the McCloud River. It is designated the Baird site. This reservoir site lies within the area which would be flooded by a dam constructed at the Kennett site and is therefore not an auxiliary reservoir thereto. Its advantage over the Kennett site is that the large cost of relocating the Southern Pacific railroad would be obviated. Its disadvantage is that, being located on the Pit River, it would not be in a position to control the run-off from the Sacramento River and several minor streams, which constitute 20 per cent of the run-off tributary to the Kennett reservoir, and furthermore would have much less value than the Kennett reservoir for controlling floods in the Sacramento River below Red Bluff.

This site is favorable for the formation of a reservoir up to a capacity of approximately 1,500,000 acre-feet with the construction of a main dam only. For a larger reservoir an auxiliary dam would be required.

Due to the fact that the Baird site is located on Pit River, it is not in a position to control as much run-off as the Kennett site and a larger reservoir would be necessary to meet the requirements under the State Water Plan. A study shows that a reservoir at this site should have a capacity of 3,175,000 acre-feet to meet the requirements of a complete initial development in the Sacramento River Basin, as these requirements are given in Chapter XI. Such a reservoir would require a main dam 420 feet high and an auxiliary dam 90 feet high. A reservoir at this site with a capacity approximately equal to that of the ultimate capacity of the Kennett reservoir would require a main dam 520 feet high and an auxiliary dam 190 feet high.

A geological investigation of this site indicates that the foundation conditions at the main dam site are favorable but that those at the auxiliary dam site are not so favorable. The site has not been explored by core drilling or other means but it is estimated that in order to secure a suitable foundation for a concrete dam on the auxiliary site, perhaps as much as 100 feet of material would have to be excavated. In support of this estimate a highway cut crossing the site shows decomposed material to a depth of about 50 feet. With this depth of excavation the auxilary dam would have heights of from 190 to 290 feet. The advisability of constructing dams of these heights along the crest of a ridge is open to serious question.

A combination of a reservoir at the Baird site with one in the lower canyon of the Sacramento River near Red Bluff might be more attractive than the Kennett reservoir if it were definitely proven that safe dams could be constructed at the Baird and Table Mountain or Iron Canyon sites. The uncertainty of constructing a safe dam at the Baird site to a height that would create a reservoir of capacity adequate to meet immediate and ultimate water requirements in accord with the State Water Plan in the Sacramento River Basin, the infeasibility of coordinating the two developments because of overlapping of the two sites, the fact that the Iron Canyon and Table Mountain sites have been rejected by geologists and the Engineering Advisory Committee, and the fact that foundations at the Kennett dam site have been proved to be most satisfactory for the construction of a masonry dam to heights proposed, lead definitely to the conclusion that the Baird reservoir on the Pit River should not be considered as an alternate for the Kennett reservoir.

Oroville Reservoir on Feather River.

A major reservoir unit of the State Water Plan is required on the Feather River to regulate water for the irrigation of the Sacramento Valley lands in the Feather River water service area described in Chapter V. Also, since the Feather River above Oroville has the second largest run-off of any stream entering the Sacramento Valley, and more than is required for its own service area, the major reservoir unit will be required to regulate the run-off of the stream not only for use in its own service area but also to aid in supplying water for irrigation to areas in the Sacramento Valley having no local supplies or insufficient supplies of their own for full development, for irrigation and salinity control in the Sacramento-San Joaquin Delta, and for supplemental supplies for irrigation and industrial uses in the San Joaquin Valley and San Francisco Bay Basin. Studies indicate that all of the water that can be economically developed in the Sacramento River Basin by the operation of the State Water Plan will ultimately be required for the full development of the Great Central Valley and that a considerable portion of the water for these ultimate uses should be derived from the reservoir on the Feather River.

Three dam sites on the Feather River between Oroville and the junction of the North and Middle forks, together with the reservoirs formed by them, were studied before selecting the site included in the State Water Plan. The lowest site is located in the northwest corner of Section 3, Township 19 North, Range 4 East, M. D. B. and M., and is the one formerly proposed for the Coordinated Plan* for the development of California's water resources. It is also the site designated as the "Lower dam site" in a former report** on a comprehensive plan for the development of the state's water resources. A 300-foot dam at this site would create a reservoir of 345,000 acre-feet capacity, but such a reservoir would require two auxiliary dams between 50 and 60 feet high, one to the north and the other to the south of the main dam. This site would have the advantage that the 300-foot dam would not flood the Las Plumas power plant of the Great Western Power Company. Its principal disadvantage would be that the reservoir capacity created by this height of dam would be too small to properly regulate the run-off of the Feather River for ultimate development and the construction of a dam high enough to create a storage capacity large enough for this purpose would be difficult, if not impossible, on account of the long, high auxiliary dams along the crests of ridges which would be required.

The dam site farthest upstream is the one referred to in the former report ** on a comprehensive plan as the "Upper dam site." It is located in Section 36, Township 20 North, Range 4 East, M. D. B. and M., about one-half mile below the junction of the North and Middle forks of Feather River. It is not the site selected for the Oroville reservoir of the State Water Plan, which is referred to in the geological report in Appendix E as the "Upper Oroville site." While

* Bulletin No. 12, "Summary Report on the Water Resources of California and a Coordinated Plan for their Development," Division of Engineering and Irrigation, 1927.

** Bulletin No. 9, "Supplemental Report on Water Resources of California," Division of Engineering and Irrigation, 1925.

much larger storage capacity could be obtained with a dam at this site than one at the lower site, there is a still better site about one and one-quarter miles downstream where a dam could be constructed to create a larger storage at a lower unit cost.

This latter site, which has been selected for the dam which would create the Oroville reservoir of the State Water Plan, is located in Sections 1 and 2, Township 19 North, Range 4 East, M. D. B. and M. The site is better geologically than the lowest site and a dam built on it could store more than five times as much water as a 300-foot dam at that site. This storage capacity would give a relatively good control of the run-off of the Feather River, which, as previously stated, is not possible with 345,000 acre-foot storage capacity at the lowest site. That a large storage capacity in the Oroville reservoir is desirable is pointed out in the discussion of the selection of the capacity of this reservoir for the State Water Plan.

The North, Middle and South forks of the river unite within the reservoir site to form the main river and water impounded in the reservoir would back up each of these branches and also up the West Branch of the North Fork.

The drainage basin tributary to the selected site has an area of about 3613 square miles which is only 14 square miles or 0.4 per cent less than the area above the United States Geological Survey gaging station at Oroville. This area is about 17 per cent of the total mountain and foothill area of the Sacramento River Basin. The drainage basin lies on the western slope of the Sierra Nevada which reach elevations within the basin in excess of 10,000 feet, the highest point being at the summit of Mount Lassen. The elevation of the stream bed at the dam site is about 200 feet. The distribution of the area above the Oroville gaging station for three ranges of elevation is shown in Table 1 in Chapter II. The watershed contains both rugged mountains and large valleys at high elevations. This condition is particularly favorable for a hydroelectric development in the mountain areas because storage reservoirs could be developed in these valleys at reasonable cost and water stored therein could be utilized through several thousand feet of power drop before entering the Oroville reservoir. Some of these reservoir sites have already been utilized for both power and irrigation developments. A large area, Sierra Valley, at the eastern edge of the drainage basin contains considerable agricultural land but has a water supply inadequate for its own needs. This area, therefore, contributes very little to the run-off of the Middle Fork on which it is located.

Water Supply.—The general methods of determining the full natural, the present net, and the ultimate net run-offs at the gaging stations have been given in Chapter II. These same methods were used in determining these run-offs at the Oroville gaging station. Since there is such a small area between the Oroville dam site and Oroville gaging station and since the run-off from this area is small, the run-off at the dam site was assumed to be the same as that at the gaging station.

Information on the run-off was obtained from the records which have been kept by the United States Geological Survey at Oroville for a period of 27 years and from records of storage and diversions which have been kept by other agencies. Precipitation data are available for a number of stations within the watershed for a longer period and were used for estimating the probable run-offs for the years prior to the period of stream flow records. Precipitation within the watershed varies from an average of seventeen inches to an average of about ninety inches per season. The lowest precipitation occurs in Sierra Valley and the highest in the headwaters of the West Branch of the North Fork near Round Valley and Philbrook reservoirs.

The records at Oroville as kept by the United States Geological Survey do not show the full natural run-offs unimpaired by upstream storage and diversions. To obtain these run-offs, the measured flows were corrected for storage in and releases from the power and irrigation reservoirs shown in Table 76, for the net use of water for irrigating from 23,000 to 37,000 acres of land, and for diversions outside of the watershed for power developments and irrigation by the Hendricks, Dewey, Miners and Upper Miocene canals from the West Branch and the Palermo and Forbestown canals from the South Fork. All of these canals are estimated to divert about 110,000 acre-feet annually.

TABLE 76

EXISTING STORAGE RESERVOIRS IN THE FEATHER RIVER WATERSHED ABOVE OROVILLE

Reservoir	Location	Capacity, in acre-feet	Use
Round Valley	West Branch	1,280	Power
Philbrook	West Branch	5,060	Power
Lake Wilenor	West Branch	8,600	Power and irrigation
Lake Almanor	North Fork	1,300,000	Power
Mountain Meadows	North Fork	36,000	Power
Butt Valley	North Fork	50,000	Power
Bucks Creek	North Fork	103,000	Power
Lost Creek	South Fork	5,200	Irrigation
Total		1,509,140	

The monthly ultimate net run-offs were obtained from the monthly full natural run-offs by deducting the ultimate net irrigation requirements within the watershed above Oroville; by deducting the ultimate gross diversions outside of the watershed for the irrigation of the area lying southeast of the watershed including the Oroville-Wyandotte Irrigation District; by deducting the ultimate gross diversions from the watershed for the development of power and for the ultimate irrigation requirements in the area lying north of Oroville and west of the watershed boundary, comprising four individual areas which can be served best by diversions from above the Oroville reservoir; and by adding or deducting respectively water released from or stored in all reservoirs now constructed, or which are necessary for complete future irrigation development.

In estimating the present net run-offs by months, the method was the same as the preceding except that present instead of ultimate uses, diversions and storage were used.

The seasonal full natural, ultimate net, and present net run-offs at the Oroville gaging station are shown in Table 77.

The wide variations in the seasonal, monthly and daily run-offs from the Feather River are shown by the following comparisons. Table 77 shows that the maximum seasonal full natural run-off in the 40-year

TABLE 77

SEASONAL RUN-OFFS OF FEATHER RIVER AT OROVILLE, 1889-1929

Season	Full natural run-off, in acre-feet	Present net run-off, in acre-feet	Ultimate net run-off, in acre-feet
1889-1890	13,278,000	11,945,000	11,474,000
1890-1891	4,158,000	4,047,000	3,827,000
1891-1892	4,842,000	4,639,000	4,344,000
1892-1893	7,535,000	7,013,000	6,714,000
1893-1894	3,589,000	3,545,000	3,305,000
1894-1895	7,093,000	6,637,000	6,327,000
1895-1896	7,786,000	7,197,000	6,886,000
1896-1897	5,440,000	5,170,000	4,919,000
1897-1898	2,304,000	2,377,000	2,207,000
1898-1899	2,872,000	2,922,000	2,713,000
1899-1900	6,788,000	6,346,000	5,948,000
1900-1901	6,281,000	5,887,000	5,601,000
1901-1902	4,561,000	4,408,000	4,148,000
1902-1903	4,543,000	4,368,000	4,105,000
1903-1904	9,439,000	8,614,000	8,313,000
1904-1905	4,594,000	4,414,000	4,175,000
1905-1906	6,855,000	6,446,000	6,101,000
1906-1907	9,492,000	9,141,000	8,830,000
1907-1908	3,639,000	3,502,000	3,279,000
1908-1909	7,517,000	7,143,000	6,840,000
1909-1910	4,638,000	4,334,000	4,109,000
1910-1911	7,121,000	6,481,000	6,132,000
1911-1912	2,244,000	2,462,000	2,311,000
1912-1913	2,823,000	2,984,000	2,796,000
1913-1914	8,110,000	7,225,000	6,851,000
1914-1915	6,067,000	5,715,000	5,426,000
1915-1916	7,006,000	6,422,000	6,146,000
1916-1917	5,075,000	4,828,000	4,537,000
1917-1918	2,745,000	2,800,000	2,625,000
1918-1919	3,649,000	3,570,000	3,337,000
1919-1920	2,203,000	2,319,000	2,139,000
1920-1921	6,038,000	5,137,000	4,780,000
1921-1922	5,076,000	4,726,000	4,419,000
1922-1923	3,070,000	2,846,000	2,626,000
1923-1924	1,296,000	1,737,000	1,642,000
1924-1925	3,152,000	2,846,000	2,611,000
1925-1926	3,174,000	2,896,000	2,714,000
1926-1927	5,848,000	5,283,000	4,957,000
1927-1928	4,246,000	4,001,000	3,764,000
1928-1929	1,838,000	2,043,000	1,902,000
40-year means, 1889-1929	5,201,000	4,910,000	4,647,000
20-year means, 1909-1929	4,271,000	4,033,000	3,791,000
10-year means, 1919-1929	3,594,000	3,383,000	3,155,000
5-year means, 1924-1929	3,652,000	3,414,000	3,190,000

TABLE 78

AVERAGE MONTHLY DISTRIBUTION OF RUN-OFF OF FEATHER RIVER AT OROVILLE

Month	Average full natural run-off	
	In acre-feet	In per cent of mean seasonal
January	477,000	9 17
February	628,000	12 07
March	828,000	15.92
April	1,001,000	19 25
May	848,000	16 30
June	423,000	8 13
July	173,000	3 33
August	108,000	2 08
September	89,000	1 71
October	116,000	2 23
November	226,000	4 35
December	284,000	5 46
Totals	5,201,000	100 00

period 1889–1929 was 13,278,000 acre-feet in 1889–1890, and the minimum was 1,296,000 acre-feet in 1923–1924, a variation of from 255 per cent to 25 per cent of the mean seasonal full natural run-off for the period. The average monthly distribution of the run-off as determined from the monthly full natural run-offs at Oroville during the same 40-year period is shown in Table 78. The variation in mean daily flows is indicated by the maximum discharges of 187,000 second-feet which occurred on March 19, 1907, and 143,000 second-feet with a peak of 211,000 second-feet on March 26, 1928; and a minimum discharge of 720 second-feet on June 30, 1924.

Reservoir Site.—The lands that would have to be acquired for the Oroville reservoir are mostly steep, rough and mountainous and of very little agricultural value. The assessed values over the entire area are low, ranging from $1.50 to $25 per acre, the greater part being assessed at $2 to $4 per acre.

There are three small settlements within the area, namely, Bidwell Bar, Las Plumas, and Enterprise. An allowance was made in making the cost estimates to take care of the flooding of these improvements. The other improvements that would be affected by the construction of the reservoir are the Western Pacific, Hutchinson Lumber Company and Swain Lumber Company railroads, the Las Plumas power plant, the State Feather River highway, the Palermo Ditch of the Oroville-Wyandotte Irrigation District, the Oroville-Quincy county road and several miles of wood pole power line and telegraph and telephone lines. The flooding of the Las Plumas power plant would require its reconstruction at an elevation high enough to clear the highest flow line for the reservoir and the compensation of the power company for the loss in electric energy caused by the decrease in head on the plant.

Several routes for the relocation of the Western Pacific railroad were studied and one of these was selected as the best and was surveyed. The relocated line would cross the Feather River about a half mile above Oroville and run northerly and easterly near the towns of Pentz and Cherokee joining the present main line at a point near the diversion dam of the Great Western Power Company near the upper end of Big Bend. This line would be 20.3 miles in length and would require sixteen miles of open track, 18,850 lineal feet of tunnel and four bridges aggregating 3590 feet in length. The relocation of the Hutchinson Lumber Company railroad would require 17 miles of new line including a bridge 690 feet in length. The relocation of the Swain Lumber Company railroad would require 10 miles of new line and rebuilding the mill at a new location.

The Feather River highway now under construction, along the west side of the main river and North Fork, would be flooded from the dam site to near Las Plumas power plant. An estimate of the cost of removing this highway to a higher elevation was furnished by the State Division of Highways. The Oroville-Quincy road, which now crosses the South Fork at Bidwell Bar, would be flooded for such a distance that it would have to be relocated from a point on the present county road west of Enterprise to a point near the settlement of Moseley. This would require 24.5 miles of relocation and the construction of 600 feet of highway bridge across the South Fork.

The Palermo Ditch would have to be reconstructed from a new diversion on the South Fork at a point about 6 miles east of the town of Enterprise to the location of the Oroville dam, a distance of 17.5 miles. At the dam the water would be dropped back into the present canal.

Relocation of power lines and telegraph and telephone lines are of minor importance, requiring 5 miles of new power line construction and 20 miles of telegraph and telephone line.

A topographic survey of the Oroville reservoir site to elevation 700 feet Western Pacific Railroad datum was made by the State in 1925, and a map was drawn from this survey at a scale of one inch equals 1000 feet, with a contour interval of 25 feet. The water surface areas measured from this map and the capacities of the reservoir computed from them are shown in Table 79. Areas and capacities for elevations from 700 to 800 feet, shown in the table, were estimated from a map of the Feather River Canyon made by the United States Geological Survey and from extensions of the area and capacity curves drawn with the use of the data computed from the State map.

TABLE 79

AREAS AND CAPACITIES OF OROVILLE RESERVOIR

Height of dam, in feet (5-foot freeboard)	[1]Water surface elevation in reservoir, in feet	Area of water surface, in acres	Capacity of reservoir, in acre-feet
125	320	440	17,000
150	345	590	29,000
175	370	790	46,000
200	395	1,010	69,000
225	420	1,270	97,000
250	445	1,570	131,000
275	470	1,900	174,000
300	495	2,280	227,000
325	520	2,660	289,000
350	545	3,110	360,000
375	570	3,630	445,000
400	595	4,150	544,000
425	620	4,740	652,000
450	645	5,420	779,000
475	670	6,090	923,000
500	695	6,730	1,084,000
525	720	7,380	1,258,000
550	745	8,000	1,450,000
575	770	8,660	1,664,000
580	775	8,800	1,705,000
600	795	9,310	1,888,000
605	800	9,440	1,933,000

[1] Western Pacific Railroad datum.

Dam and Power Plant.—A survey of the dam site was made by the State in 1928. A topographic map drawn from this survey at a scale of one inch equals 200 feet, with a contour interval of 25 feet, was used in laying out and estimating the cost of the Oroville dam. A geological investigation of the dam site was made and the report covering it will be found in Appendix E. No explorations of this site by borings or tunnels have been made. The stream at the dam site has cut a deep stream bed through the massive amphibolite which is exposed in the channel and for a considerable height above the low water surface on each side. This rock lies in bands but the joints are close and, according to the geologist, it is unlikely that they would cause uplift on the base of the dam or allow leakage under it. They would probably be easily sealed with a small amount of grouting. Above the exposed rock in the stream bed the surface is covered by a top soil and disintegrated rock. There are, however, rock outcrops indicating the character of the underlying foundation material. This depth of soil covering probably increases at the higher elevations and a liberal allowance was made in the estimates for the excavation of this material.

PLATE XXVII

Oroville Dam Site on Feather River

The only type of dam considered for this site is the gravity concrete dam. Gravel for use in the construction of such a dam could be obtained in the vicinity of Oroville about nine miles downstream and could be hauled to the site over the present track of the Western Pacific railroad.

Estimates of cost were made for the Oroville dam and reservoir for four heights of dam ranging from 455 to 605 feet. The detailed estimate and layout for only one of these heights, 580 feet, are given in this report. The features for this dam are typical of those for other heights and are described herein for illustration. The layout for this dam is shown on Plate XXVIII, "Oroville Reservoir on Feather River."

The dam would be slightly arched in plan to fit the topography of the site. All overlying soil and decomposed rock would be excavated so that the dam would rest on a good clean rock foundation. There would be a cut-off wall at the upstream toe, beneath which the rock would be sealed by grouting. The foundation would be drained by a row of drainage wells, just downstream from the upper cut-off wall, which would be connected to a gallery in the dam.

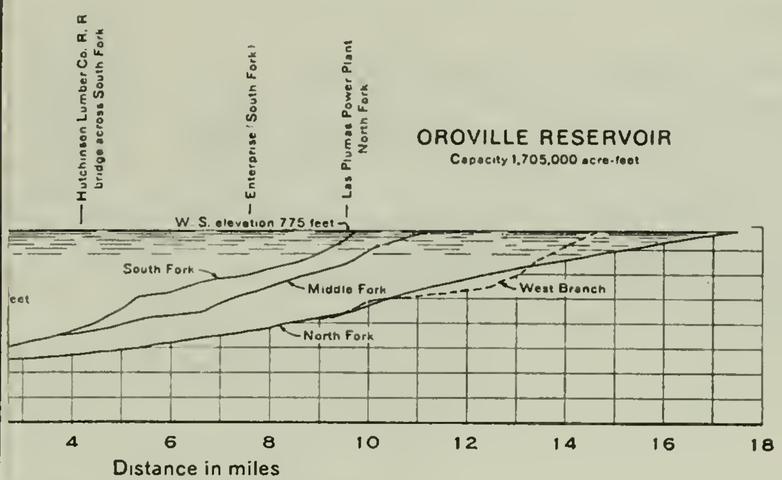
The stream flow would be diverted during the excavation for the foundation and the construction of the lower portion of the dam by means of rock-fill coffer dams with earth blankets placed above and below the excavation. The water would be conveyed around the excavation by a concrete lined horseshoe shaped tunnel which would have a capacity of 5000 second-feet. This tunnel would be plugged and backfilled after the completion of the dam.

The spillway would be located in the main section of the dam near its right end. It would be of the gravity concrete overflow type designed for a depth of 20 feet of water over its crest and would have a discharging capacity of 200,000 second-feet. The flow over the spillway would be controlled by twelve 50-foot hydraulically operated steel segmental drum gates set in the crest. These gates would be separated by concrete piers 10 feet in width and 25 feet high in which the operating mechanism for the gates would be located. It is believed that the character of the rock at the dam site is such that no protection from flowing water would be required and therefore no channel would be provided to carry the water from the spillway to the stream channel.

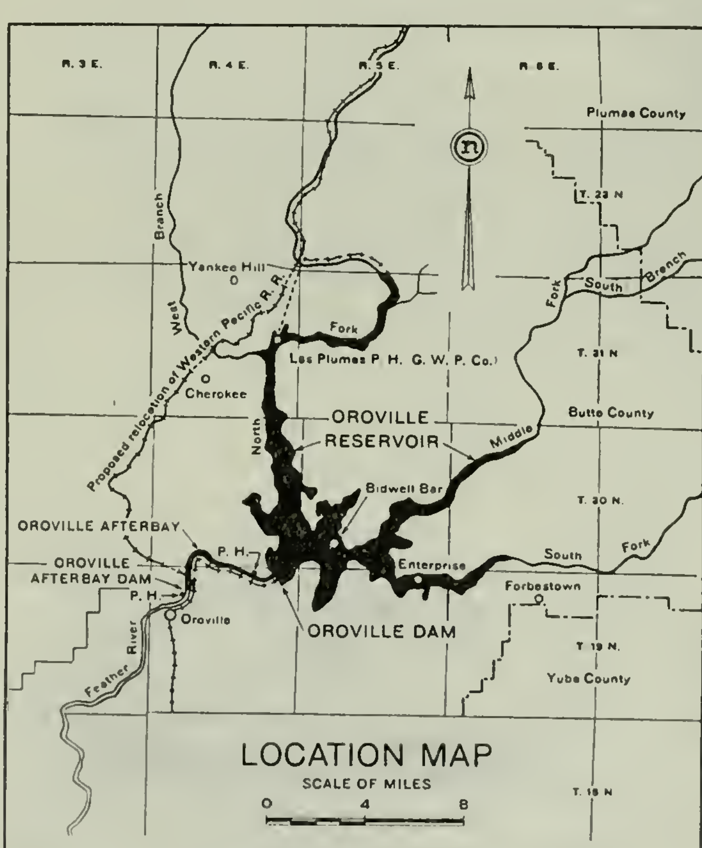
Twenty outlets would be provided in the dam near its left end for the control of floods. They would have a capacity of 100,000 second-feet with the water in the reservoir drawn down a sufficient depth to give the reserve space required for controlling floods to this amount. The outlets would be 14 feet square, would be spaced 30 feet center to center, and would be located at a distance of 90 feet below the top of the dam. Flow through each outlet would be controlled by a caterpillar type self-closing sluice gate at the upstream face of the dam, which would be protected by steel trash racks set in a semicircular concrete structure and would be operated, from the top of the dam, in a concrete enclosed gate well extending to the top of the dam. No channel for the water discharged from these outlets would be provided as it could flow over the bed rock to the stream channel without damage.

Outlets also would be provided in the section of dam over the stream channel to serve as sluiceways and to release water for irrigation. There would be eight of these openings each 94 inches in diameter, lined with steel. Six of the outlets would be at a depth of 305 feet below the top of the dam and two would be at a depth of 500 feet. Flow through each opening would be controlled by a caterpillar type sluicegate, at the upstream face of the dam, which would be protected by steel trash racks set in a semicircular concrete structure and would be operated, from the top of the dam, in a gate well extending to the top of the dam. Further control on each outlet would be provided by an auxiliary slide valve, a short distance from the upstream face, operated from a chamber inside of the dam. One of the lower outlets would be provided also with a 94 inch balanced needle valve at its outlet end to give more accurate regulation of irrigation releases.

The power house would be located on the right bank of the stream about 4400 feet below the dam. Water would be conveyed to it from the reservoir by two horseshoe shaped concrete lined tunnels 18.1 feet in diameter, each of which at a point opposite the power house would divide into five steel pipe penstocks 102 inches in diameter which would carry the water to the turbines in the power house. These steel penstocks would be laid in separate concrete lined tunnels of horseshoe shape, 12.5 feet in diameter. Water would enter each of the main tunnels through a concrete gate tower over a vertical concrete lined shaft. Water would enter the tower through several openings, flow



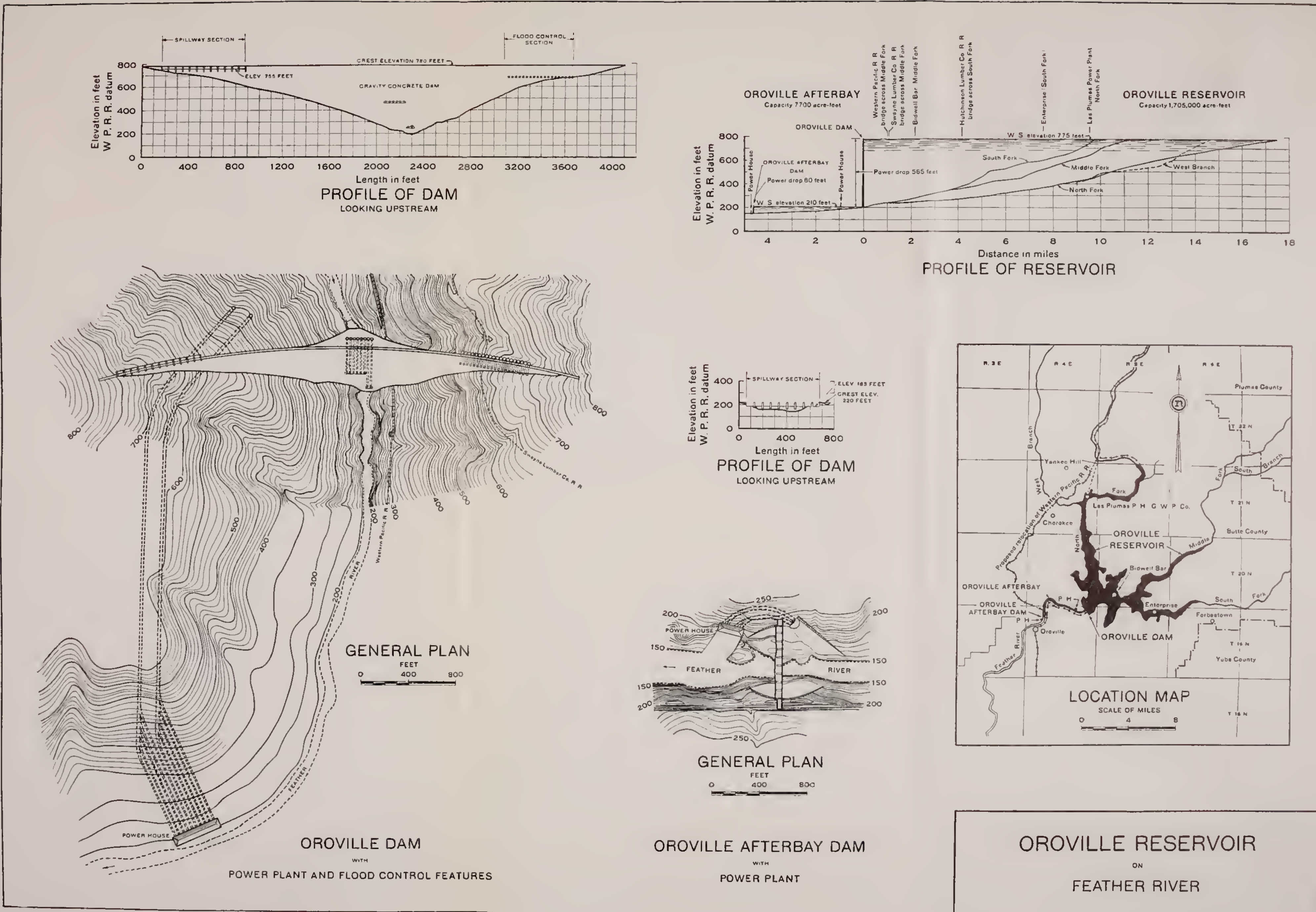
PROFILE OF RESERVOIR



OROVILLE RESERVOIR

ON

FEATHER RIVER


SPILLWAY SECTION
FLOOD CONTROL SECTION
CREST ELEVATION 780 FEET
ELEV 755 FEET
CRAVITY CONCRETE DAM
Elevation in feet W P. R. R. datum
Length in feet
PROFILE OF DAM
LOOKING UPSTREAM
OROVILLE AFTERBAY
Capacity 7700 acre-feet
OROVILLE DAM
Western Pacific R R bridge across Middle Fork
Sweyne Lumber Co R R bridge across Middle Fork
Bidwell Bar Middle Fork
Hutchinson Lumber Co R R bridge across South Fork
Enterprise South Fork
Las Plumas Power Plant North Fork
OROVILLE RESERVOIR
Capacity 1,705,000 acre-feet
W S elevation 775 feet
Power House
OROVILLE AFTERBAY DAM
Power drop 60 feet
W S elevation 210 feet
Power drop 565 feet
South Fork
Middle Fork
West Branch
North Fork
Distance in miles
PROFILE OF RESERVOIR
ELEV 183 FEET
CREST ELEV. 220 FEET
PROFILE OF DAM
LOOKING UPSTREAM
GENERAL PLAN
FEET
Western Pacific R R
RIVER
FEATHER
Sweyne Lumber Co R R
POWER HOUSE
OROVILLE DAM
WITH
POWER PLANT AND FLOOD CONTROL FEATURES
GENERAL PLAN
FEET
POWER HOUSE
FEATHER
RIVER
OROVILLE AFTERBAY DAM
WITH
POWER PLANT
Plumas County
Yankee Hill
West Branch
Proposed relocation of Western Pacific R R
Cherokee
Las Plumas P H G W P Co.
North Fork
OROVILLE RESERVOIR
Middle
Bidwell Bar
Butte County
OROVILLE AFTERBAY
OROVILLE AFTERBAY DAM
P H
Oroville
Feather River
Enterprise
South Fork
Forbestown
OROVILLE DAM
Yuba County
LOCATION MAP
SCALE OF MILES
OROVILLE RESERVOIR
ON
FEATHER RIVER

through each of which would be controlled by a caterpillar type sluicegate operated from the top of the tower. Each gate would be protected by steel trash racks and would be operated in a concrete enclosed gate well.

Studies made to estimate the economic installation of generating equipment for this power plant indicate that with a load factor of 0.75 and a power factor of 0.80 the total installed generator capacity should be 280,000 kilovolt amperes. This would be divided equally among ten generators, each of which would be direct connected to a vertical shaft variable head reaction turbine. The power house would be of steel and concrete construction. Transformers and protective equipment would be of the outdoor type.

Yields of Reservoir in Water for Irrigation and in Hydroelectric Energy—Reservoir Operated Primarily for Irrigation.—Studies were made to estimate the amounts of water that would have been made available annually during the 40-year period 1889–1929 at the Oroville dam site for irrigation use, with the reservoir operated primarily for supplying irrigation water, and the amounts of these yields that would have been new water. These studies were made for the four heights of dam shown in Table 82 by the method described in the fore part of this chapter. In making these studies, the entire capacity of the reservoir was utilized in the years of deficiency in supply. The total yields and the yields in new water for these four heights of dam, as shown by these studies, are given in Table 82. These yields would have been obtained with a maximum seasonal deficiency not exceeding 35 per cent, or an average for the 40-year period not exceeding two per cent.

A similar study was made for the reservoir having the 580-foot height of dam operating primarily for irrigation with incidental power during the same 40-year period 1889–1929. This study differed from the previous one in that the entire reservoir capacity was not utilized, it being assumed that the reservoir would have been operated so that the minimum head for power development would have been 50 per cent of the maximum obtainable. It was assumed also that the power plant would have had the same installed capacity as that for the reservoir operating primarily for the generation of power. With this method of operation, the annual yield in irrigation water would have been 2,480,000 acre-feet, with a maximum seasonal deficiency of 34.3 per cent and an average of two per cent for the period, of which 1,910,000 acre-feet would have been new water. The electric energy would have had a low value on account of there being some months in each year when none would have been generated. However, by a slight modification in releases so that some water would have been available for power in the months when none was released for irrigation uses, the irrigation yield would have been practically the same as with the former method of operation and the power value would have been substantially increased. The average annual electric energy output with this modified operation would have been 1,043,900,000 kilowatt hours. The value of this energy at the power plant, based on the cost of producing an equivalent amount of electric energy of the same characteristics with a steam-electric plant located in the area of consumption taking into account the cost of transmission from point of generation to load

through each of which would be controlled by a caterpillar type sluice-gate operated from the top of the tower. Each gate would be protected by steel trash racks and would be operated in a concrete enclosed gate well.

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Yields of Reservoir in Hydroelectric Energy and in Water for Irrigation—Reservoir Operated Primarily for Generation of Power.—A study also was made to estimate the amount of electric energy which would have been developed in the 40-year period 1889–1929, with the Oroville reservoir operated primarily for this purpose, and the amount of new water which would have been made available with this method of operation of the reservoir. The study was made by the method described in the fore part of this chapter and was made only for the reservoir having a 580-foot dam and a power plant of 280,000 kilovolt ampere capacity. This plant operated on a load factor of 0.75 and with a power factor of 0.80 would have produced an average annual output of 1,254,100,000 kilowatt hours. The output in the minimum year would have been 880,700,000 kilowatt hours and in the maximum year 1,455,700,000 kilowatt hours. The value of this electric energy was estimated to be $.0031 per kilowatt hour. The average annual revenue at this value would have been $3,888,000.

The reservoir, operated primarily for the generation of power, would also have made available an annual yield of 1,117,000 acre-feet of water for irrigation, distributed in accordance with the irrigation demand. This yield would have had a maximum seasonal deficiency of 9.2 per cent and an average for the 40-year period 1889–1929 of two per cent. This yield amounts to 43 per cent of that with the reservoir operated primarily for irrigation. Of this yield, 547,000 acre-feet would have been new water. This is 27 per cent of the yield in new water with the reservoir operated primarily for irrigation.

Flood Control.—Studies were made to estimate the value of the Oroville reservoir in controlling floods to specified flows at the Oroville gaging station. The method of making these studies and the curves derived for showing the probable frequency of occurrence of flood flows of certain amounts at Oroville, and the reservoir space required at this point to control floods which may be expected to occur at certain intervals of time to definite regulated flows, are set forth in Chapter VI. Although the Oroville reservoir would not be located at the gaging station, the control by it would be practically the same as if it were located at this point on account of the small drainage area which would not be controlled.

Curves on Plate VIII and data in Table 32 in Chapter VI show the probable frequency of occurrence of flood flows of certain amounts at the Oroville gaging station. The reservoir spaces required to control flows below Oroville to certain specified amounts are shown by the curves on Plate X and the data in Table 35, in the same chapter.

It is believed that the control of flows at Oroville to 100,000 second-feet, exceeded not oftener than once in 100 years on the average, would provide a sufficient degree of protection to flood control works on the Feather River if similar control were provided on the Yuba and Bear rivers. This control also would be of material aid in reducing flood flows in the lower Sacramento Valley. This control, as shown in Table 35, would require 521,000 acre-feet of storage space, which would be held in reserve in accordance with the rule given in Chapter VI. The reserve space would be held in the top portion of the reservoir and would occupy the upper 65 feet of the reservoir having a 580-foot dam.

The effect of holding this space in the reservoir for controlling floods is best illustrated by showing its effect on two of the largest floods of record. The largest flood, that of March 19, 1907, with a maximum mean daily discharge of 187,000 second-feet could have been controlled to a flow not exceeding 100,000 second-feet at any time by the use of 300,000 acre-feet of the reserve storage space. The second largest flood, that of March 26, 1928, with a mean daily discharge of 143,000 second-feet and a peak discharge of 211,000 second-feet would have required only 169,000 acre-feet of storage space for its control to 100,000 second-feet. The effect of this control on the works along the Feather River has been discussed in Chapter VI.

Cost of Reservoir and Power Plant.—Estimates of the cost of the Oroville reservoir were prepared for the four heights of dam shown in Table 82. These estimates were made as generally outlined in the fore part of this chapter and include all of the items except the power plant, which have been briefly described in the foregoing paragraphs. The costs are listed in Table 82.

A somewhat detailed estimate is given in Table 80 for the reservoir having a 580-foot dam. In this table, the items included under miscellaneous are a construction railroad and siding, a permanent camp and cleaning up after construction. The same items and similar unit prices were used in estimating the costs for reservoirs with other heights of dam.

TABLE 80

COST OF OROVILLE RESERVOIR WITH FLOOD CONTROL FEATURES

Height of dam, 580 feet. Capacity of reservoir, 1,705,000 acre-feet.
Capacity of overflow spillway, 200,000 second-feet.
Capacity of flood control outlets, 100,000 second-feet.

Exploration and core drilling		$30,000
Diversion of river during construction		185,000
Clearing reservoir site		425,000
Excavation for dam, 2,452,000 cu. yds. at $2.50 to $5	$6,583,000	
Mass concrete, 7,838,000 cu. yds. at $6.85	53,690,000	
Reinforced concrete, 8400 cu. yds. at $15.50 to $24	145,000	
Spillway gates	379,000	
Irrigation outlets and sluiceways	625,000	
Flood control features	577,000	
Drilling and grouting foundation	96,000	
		62,095,000
Lands and improvements flooded		25,208,000
Miscellaneous		100,000
Subtotal		$88,043,000
Administration and engineering, 10 per cent		8,804,000
Contingencies, 15 per cent		13,206,000
Interest during construction based on a rate of 4.5 per cent per annum		16,347,000
Total cost of dam and reservoir		$126,400,000

The estimated cost for the 280,000 kilovolt ampere power plant previously described in connection with the 580-foot dam is shown in Table 81.

TABLE 81

COST OF POWER PLANT FOR OROVILLE RESERVOIR WITH 580-FOOT DAM

Installed capacity, 280,000 kilovolt amperes.
Power factor = 0.80. Load factor = 0.75.

Intake structures	$540,000
Penstocks	5,535,000
Building and equipment	6,054,000
Subtotal	$12,129,000
Administration and engineering, 10 per cent	1,213,000
Contingencies, 15 per cent	1,819,000
Interest during construction based on a rate of 4.5 per cent per annum	1,039,000
Total cost of power plant	$16,200,000

The total estimated capital cost of the Oroville reservoir, with a 580-foot dam, and its power plant, would be $142,600,000.

The annual cost for each of the four sizes of reservoir previously referred to, without a power plant, was estimated on the bases shown in the fore part of this chapter and is given in Table 82. The annual costs of the Oroville reservoir and power plant, based on the capital costs given in Tables 80 and 81, are estimated to be $7,380,000 and $1,261,000 respectively, or a total of $8,641,000.

Comparison of Sizes of Reservoir.—The principal use of the Oroville reservoir would be for the regulation of water for irrigation and salinity control. Although the salinity control demand would vary somewhat from that for irrigation, the relative cost of regulated water from reservoirs of different capacities may be compared on the basis of the cost of irrigation yield when operated primarily for that purpose. Comparisons of reservoirs of different capacities at the Oroville site therefore were made on the bases of the cost of storage, the cost of the total seasonal irrigation yield and yield in new water, the cost of the reservoir per acre-foot increase in each of these items, and the annual cost for irrigation water for both the total yield and the yield in new water. These items are given in tabular form in Table 82 and are shown graphically on Plate XXIX, "Cost of Reservoir Capacity and Unit Yield of Water for Irrigation from Oroville Reservoir." The capital costs do not include the costs of power features and the annual costs are gross costs from which no deductions have been made for revenue from the sale of electric energy. The average annual revenue from the sale of electric energy generated at the Oroville reservoir with the 580-foot dam and the Oroville afterbay, when operated primarily for irrigation with incidental power, and the average net annual cost not covered by revenue from the sale of this electric energy, are set forth in Table 136. This table shows that the average net annual costs per acre-foot of total seasonal irrigation yield and yield in new water are considerably reduced by the revenue from the sale of electric energy.

The data in Table 82 and the curves on Plate XXIX indicate that the cost per acre-foot of yield in irrigation water from the Oroville reservoir would increase as the height of dam, or size of reservoir, is increased. They also show that for heights above 525 feet the rate of increase in these costs would become greater, while from this height down to 455 feet the unit costs would remain practically constant. This would indicate that about 525 feet is probably the most economical height to which a dam could be built. The total seasonal irrigation

TABLE 82

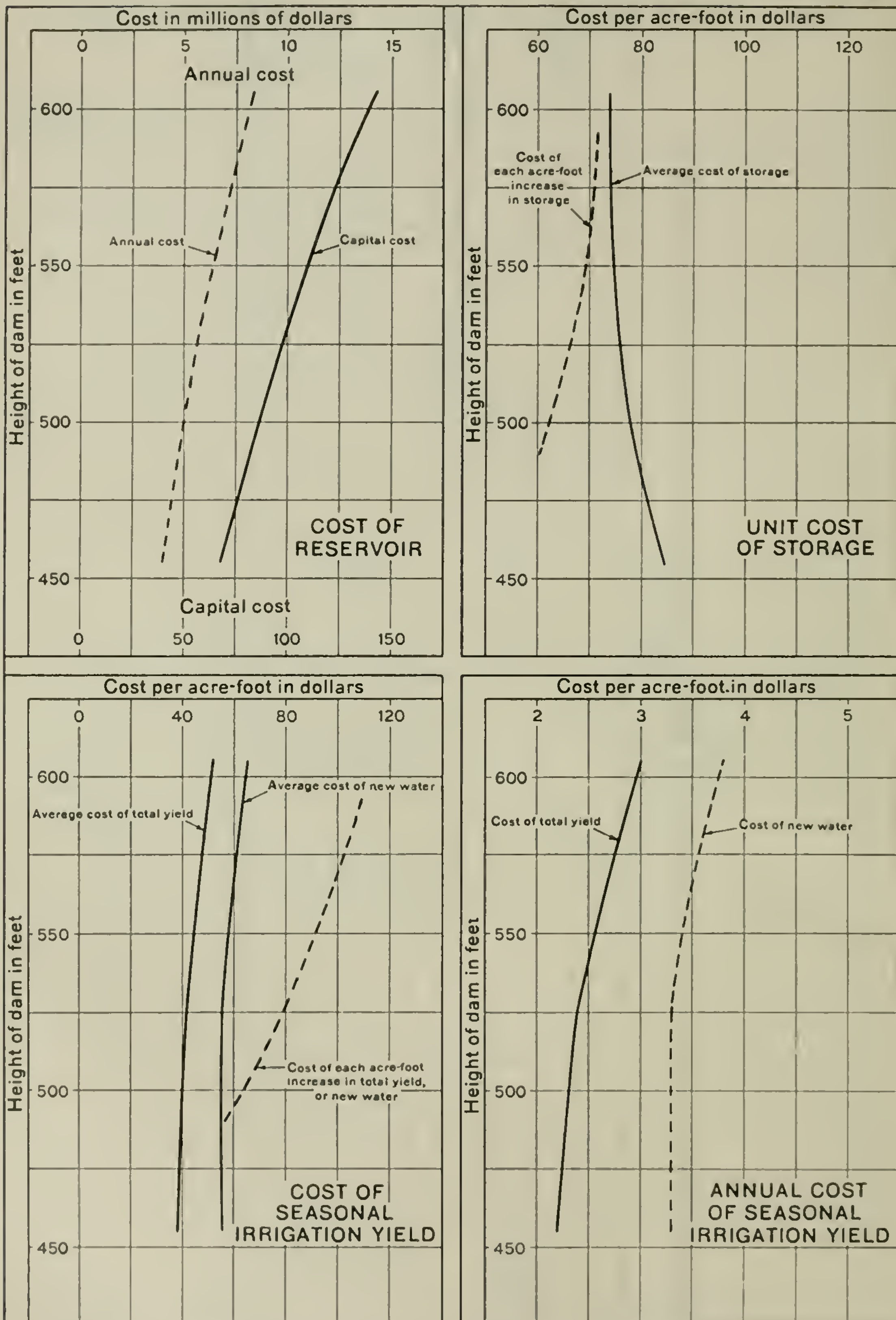
COST OF RESERVOIR CAPACITY AND UNIT YIELD OF WATER FOR IRRIGATION FROM OROVILLE RESERVOIR

With Flood Control Features and Without Power Plant

Height of dam, in feet	Elevation of water surface, in feet	Capacity of reservoir, in acre-feet	Seasonal irrigation yield[1]		Cost of reservoir		Capital cost, per acre-foot						Annual cost per acre-foot of irrigation yield	
							Total storage	Increase in storage	Irrigation yield		Increase in irrigation yield			
			Total yield, in acre-feet	New water, in acre-feet	Capital	Annual			Total yield	New water	Total yield	New water	Total yield	New water
455	650	807,000	1,791,000	1,221,000	$68,000,000	$3,990,000	$84 30		$38 00	$55 70			$2 23	$3 27
								$60 50			$56 30	$56 30		
525	720	1,258,000	2,276,000	1,706,000	95,300,000	5,574,000	75 80		41 90	55 90			2 45	3 27
								69 60			93 10	93 10		
580	775	1,705,000	2,610,000	2,040,000	126,400,000	7,380,000	74 10		48 40	62 00			2 83	3 62
								71 50			108 70	108 70		
605	800	1,933,000	2,760,000	2,190,000	142,700,000	8,322,000	73 80		51 70	65 20			3 02	3 80

[1] Entire capacity of reservoir utilized in years of deficiency in supply. Yields shown are based on run-off for the 40-year period 1889-1929. Each yield would have had a maximum seasonal deficiency not exceeding 35 per cent and an average deficiency for the 40-year period not exceeding two per cent.

PLATE XXIX



COST OF RESERVOIR CAPACITY AND UNIT YIELD OF WATER FOR IRRIGATION FROM OROVILLE RESERVOIR yield with a 525-foot dam, however, would be only 49 per cent of the mean seasonal ultimate net run-off of the Feather River at Oroville for the 40-year period 1889–1929. This yield could be increased to 56.2 per cent of the 40-year mean by increasing the height of dam to 580 feet and the increase in the annual cost of new water would be only 30 cents per acre-foot. The yield could be still further increased to 59.4 per cent of the 40-year mean by increasing the height of dam to 605 feet and the resulting increase in annual cost of new water would be only 20 cents per acre-foot. The cost of new water from reservoirs of all sizes at Oroville is relatively high as compared to the cost from other large major reservoir units in the Sacramento River Basin.

Selection of Capacity of Reservoir.—It is shown at the end of this chapter and in Chapter XI that although a reservoir could be built at the Oroville site which would yield sufficient water to meet the requirements of an initial development in the Sacramento River Basin, other units, on account of lower cost, greater accomplishments, or both, are more attractive for such a development.

The Oroville reservoir, therefore, will be considered only as one of the units for the ultimate development of the water resources of the Great Central Valley. As such a unit, it should have sufficient capacity to yield at least the amount of water required to irrigate the Feather River water service area. However, since the Feather River has the second largest run-off of any stream entering the Sacramento Valley, it also would be desirable to develop as much additional yield as possible from the Oroville reservoir to furnish an irrigation supply to areas in the Sacramento Valley having no local supply or insufficient supply from local streams, to aid in the control of salinity in the Sacramento-San Joaquin Delta and to furnish surplus water for exportation to the San Joaquin Valley and the San Francisco Bay Basin, both of which areas have insufficient local supplies for their full development.

It is shown in Table 28 in Chapter V that the gross allowance of water for the ultimate irrigation of the net irrigable area of the Feather River service area is 1,395,000 acre-feet per season. This amount could have been furnished in all years by a reservoir with a dam somewhat less than 455 feet in height, since the yield from a reservoir with this height of dam would have been 1,523,000 acre-feet in the year of maximum deficiency.

It, therefore, would be possible to develop considerable yield from the Oroville reservoir for use in supplying the other requirements listed in the second preceding paragraph by building a dam higher than 455 feet. The height selected for this dam is 580 feet. With this height of dam, the reservoir would have yielded 819,000 acre-feet per year more, with an average deficiency of two per cent in the 40-year period 1889–1929, than the reservoir with a 455-foot dam. Another increase of 25 feet in the height of dam would have increased the yield 150,000 acre-feet. The capital cost of this latter increase in yield, however, would have been $108.70 per acre-foot which is considerably higher than the average cost of yield from any other major reservoir unit in the Sacramento River Basin. It is believed that this increase in yield would not be used unless future conditions show the necessity for additional water even at high cost.

That a reservoir of at least the capacity selected is required in the ultimate development is shown by the discussion for the selection of the ultimate capacity of Kennett reservoir, as this discussion also applies to the Oroville reservoir. This discussion shows that the Oroville reservoir with the capacity selected, as well as the other major reservoir units with the capacity selected for each, would have been required for the regulation of the water required for the ultimate development of the Great Central Valley during the period 1918–1929 if deficiencies in supply had been held to endurable amounts.

Oroville Afterbay on Feather River.

With the Oroville reservoir operating for the development of hydroelectric energy, the water released through the power plant would vary throughout the day and week, unless the plant were operated on a unity load factor. In order to reregulate this fluctuating flow to a uniform one suitable for irrigation diversions, an afterbay would be required.

A study was made of the lower Feather River Canyon in connection with power development projects proposed by the Great Western Power Company and two afterbay sites below the Oroville dam site were found. One of these sites is located about a half mile above the Oroville highway bridge and the other about two miles above. Both sites were surveyed by the State in 1929 and a map was drawn from these surveys at a scale of one inch equals 400 feet, with a contour interval of 25 feet. Estimates for constructing a dam and a small power plant to develop the power from the additional head which would be created also were made for each site. These estimates indicate that the lower site is the better and it, therefore, was adopted.

The reservoir would have a storage capacity of 7700 acre-feet, only a portion of which would be required to reregulate the daily and weekly fluctuations in discharge from the Oroville power plant. Since, however, there is an opportunity to develop an additional power drop, the dam would be constructed to such a height that water would be backed up to the tail race of the plant at the Oroville dam. The construction of the dam to a greater height than is required for reregulation, for power development purposes, was shown by studies to be economically justified.

Reservoir Site.—The reservoir would be about 4.7 miles long and, since it would lie in the bottom of the canyon, would be only a few hundred feet wide. The area flooded is mostly rock stream channel. The Western Pacific railroad, which now follows the south side of the canyon, would be raised to a sufficient elevation to clear the water surface in the afterbay in making the relocation for the construction of the Oroville reservoir. There are no other improvements of any importance within the area.

Dam and Power Plant.—A survey of the dam site was made by the State in 1929. A topographic map drawn from this survey at a scale of one inch equals 200 feet, with a contour interval of five feet, was used in laying out and estimating the costs of the afterbay dam and power plant. The canyon at the dam site is wide enough to permit the construction of an overflow dam 750 feet in length, which is sufficient to pass the largest floods expected to occur in this portion of the Feather River.

PLATE XXX

Oroville Afterbay Dam Site on Feather River

The foundation conditions are excellent. Sound fresh diabase rock is exposed over the entire area which would be occupied by the dam and very little excavation would be required except for cutoff walls and to provide additional width of spillway crest and gate chamber space for the spillway gates.

The dam would be of the gravity concrete overflow type except at each abutment where there would be a short length of nonoverflow gravity section. The foundation would be sealed by grouting and drainage wells would be provided near the upstream face.

The stream flow would be diverted during construction through the tunnels which would afterward be used for conducting water to the power house.

The spillway section would be 600 feet in length with the crest at elevation 183 feet. The flow over the spillway would be controlled by hydraulically operated steel segmental drum gates 27 feet deep set in the crest. These gates would hold the water level above the dam at elevation 210, the tail race elevation of the Oroville reservoir power plant, when the afterbay is full.

The layout for this dam and power plant and their relation to the Oroville dam and power plant are shown on Plate XXVIII.

The power house would be located on the left bank of the river at a point 400 feet below the dam. It would be at the river's edge and founded on bedrock. Water would be conducted to it through two tunnels excavated under the right abutment of the dam. These tunnels would have horseshoe shaped sections 20.6 feet in diameter and would be concrete lined. Each tunnel would divide, a short distance from the power plant, into two steel penstocks 180 inches in diameter which would convey the water to the turbines in the power house. Water would enter the tunnels through a concrete inlet structure equipped with self-closing caterpillar type sluice gates protected by steel trash racks. The power house would be of steel and concrete construction and would house the four 8500 kilovolt ampere generators which would be direct connected to low head vertical shaft reaction turbines. In order to release water for irrigation at a uniform rate, the plant would be operated on a unity load factor.

Power Output.—The only yield of this afterbay would be in power output from the reregulated water. The seasonal and monthly variations of this power would be dependent upon the Oroville reservoir releases since water from this afterbay would be used for the generation of power without holdover storage of more than one or two days.

With the Oroville reservoir, 580-foot dam, operated primarily for the generation of power, the afterbay power plant would have produced an average annual electric energy output during the 40-year period 1889–1929, of 155,000,000 kilowatt hours. The value of this energy was estimated to be $.0031 per kilowatt hour, the same as that for the Oroville power plant under the foregoing described method of operation. At this rate the average annual revenue from the electric energy from the afterbay plant would have been $481,000.

With the Oroville reservoir operated primarily for irrigation yield, the afterbay power plant would have produced an average annual electric energy output during the same 40-year period, of 128,300,000 kilowatt hours. The value of this energy also was estimated to be the same as that from the Oroville power plant under this method of operation or $.00225 per kilowatt hour. At this rate the average annual return from the electric energy from the afterbay plant would have been $288,000.

Cost of Reservoir and Power Plant.—The costs of the Oroville afterbay and power plant were estimated by the methods generally outlined in the fore part of this chapter and are shown in Table 83.

TABLE 83

COST OF OROVILLE AFTERBAY AND POWER PLANT

Height of dam, 69 feet. Installed capacity of power plant, 34,000 kilovolt amperes. Power factor = 0.80. Load factor = 1.00.

Dam and Reservoir

Exploration and core drilling		$10,000
Diversion of river during construction		150,000
Clearing reservoir		18,000
Excavation for dam, 109,000 cu. yds. at $2.50 to $5	$331,000	
Mass concrete, 51,600 cu. yds. at $6.85	353,000	
Reinforced concrete, 5000 cu. yds. at $15.50 to $24	85,000	
Spillway gates	519,000	
Drilling and grouting foundation	16,000	
		$1,304,000
Lands and improvements flooded		15,000
Permanent camp, siding, and clean-up after construction		50,000
Subtotal		$1,547,000
Administration and engineering, 10 per cent		155,000
Contingencies, 15 per cent		232,000
Interest during construction based on a rate of 4.5 per cent per annum		66,000
Total cost of dam and reservoir		$2,000,000

TABLE 83—Continued

Power Plant

Intake structure	$183,000
Penstocks	363,000
Building and equipment	1,852,000
Subtotal	$2,398,000
Administration and engineering, 10 per cent	240,000
Contingencies, 15 per cent	360,000
Interest during construction based on a rate of 4.5 per cent per annum	102,000
Total cost of power plant	$3,100,000
Total cost of dam, reservoir and power plant	$5,100,000

The annual cost of the Oroville afterbay and power plant computed on the bases outlined in the fore part of this chapter would be $360,000. Of this, the annual cost for the dam and reservoir would be $122,000 and for the power plant $238,000.

Oroville Reservoir Unit.

The Oroville reservoir unit would comprise the Oroville reservoir and power plant and the Oroville afterbay and power plant.

The capital cost of the unit with a 580-foot dam for the Oroville reservoir would be:

Oroville reservoir	$126,400,000
Oroville power plant	16,200,000
Oroville afterbay	2,000,000
Oroville afterbay power plant	3,100,000
Total	$147,700,000

The annual cost of the unit with the same height of dam for the Oroville reservoir would be:

Oroville reservoir	$7,380,000
Oroville power plant	1,261,000
Oroville afterbay	122,000
Oroville afterbay power plant	238,000
Total	$9,001,000

Narrows Reservoir on Yuba River.

A major reservoir unit on the Yuba River, located near the edge of the Sacramento Valley floor, is required in the State Water Plan for the irrigation of the lands in the Yuba River water service area described in Chapter V. These lands, it is believed, can be more economically watered from this source than from any other. Also, since the river has a much greater run-off than is required for this purpose alone, and since studies that have been made indicate that all of the water which can be economically developed in the Sacramento River Basin by the operation of the State Water Plan will ultimately be required for the full development of the Great Central Valley, the major reservoir unit on the Yuba River also will be required to regulate water surplus to the local irrigation needs and make it available for supplies for other uses. The surplus water so regulated could be used for irrigation supplies for lands in the Sacramento Valley having no local supplies or insufficient supplies of their own for full development, for irrigation and salinity control in the Sacramento-San Joaquin Delta and for exportation to the San Joaquin Valley and San Francisco Bay Basin to supplement local supplies in these areas for irrigation and industrial uses.

There are two possible sites for a dam in the lower canyon of the Yuba River. One site is at "The Narrows" at the location of the United States Geological Survey gaging station and is the site formerly selected* for the reservoir to develop the water resources of the Yuba River, and the other is about three-quarters of a mile upstream from the mouth of Deer Creek and about 1¾ miles above the lower site at The Narrows.

Geological examinations were made of both sites and each is reported by the geologist to be suitable for the construction of a high dam. At the site at The Narrows, the stream bed is filled with gravel to a depth of 60 to 70 feet which would add greatly to the cost of construction of a dam at that point. At the site above Deer Creek, there is probably very little if any gravel in the stream bed and, in addition, the canyon is narrower at an elevation of 600 feet above the stream bed than at the lower site. Comparison was made of the cost of a dam at each site which would create the same reservoir capacity, and the one at the upper site was found to be the cheaper. Construction conditions being more favorable at the upper site and the geologic conditions just as good as at the lower, it was chosen as the site for the dam for the major reservoir unit of the State Water Plan on the Yuba River. While the dam site chosen is not in The Narrows, the reservoir created by it contains a large part of the area which would be flooded by a dam at The Narrows site, and the name Narrows is therefore used for both the dam and reservoir at this upper site.

TABLE 84

DISTRIBUTION OF AREAS BY RANGE OF ELEVATION IN YUBA RIVER DRAINAGE BASIN ABOVE NARROWS DAM SITE

Elevations above sea level	Drainage area	
	In square miles	In per cent of total drainage area
Below 2,500 feet	515	46
Between 2,500 and 5,000 feet	432	39
Above 5,000 feet	161	15
Totals	1,108	100

The area of the drainage basin tributary to the selected site is about 1108 square miles which is 92 per cent of the total area tributary to the gaging station at The Narrows and five per cent of the total mountain and foothill area of the Sacramento River Basin. The area between the gaging station and the reservoir site lies principally

* Bulletin No. 9, "Supplemental Report on Water Resources of California," Division of Engineering and Irrigation, 1925.

Bulletin No. 12, "Summary Report on the Water Resources of California and a Coordinated Plan for Their Development," Division of Engineering and Irrigation, 1927.

in the Deer Creek drainage basin. The main river is formed by three main forks, the North, Middle and South, which unite above the dam site. These rise in the high Sierra Nevada at elevations as high as 8000 feet. Elevations within the watershed vary from 290 feet at the dam site to a maximum of about 9100 feet at the crest of the mountains. The distribution of this area for three ranges of elevation is given in Table 84. Most of the area within the watershed is rough mountainous land. However, there are some lands, particularly on San Juan Ridge between the Middle and South forks, which are classified as agricultural and are partially irrigable.

Water Supply.—The full natural and net run-offs were estimated at both the United States Geological Survey gaging station and the Narrows dam site. The general methods used in making these estimates are the same as described in Chapter II, in which chapter the seasonal full natural run-offs are tabulated for the gaging station.

The stream discharge records which were obtained by the United States Geological Survey at the gaging station in The Narrows for the 26-year period 1903–1929, and records of diversion and storage obtained by other agencies were used in estimating the full natural run-offs. Estimates of run-off for the period prior to stream flow record were made from precipitation data which are available for a number of stations in the watershed, some of which have long records. Rainfall within the watershed varies from an average of 35 inches in one portion to an average of 80 inches per season in another.

The monthly full natural run-offs at the gaging station for the period of record were obtained from the measured flows by adding the estimated net use of water for irrigation on the San Juan Ridge, in the areas near Sierra City and Goodyear Bar and in what is now the Nevada Irrigation District; by adding the monthly diversions from the watershed by the Drum and Brown's Valley Irrigation District canals; by adding the diversions to the Boardman Canal, and the losses from the South Yuba Canal; and by adding water stored in and subtracting water released from the Bullards Bar, Spaulding and other Pacific Gas and Electric Company reservoirs on the South Fork, and the Bowman and French reservoirs of the Nevada Irrigation District.

The monthly ultimate net run-offs at the gaging station were obtained from the monthly full natural run-offs by deducting the ultimate net irrigation needs in the watershed above the gaging station; by deducting the gross diversions to serve the ultimate irrigation requirements in the Bear River and Dry Creek watershed areas which would be served by Yuba River water; by deducting the diversions through the Drum Canal; and by deducting water stored in and adding water released from reservoirs now in use for both irrigation and power development and those which would be necessary for complete future irrigation development in the basin above the gaging station.

The monthly present net run-offs were estimated in the same way as the ultimate except that present instead of ultimate uses were used.

The estimated full natural and ultimate and present net run-offs at the dam site were obtained from the same estimated run-offs at the gaging station by subtracting from the latter the estimated full natural and ultimate and present net run-offs, respectively, of the total Deer Creek drainage area.

The seasonal full natural, ultimate net, and present net run-offs at the dam site are shown in Table 85.

TABLE 85

SEASONAL RUN-OFFS OF YUBA RIVER AT NARROWS DAM SITE, 1889-1929

Season	Full natural run-off, in acre-feet	Present net run-off, in acre-feet	Ultimate net run-off, in acre-feet
1889-1890	6,657,000	6,340,000	6,132,000
1890-1891	1,917,000	1,608,000	1,400,000
1891-1892	1,671,000	1,354,000	1,146,000
1892-1893	3,306,000	2,970,000	2,762,000
1893-1894	2,270,000	1,968,000	1,760,000
1894-1895	3,747,000	3,411,000	3,203,000
1895-1896	2,480,000	2,166,000	1,957,000
1896-1897	3,204,000	2,897,000	2,689,000
1897-1898	1,271,000	968,000	760,000
1898-1899	2,062,000	1,742,000	1,534,000
1899-1900	2,954,000	2,629,000	2,421,000
1900-1901	2,686,000	2,370,000	2,162,000
1901-1902	2,602,000	2,290,000	2,082,000
1902-1903	2,347,000	2,028,000	1,820,000
1903-1904	4,038,000	3,713,000	3,505,000
1904-1905	2,386,000	2,080,000	1,872,000
1905-1906	3,570,000	3,234,000	3,026,000
1906-1907	4,366,000	4,052,000	3,844,000
1907-1908	1,624,000	1,327,000	1,119,000
1908-1909	3,847,000	3,516,000	3,308,000
1909-1910	2,669,000	2,370,000	2,161,000
1910-1911	3,472,000	3,135,000	2,926,000
1911-1912	1,169,000	872,000	663,000
1912-1913	1,445,000	1,125,000	918,000
1913-1914	2,945,000	2,618,000	2,410,000
1914-1915	2,584,000	2,271,000	2,063,000
1915-1916	3,158,000	2,833,000	2,625,000
1916-1917	2,433,000	2,125,000	1,917,000
1917-1918	1,308,000	1,000,000	791,000
1918-1919	1,893,000	1,583,000	1,375,000
1919-1920	1,259,000	934,000	730,000
1920-1921	3,040,000	2,715,000	2,506,000
1921-1922	2,861,000	2,539,000	2,331,000
1922-1923	1,974,000	1,660,000	1,452,000
1923-1924	586,000	481,000	263,000
1924-1925	2,050,000	1,665,000	1,456,000
1925-1926	1,541,000	1,234,000	1,026,000
1926-1927	3,415,000	3,074,000	2,866,000
1927-1928	2,354,000	2,064,000	1,855,000
1928-1929	974,000	631,000	440,000
40-year means, 1889-1929	2,553,000	2,240,000	2,032,000
20-year means, 1909-1929	2,157,000	1,846,000	1,639,000
10-year means, 1919-1929	2,005,000	1,700,000	1,492,000
5-year means, 1924-1929	2,067,000	1,734,000	1,529,000

The wide variations in the seasonal, monthly and daily run-offs from the Yuba River are shown by the following comparisons. Table 85 shows that the maximum seasonal full natural run-off in the 40-year period 1889–1929 was 6,657,000 acre-feet in 1889–1890 and the minimum was 586,000 acre-feet in 1923–1924, a variation of from 261 per cent to 23 per cent of the mean seasonal full natural run-off for the period. The average monthly distribution of the run-off as determined from the estimated monthly full natural run-offs at the Narrows dam site during the same 40-year period, is shown in Table 86. The variation in the mean daily flows is indicated by the maximum discharges of 111,000 second-feet on January 15, 1909, and 100,000 second-feet on March 19, 1907, and a minimum discharge of 71 second-feet on July 30, 1924.

TABLE 86

AVERAGE MONTHLY DISTRIBUTION OF RUN-OFF OF YUBA RIVER AT NARROWS DAM SITE

Month	Average full natural run-off	
	In acre-feet	In per cent of mean seasonal
January	268,000	10.50
February	310,000	12.14
March	392,600	15.38
April	447,000	17.51
May	477,200	18.69
June	267,600	10.48
July	73,200	2.87
August	25,400	0.99
September	23,200	0.91
October	34,800	1.36
November	90,300	3.54
December	143,700	5.63
Totals	2,553,000	100.00

Reservoir Site.—The lands which would have to be acquired for the Narrows reservoir are mostly steep and rough and lie in the bottom and along the sides of the canyons of the main Yuba River and the Middle and South forks. There are small tracts of agricultural land and a few buildings in this site, principal among which is the small settlement at Bridgeport. The remainder of the lands are suitable only for grazing and are not particularly good for this purpose.

The principal improvement that would be affected by the construction of the reservoir is the Colgate power plant of the Pacific Gas and Electric Company, located on the Middle Fork near the upper end of the reservoir. A dam built to the proposed height of 580 feet would flood the present plant to a depth of 330 feet. It therefore would be necessary to reconstruct the power house at an elevation above the highest water level in the reservoir and an allowance was made in the cost estimates for constructing a modern plant of 7000 kilovolt ampere capacity, using the penstocks and flume which now carry water to the plant. An allowance also was made for compensation to the power company for the loss in energy on account of the decreased head on this plant. Credit was taken, however, for the estimated cost of modernizing the present plant to make it comparable with the proposed new plant. The only other improvement which would be affected is a short length of wood pole power transmission line which would have to be moved.

No survey of the Narrows reservoir site was made during this investigation but the United States Geological Survey made a topographic map of the site and vicinity in 1909. This map is published as the Parks Bar sheet and has a scale of two inches equals one mile and contour interval of 25 feet. It is believed to be of sufficient scale and accuracy for estimating reservoir capacities and was used for estimating those of the Narrows reservoir site. The areas measured from this map and the computed capacities of the reservoir are given in Table 87.

TABLE 87

AREAS AND CAPACITIES OF NARROWS RESERVOIR

Height of dam, in feet (5-foot freeboard)	Water surface elevation of reservoir, in feet[1]	Area of water surface, in acres	Capacity of reservoir, in acre-feet
0	290	0	0
50	335	100	2,300
75	360	150	5,200
100	385	200	9,700
125	410	290	16,000
150	435	400	24,800
175	460	490	35,900
200	485	580	49,200
225	510	680	64,900
250	535	830	84,100
275	560	1,000	107,000
300	585	1,210	134,500
325	610	1,430	167,500
350	635	1,630	205,900
375	660	1,850	249,400
400	685	2,060	298,100
425	710	2,300	352,600
450	735	2,600	414,200
475	760	2,870	482,500
500	785	3,120	557,200
525	810	3,460	639,400
550	835	3,830	731,000
575	860	4,220	831,500
580	865	4,290	853,000

[1] United States Geological Survey datum.

Selection of Capacity of Reservoir.—An analysis of the operation and yields of the Narrows reservoir shows that any reservoir at this site with a reasonable height of dam would be unable to meet salinity control requirements in a year like 1924 with the existing irrigation and storage developments in the Sacramento River and San Joaquin River basins. If perfect salinity control would not be required, then the Narrows reservoir would be capable of meeting the situation. Although salinity control is one of the principal requirements of an initial unit in the Sacramento River Basin, the unit also should be capable of improving irrigation conditions in the Sacramento Valley and Sacramento-San Joaquin Delta and furnishing a supplemental water supply to the San Joaquin Valley and the industrial area along the south shore of Suisun Bay in Contra Costa County. Since the Narrows reservoir could not even accomplish perfect salinity control it is apparent that it could not accomplish these other desirable features in addition. It also is shown near the end of this chapter that a regulated water supply could be obtained more cheaply from other major reservoir units in the Sacramento River Basin than from the Narrows reservoir. This reservoir, therefore, has not been considered for an initial development. It, however, would be one of the important major units for the ultimate development of the water resources of the entire Great Central Valley.

As a unit in the ultimate development, the reservoir should have sufficient capacity to yield at least the amount of water required for the supply for the Yuba River water service area, which is given in Chapter V as 465,000 acre-feet per season. Since, however, the mean seasonal ultimate net run-off of the Yuba River at the Narrows dam site would have been over 2,000,000 acre-feet for the 40-year period 1889–1929, and about 1,500,000 acre-feet for the ten-year dry period 1919–1929, the greatest possible yield in excess of that necessary for the

Yuba River service area should be developed for other requirements in the ultimate development of the Great Central Valley. These requirements are irrigation supplies for areas in the Sacramento Valley having insufficient supplies from their local streams, water for irrigation and salinity control in the Sacramento-San Joaquin Delta, and water for supplemental supplies for the San Joaquin Valley and the San Francisco Bay Basin, both of which areas have insufficient local supplies for their full development.

The Narrows dam site is topographically and, from indications, geologically favorable for a dam 580 feet high. It is shown hereinafter that the yield of the reservoir with this height of dam, when operated primarily for irrigation, would have been, during the 40-year period 1889–1929, 1,064,000 acre-feet per season with a maximum seasonal deficiency of 35 per cent. The minimum seasonal yield, therefore, would have been about 692,000 acre-feet which is more than is required for a perfect supply for the Yuba River service area. The surplus yield would be used for the other requirements for the ultimate development of the Great Central Valley, stated above.

While a reservoir with a 580-foot dam would have yielded 1,064,000 acre-feet per season during the 40-year period 1889–1929, distributed in accordance with the irrigation demand, this yield is only 52.4 per cent of the mean ultimate net run-off for the same 40-year period. This percentage is somewhat lower than that for some of the other reservoirs, which would indicate that a larger reservoir would be desirable. A dam somewhat higher than 580 feet could be built but this latter height appears to be most suitable for the topography of the site. That a reservoir with a dam of this height would have been required to obtain the desired accomplishments under a condition of ultimate development in the Great Central Valley, during the period 1918–1929, is shown by the discussion for the selection of the ultimate capacity of Kennett reservoir in this chapter, as this discussion also applies to the Narrows reservoir.

A height of 580 feet, therefore, was selected for the dam for the Narrows reservoir as one of the major units of the State Water Plan.

Dam and Power Plant.—A survey of the dam site was made by the State in 1930. A topographic map drawn from this survey at a scale of one inch equals 200 feet, with a contour interval of 10 feet, was used in laying out and estimating the cost of the Narrows dam and power plant. No core drillings or other explorations were made at the site but a detailed geological examination was made, the report on which may be found in Appendix E. This examination determined the character of the foundation rock to be a massive diabase. The left abutment is a relatively steep cliff to a point about 200 to 300 feet above the stream bed. Above this cliff the outcropping rock is considerably jointed. Good sound rock for a dam foundation would be obtained by removing the decomposed rock at the surface and the soil overburden. A dam of the height proposed would require the construction of an auxiliary dam, which would be used as a spillway, in a saddle about one-fourth of a mile east of the main dam. Rock foundations also are available for this dam.

PLATE XXXI

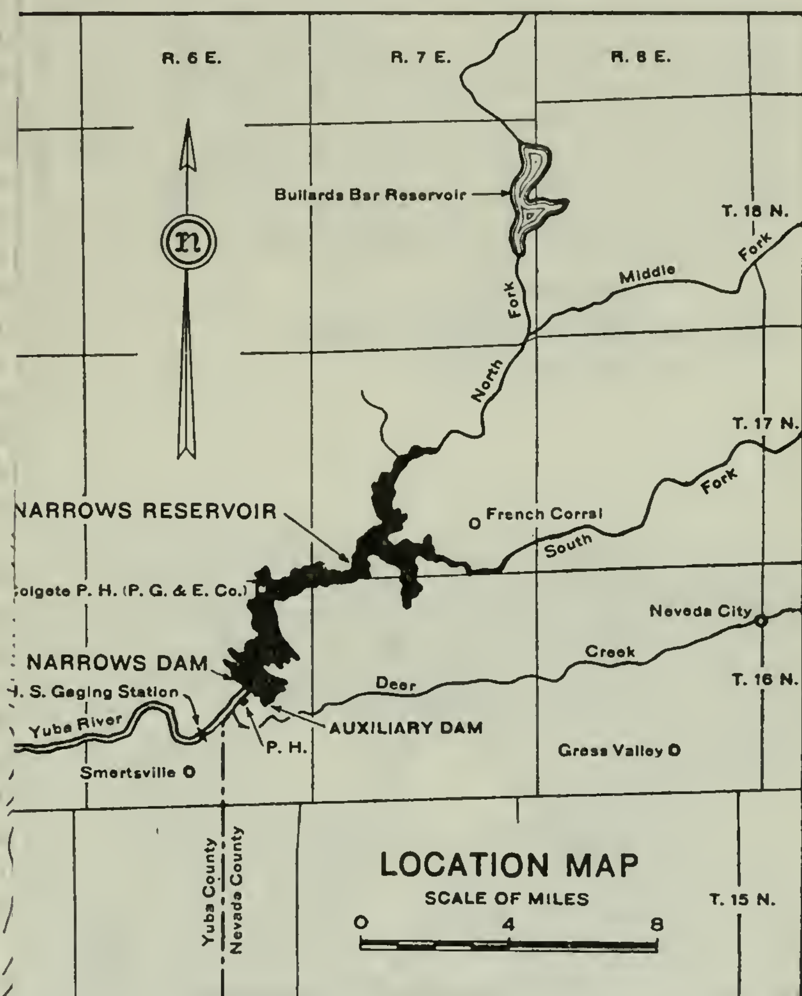
Narrows Dam Site on Yuba River

On account of the great height of this dam, the only type considered is the gravity concrete. A sufficient quantity of suitable gravel and sand for the concrete for such a dam could be obtained in the river channel a short distance below the dam site. The layout for the dam, power plant and auxiliary dam is shown on Plate XXXII, "Narrows Reservoir on Yuba River."

The main dam would be slightly arched in plan to fit the topography of the site. As previously stated, a reasonable amount of excavation would uncover a good firm rock foundation for the dam, capable of withstanding the pressures developed by it. There would be a cut-off wall at the upstream toe, beneath which any seams in the rock would be sealed by grouting. The foundation would be drained by a row of drainage wells, just downstream from the upper cut-off wall, which would be connected to a gallery in the dam.

Diversion of the stream flow during the excavation for the foundation and construction of the lower portion of the dam in the stream channel would be accomplished by rock fill dams with clay blankets, above and below the limits of the toes of the dam. The water would be conveyed around the excavation by a concrete lined horseshoe shaped tunnel which would have a capacity of 5000 second-feet. This tunnel would be plugged and back-filled after the completion of the dam.

The spillway, as previously stated, would be constructed in the auxiliary dam. The spillway section of this dam would be of the gravity concrete overflow type with an over-all length of 650 feet and would have a discharging capacity of 185,000 second-feet. The total length of the auxiliary dam would be 1260 feet and the maximum height 35 feet above the ground level. The two abutment sections would be of the gravity concrete type. Water passing over the spillway would be carried through an excavated channel, partially concrete lined, into a gulch leading into Deer Creek and through it back into the Yuba River.



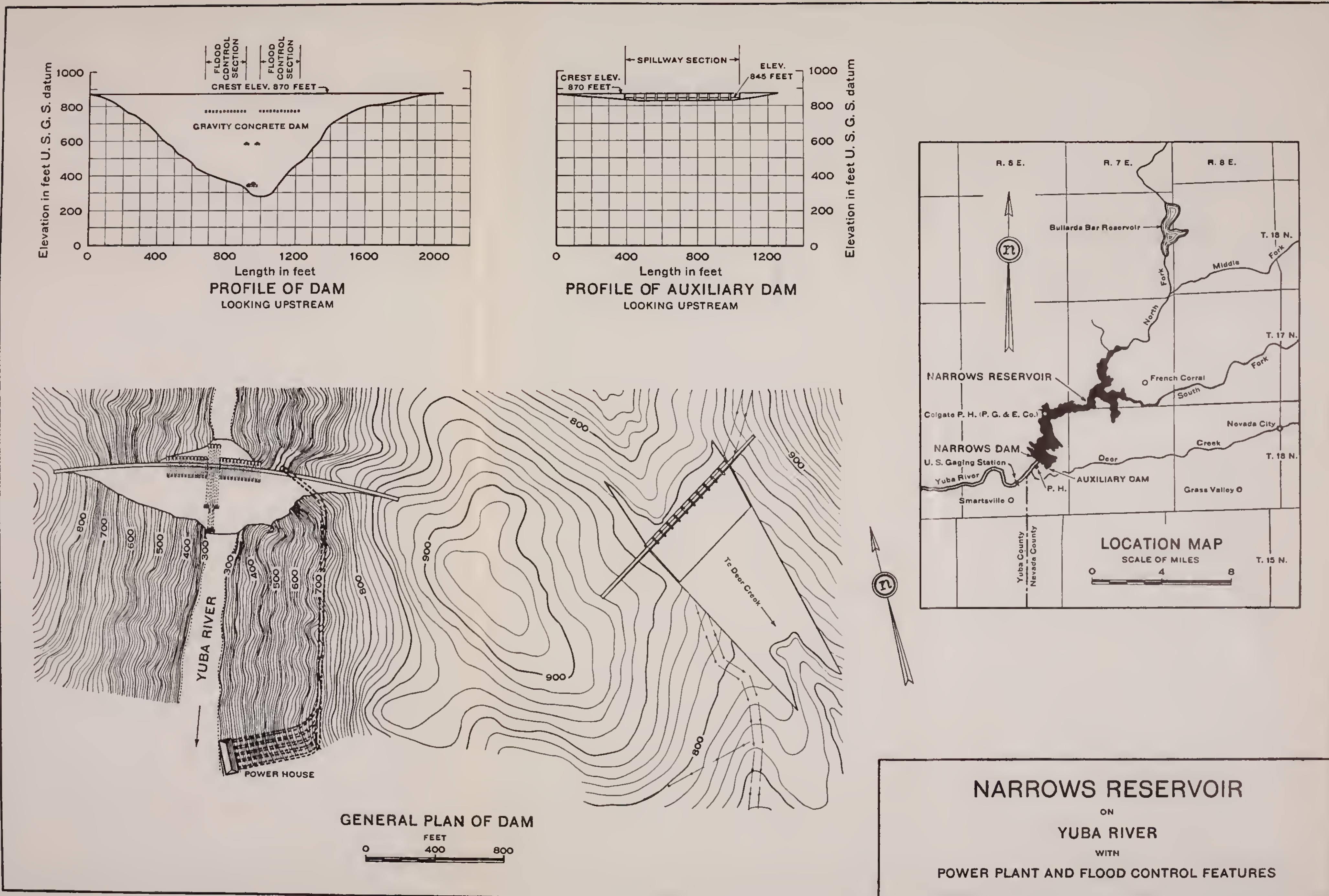
NARROWS RESERVOIR

ON

YUBA RIVER

WITH

POWER PLANT AND FLOOD CONTROL FEATURES



NARROWS RESERVOIR
ON
YUBA RIVER
WITH
POWER PLANT AND FLOOD CONTROL FEATURES

The flow over the spillway would be controlled by eleven hydraulically operated steel segmental drum gates 50 feet long and 20 feet high set in the crest. These gates would be separated by ten-foot concrete piers in which the operating mechanism would be located.

Outlets through the dam would be provided for controlling floods. These outlets would have a capacity of 70,000 second-feet with the water in the reservoir drawn down a sufficient depth to give the reserve storage space required for controlling floods to this amount. There would be 24 openings, each ten feet square, spaced 20 feet center to center, at a distance of 100 feet below the top of the dam. Flow through each outlet would be controlled by a caterpillar type self-closing sluice gate, at the upstream face of the dam, which would be protected by steel trash racks set in a semicircular concrete structure, and would be operated, from the top of the dam, in a concrete enclosed gate well extending to the top of the dam. Discharge from these outlets would flow over the downstream face of the dam into the river channel below.

Outlets at a lower elevation also would be provided for the discharge of irrigation water and for draining the reservoir. There would be four of these outlets, each 82 inches in diameter, lined with steel. Two of these outlets would be located about 300 feet, and the other two about 520 feet, below the top of the dam. Flow through each outlet would be controlled by a caterpillar type self-closing sluice gate at the upstream face of the dam, which would be protected by steel trash racks mounted in a semicircular concrete structure and would be operated in a concrete enclosed gate well extending to the top of the dam. Additional control on each outlet would be provided by a slide valve located a short distance from the upstream end and operated from a chamber within the dam. One of the lower outlets would be provided also with an 82-inch balanced needle valve at its outlet end to give more accurate regulation of irrigation releases.

The power house would be located on the left bank of the stream about 1200 feet below the dam. Water would be conveyed to it from the reservoir through a concrete lined horseshoe shaped tunnel 19 feet in diameter. At a point opposite the power house, the tunnel would divide into five steel pipe penstocks, 106 inches in diameter and 600 feet in length, which would carry the water to the five turbines in the power house. These steel penstocks would be laid in separate concrete lined tunnels 12.8 feet in diameter. Water would enter the main tunnel through a concrete gate tower over a vertical concrete lined shaft. Water would enter the tower through several openings, flow through each of which would be controlled by a caterpillar type sluice-gate operated from the top of the tower. Each gate would be protected by steel trash racks and would operate in a concrete enclosed gate well extending to the top of the tower.

Studies to estimate the economic installation of generating equipment to be placed in the power house indicate that with a load factor of 0.75 and a power factor of 0.80, the generators should have a total capacity of 160,000 kilovolt amperes. This would be divided equally among five generators each of which would be direct connected to a vertical shaft variable head reaction turbine. The power house would

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be of concrete and steel construction. The transformers and protective equipment would be of the outdoor type.

Yields of Reservoir in Water for Irrigation and in Hydroelectric Energy—Reservoir Operated Primarily for Irrigation.—A study was made to estimate the amounts of water that would have been made available at the Narrows gaging station, for irrigation use, in each of the years from 1889 to 1929, with the reservoir operated primarily for supplying irrigation water, and the amount of this yield that would have been new water. These studies were made by the methods described in the fore part of this chapter. In making this study, the entire capacity of the reservoir was utilized in the years of deficiency in supply. The drafts from the reservoir were those that would have been necessary to supplement the run-off from the area between the dam and the gaging station to give an irrigation draft at the latter point distributed in accordance with the demand in the Sacramento Valley. These studies indicate that a seasonal irrigation draft of 1,064,000 acre-feet would have been obtainable with a maximum deficiency of 35 per cent in the driest year and an average of a little less than two per cent for the period. The seasonal yield in new water would have been 958,000 acre-feet, with corresponding deficiencies.

A similar study was made for the reservoir operating primarily for irrigation with incidental power during the same 40-year period 1889–1929. This study differed from the previous one in that the entire capacity of the reservoir was not utilized, it being assumed that the reservoir would have been operated so that the minimum head for power development would have been 50 per cent of the maximum obtainable. It also was assumed that the power plant would have had the same installed capacity as that for the reservoir operating primarily for the generation of power. With this method of operation, the annual yield in irrigation water, with deficiencies corresponding to those for the reservoir operated primarily for irrigation without power, would have been 975,000 acre-feet, of which 869,000 acre-feet would have been new water. The electric energy would have had a low value on account of there being some months in each year when none would have been generated. However, by a slight modification in releases so that some water would have been available for power in the months when none was released for irrigation uses, the irrigation yield would have been practically the same as with the former method of operation and the power value would have been substantially increased. The average annual electric energy output with this modified operation would have been 528,100,000 kilowatt hours. The value of this energy at the power plant, based on the cost of producing an equivalent amount of electric energy of the same characteristics with a steam-electric plant located in the area of consumption, taking into account the cost of transmission from the point of generation to the load center, was estimated to be $.00235 per kilowatt hour. The average annual revenue at this value would have been $1,241,000.

Yields of Reservoir in Hydroelectric Energy and in Water for Irrigation—Reservoir Operated Primarily for Generation of Power.—A study also was made to estimate the amount of electric energy that would have been developed in the 40-year period 1889–1929 with the reservoir operated primarily for this purpose, and the amount of new water that would have been made available with this method of operation of the reservoir. The study was made by the method described in the fore part of this chapter. The 160,000 kilovolt ampere plant operated on a load factor of 0.75 and with a power factor of 0.80 would have produced an average annual output of 570,300,000 kilowatt hours. The output in the minimum year would have been 333,000,000 kilowatt hours and in the maximum year 695,600,000 kilowatt hours. The value of this electric energy was estimated to be $.00298 per kilowatt hour. The average annual revenue at this value would have been $1,699,000.

The reservoir while operating primarily for the generation of power, would have made available an annual yield of 377,000 acre-feet of water which would have been available for irrigation, distributed in accordance with the irrigation demand. This yield would have had a maximum seasonal deficiency of four per cent and an average for the 40-year period of two per cent. This yield amounts to 35 per cent of that with the reservoir operated primarily for irrigation. Of this yield, 271,000 acre-feet would have been new water. This is 28 per cent of the yield in new water with the reservoir operated primarily for irrigation.

Flood Control.—The reservoir could be used to control flows to certain specified amounts at the Narrows gaging station the same as if the dam were located at that point. This could be accomplished by releasing water at such a rate that the controlled flows would not exceed these amounts.

Curves on Plate VIII and data in Table 32 in Chapter VI show the probable frequency of occurrence of mean daily flood flows of certain amounts at the gaging station. The reservoir spaces required at this point to control flood flows which are expected to occur at different intervals of time, to certain specified amounts below the gaging station, are shown by the curves on Plate X and the data in Table 35, in the same chapter.

The selected controlled flow at the gaging station is 70,000 second-feet, exceeded once in 100 years on an average. It is believed that this control would give sufficient protection to the lands and flood control works along the Yuba River. It also would materially aid in reducing the flood flows in the Feather and lower Sacramento rivers, thereby increasing the degree of protection afforded by the flood control works along these streams. This control would require 272,000 acre-feet of reserve storage space, which would be held in reserve in accordance with the rule given in Chapter VI. The reserve space would occupy the upper 73 feet of the reservoir.

The effectiveness of the reservation of this amount of space for controlling floods is illustrated by showing its effect on two of the largest floods of record. The largest flood, that of January, 1909, with a maximum mean daily discharge of 111,000 second-feet, would have been controlled to a flow not exceeding 70,000 second-feet by the use of 155,000 acre-feet of the reserve storage space. The flood of March, 1907, with a maximum mean daily discharge of 100,000 second-feet, would have required only 89,000 acre-feet of storage space for its control to a maximum flow of 70,000 second-feet.

Cost of Reservoir and Power Plant.—Estimates of the costs of the Narrows dam, reservoir and power plant were made as generally outlined in the fore part of this chapter and include all of the items which have been briefly described in the foregoing paragraphs. These estimates are shown in Tables 88 and 89. The items included under miscellaneous, in the cost estimate in Table 88 are a construction railroad, a short railroad spur to the gravel pit, a permanent camp and cleaning up after construction.

TABLE 88

COST OF NARROWS RESERVOIR WITH FLOOD CONTROL FEATURES

Height of dam, 580 feet. Capacity of reservoir, 853,000 acre-feet.
Capacity of overflow spillway, 185,000 second-feet.
Capacity of flood control outlets, 70,000 second-feet.

Exploration and core drilling		$30,000
Diversion of river during construction		235,000
Clearing reservoir site		215,000
Excavation for dam 1,010,000 cu. yds. at $2.50 to $5	$2,844,000	
Mass concrete, 4,044,000 cu. yds. at $6.35	25,679,000	
Reinforced concrete, 6,500 cu. yds. at $15 to $23.50	109,000	
Spillway gates	330,000	
Spillway channel	240,000	
Irrigation outlets and sluiceways	294,000	
Flood control features	362,000	
Drilling and grouting foundation	76,000	
		29,934,000
Lands and improvements flooded		1,406,000
Miscellaneous		1,033,000
Subtotal		$32,853,000
Administration and engineering, 10 per cent		3,285,000
Contingencies, 15 per cent		4,928,000
Interest during construction based on a rate of 4.5 per cent per annum		4,534,000
Total cost of dam and reservoir		$45,600,000

TABLE 89

COST OF POWER PLANT FOR NARROWS RESERVOIR

Installed capacity, 160,000 kilovolt amperes.
Power factor = 0.80. Load factor = 0.75.

Intake structure	$226,000
Penstocks	1,671,000
Building and equipment	3,703,000
Subtotal	$5,600,000
Administration and engineering, 10 per cent	560,000
Contingencies, 15 per cent	840,000
Interest during construction based on a rate of 4.5 per cent per annum	400,000
Total cost of power plant	$7,400,000

The total estimated capital cost of the Narrows reservoir with a 580-foot dam, and its power plant, is $53,000,000.

The annual costs for the reservoir and power plant, estimated on the bases given in the fore part of this chapter and the capital costs given in Tables 88 and 89, would be $2,761,000 and $603,000 respectively, or a total of $3,364,000.

Camp Far West Reservoir on Bear River.

Since the run-off of the Bear River is relatively small, there would be very little, if any, yield from a reservoir constructed on it in excess of the irrigation requirements of its own water service area described in Chapter V. The need for a major reservoir unit of the State Water Plan on the Bear River, therefore, would be principally to regulate as large a portion of the run-off of the stream as practicable for this purpose, thereby conserving water which might be obtained for the area from major reservoir units on other streams for use in areas in the Great Central Valley where there is no local water supply or an insufficient supply for full development.

There are two reservoir sites on the Bear River which could be developed to about the same capacity. The site formerly included in the Coordinated Plan* for the development of the water resources of California was the Parker site about five miles upstream from the Auburn-Grass Valley State highway crossing. That site, however, does not offer as good an opportunity for control of the run-off from the entire watershed as the Camp Far West site about six miles northeast of the town of Wheatland. Furthermore, the Parker site probably will be utilized for developing a water supply for the lands in the foothill area. In these investigations and studies, it has been so utilized in evolving a plan for the ultimate irrigation development of these lands. For these reasons, the Camp Far West site was selected for the major reservoir unit in the State Water Plan on the Bear River.

The site for the dam for the Camp Far West reservoir is located in Section 21, T. 14 N., R. 6 E., M. D. B. and M. There is a concrete dam at this site at the present time, which is used by the Camp Far West Irrigation District to store about 5000 acre-feet of water. The site is satisfactory, however, for a dam which would create a much larger reservoir.

The area of the drainage basin above the Camp Far West site is about 282 square miles, which is 20 square miles more than the area above the United States Geological Survey gaging station at Van Trent. This additional area lies mostly in the watershed of Rock Creek which enters the river within the reservoir site. The drainage basin contains only about 1.3 per cent of the total mountain and foothill area of the Sacramento River Basin. The Bear River watershed is a narrow basin lying between the Yuba and American river basins and does not reach the crest of the Sierra Nevada. The stream heads at an elevation of about 5300 feet, just south of Lake Spaulding, and the elevation of the stream bed at the Camp Far West dam site is a little less than 150 feet. The distribution of the area by three ranges of elevation is given in Table 1 in Chapter II for the basin above the gaging station and this is practically the same distribution as at the dam site. The drainage basin is all mountain and foothill land but it is not as rugged as the upper watersheds of the adjoining major streams. There is very little forest cover in the basin. A large portion of the watershed lies at low elevation and snow that falls in the basin disappears in the early spring. A considerable area of the foothill land is suitable for agriculture and some of this land is now included in the Nevada Irrigation District.

Water Supply.—Although the watershed above the dam site is slightly larger than above the gaging station at Van Trent, the additional area lies at low elevation and is not productive of much run-off. The run-off at the dam site, therefore, has been assumed to be the same as at the gaging station.

Information on the run-off at the dam site was obtained from stream flow records kept by the United States Geological Survey at the

* Bulletin No. 12, "Summary Report on the Water Resources of California and a Coordinated Plan for their Development," Division of Engineering and Irrigation, 1927.

Van Trent station from October, 1904, to January, 1928, a period of about 23¼ years. The construction of the present Camp Far West reservoir interfered with the flow measurements at this station, so in October, 1928, a new station was established near Wheatland and after that date the discharge records at this latter station were used to estimate the run-off at the dam site.

Water is diverted into the Bear River watershed above the Van Trent gaging station from both the Yuba and American rivers. The diversion from the Yuba River is made by the Drum Canal which heads at Lake Spaulding and conveys water to the Drum Power House on Bear River. The diversion from the American River was formerly made through the Towle Canal but this canal has been abandoned and the diversion is now made through the Lake Valley Canal which flows into the Drum Canal.

Diversions of water from the watershed above the Van Trent gaging station are made by the Boardman, Bear River and Gold Hill canals, all of which head on the south side of the river. The Boardman Canal diverts water from both the Bear River and Drum Canal. The Bear River Canal diverts water from the river some distance below the Drum Power House and therefore may take both Bear River water and that imported from the Yuba and American rivers. The water diverted through both of these canals is used for the generation of power and for irrigation and domestic use. The Gold Hill Canal diverts water at a point about due north of the city of Auburn for irrigation in the areas northwest of Auburn and Newcastle.

Records of flow in these canals at different points, and in the Bear River at the intake of the Bear River Canal, were available for this investigation and were used to estimate past, present and future diversions into and out of the drainage basin.

The general methods of estimating the full natural, the present net, and the ultimate net run-offs at gaging stations and other selected points have been given in Chapter II, in which chapter the seasonal full natural run-offs are tabulated for the gaging station. Estimates of run-off for the period prior to obtaining stream flow records were made from precipitation data for stations within the watershed. These data were available for several stations having records of considerable length. Precipitation within the watershed, as shown by the records at the precipitation stations varies from a mean of 26 inches per season in one portion to 72 inches in another.

The monthly full natural run-offs at the gaging station for the period of record, were obtained from the measured flows by adding the diversions out of the watershed by the Gold Hill, Bear River, and Boardman canals; by subtracting the diversions into the watershed by the Drum, Towle, and Lake Valley canals; by adding water stored in and subtracting water released from the Bear Valley and Van Giesen reservoirs during the time that they were in operation; and by adding the estimated net amounts of water used for irrigation above the station.

The monthly ultimate net run-offs at the gaging station were obtained from the monthly full natural run-offs by adding the discharges from the Drum and Lake Valley canals; by subtracting the diversions from the watershed by the Bear River Canal; by subtracting water stored in and adding water released from the proposed Parker reservoir; by subtracting the gross diversions for irrigation both within the watershed and in the area between the Bear and American rivers watered by Bear River water; and by adding the return flow from the areas irrigated within the watershed.

The seasonal full natural and ultimate net run-offs at the Van Trent gaging station, which are assumed to be the same as at the dam site, are shown in Table 90.

TABLE 90

SEASONAL RUN-OFFS OF BEAR RIVER AT VAN TRENT, 1889-1929

Season	Full natural run-off, in acre-feet	Ultimate net run-off, in acre-feet
1889-1890	1,212,000	1,116,000
1890-1891	235,000	240,000
1891-1892	242,000	190,000
1892-1893	553,000	519,000
1893-1894	336,000	306,000
1894-1895	841,000	792,000
1895-1896	560,000	524,000
1896-1897	399,000	387,000
1897-1898	129,000	131,000
1898-1899	251,000	192,000
1899-1900	388,000	345,000
1900-1901	425,000	394,000
1901-1902	351,000	319,000
1902-1903	338,000	310,000
1903-1904	679,000	626,000
1904-1905	375,000	341,000
1905-1906	618,000	570,000
1906-1907	782,000	757,000
1907-1908	246,000	220,000
1908-1909	575,000	548,000
1909-1910	317,000	285,000
1910-1911	567,000	523,000
1911-1912	152,000	141,000
1912-1913	177,000	154,000
1913-1914	502,000	456,000
1914-1915	430,000	384,000
1915-1916	605,000	565,000
1916-1917	361,000	332,000
1917-1918	147,000	138,000
1918-1919	318,000	272,000
1919-1920	145,000	135,000
1920-1921	486,000	437,000
1921-1922	437,000	388,000
1922-1923	363,000	329,000
1923-1924	66,000	101,000
1924-1925	268,000	209,000
1925-1926	243,000	218,000
1926-1927	523,000	479,000
1927-1928	329,000	304,000
1928-1929	124,000	129,000
40-year means, 1889-1929	402,000	370,000
20-year means, 1909-1929	328,000	299,000
10-year means, 1919-1929	298,000	273,000
5-year means, 1924-1929	297,000	268,000

Like the other streams in the Sacramento River Basin, the Bear River has wide variations in its seasonal, monthly, and daily run-offs. The variations in the full natural and ultimate net seasonal run-offs at the gaging station are shown by the amounts given in Table 90. From that table it will be seen that the maximum seasonal full natural run-off in the 40-year period 1889–1929 was 1,212,000 acre-feet in 1889–1890, and that the minimum was 66,000 acre-feet in 1923–1924, a variation of from 302 per cent to 16 per cent of the mean seasonal full natural run-off for the period. The average monthly distribution of the run-off as determined from the estimated monthly full natural run-offs at the gaging station, during the same 40-year period, is shown in Table 91. The variation in the mean daily flows is indicated by the maximum discharge of 25,800 second-feet on March 19, 1907, and 25,300 second-feet, with a peak discharge of 29,600 second-feet, on January 14, 1909; and a minimum mean daily discharge of 1.8 second-feet on October 2, 1924.

TABLE 91

AVERAGE MONTHLY DISTRIBUTION OF RUN-OFF OF BEAR RIVER AT VAN TRENT

Month	Average full natural run-off	
	In acre-feet	In per cent of mean seasonal
January	76,400	19.01
February	87,100	21.67
March	78,300	19.48
April	51,100	12.71
May	25,200	6.27
June	13,600	3.38
July	6,000	1.49
August	4,600	1.15
September	4,800	1.19
October	8,000	1.99
November	13,000	3.23
December	33,900	8.43
Totals	402,000	100.00

Reservoir Site.—The lands required for the Camp Far West reservoir are mostly unimproved low foothill lands along the Bear River and Rock Creek. There are no towns or settlements in the site and very few buildings and improvements. A part of the area is now flooded by the present Camp Far West reservoir. The principal improvements which would be flooded are the old Dairy Farm Mine, which has not been in operation for a number of years, and several miles of county roads. The roads could be relocated readily so that there would be no interference with travel.

A topographic survey of the Camp Far West reservior site to an elevation of 225 feet was made by the Camp Far West Irrigation District in 1922. This survey was extended to elevation 320 feet by the State in 1930 and a map was drawn from both surveys at a scale of one inch equals 500 feet with a contour interval of ten feet. The water surface areas measured from this map and the computed capacities of the reservoir are shown in Table 92.

Selection of Capacity of Reservoir.—An analysis of the run-offs of the Bear River watershed and of the operation and yields of the Camp Far West reservoir show that no reservoir at this site could supply sufficient water to control salinity conditions in the Sacramento-San Joaquin Delta, which is one of the principal requirements of an initial unit in the Sacramento River Basin. The unit cost of the yield in water from the Camp Far West reservoir which could be used for salinity control or irrigation also is greater than that from any other major unit in the Sacramento River Basin except the Oroville reservoir. This reservoir, therefore, was not considered for development as an initial unit but is included in the State Water Plan as one of the major units for ultimate development.

TABLE 92

AREAS AND CAPACITIES OF CAMP FAR WEST RESERVOIR

Height of dam, in feet (5-foot freeboard)	[1]Water surface elevation of reservoir, in feet	Area of water surface, in acres	Capacity of reservoir, in acre-feet
0	145	0	0
20	160	70	500
30	170	100	1,400
40	180	140	2,500
50	190	180	4,200
60	200	260	6,500
70	210	380	9,800
80	220	480	14,000
90	230	600	19,400
100	240	730	26,100
110	250	890	34,200
120	260	1,060	43,900
130	270	1,260	55,500
140	280	1,500	69,300
150	290	1,750	85,600
160	300	2,020	104,400
170	310	2,330	126,100
180	320	2,620	151,000

[1] United States Geological Survey datum.

As a unit in the ultimate development, the Camp Far West reservoir should have sufficient capacity to yield at least the amount of water required for the supply for the Bear River water service area, which is given in Chapter V as 187,000 acre-feet per season, gross allowance. Studies of the irrigation yield of the reservoir with a 180-foot dam show that it would have been 192,000 acre-feet per season during the 40-year period 1889–1929, with a maximum seasonal deficiency of 23 per cent. This shows that a reservoir of this size would have been large enough to furnish sufficient water for the entire service area in seasons of full supply but that there would have been a deficiency in other seasons, with a maximum of 39,000 acre-feet. It would be desirable, therefore, to have a reservoir larger than that created by a 180-foot dam, but since the dam site is not topographically favorable for a higher structure and since deficiencies in irrigation supply for the Bear River water service area could be made up from the Narrows reservoir on Yuba River, the 180-foot height was selected for the Camp Far West dam.

Dam and Appurtenant Works.—A survey of the dam site was made by the state in 1930. A topographic map drawn from this survey at a scale of one inch equals 200 feet, with a contour interval of ten feet, was used in laying out and estimating the cost of the Camp Far West dam. A dam 180 feet in height at this site would have a length of 7720 feet but a large portion of this length would be a low dike not exceeding 30 feet high. The only explorations at the dam site are a few borings made in the center of the river by the Camp Far West Irrigation District, to determine the depth of the gravel fill. A geological examination of the site, however, was made during this investigation. The report on this examination may be found in Appendix E.

According to the geologist, the entire dam could be founded on rock with a reasonable amount of excavation of the overlying soil and decomposed surface rock.

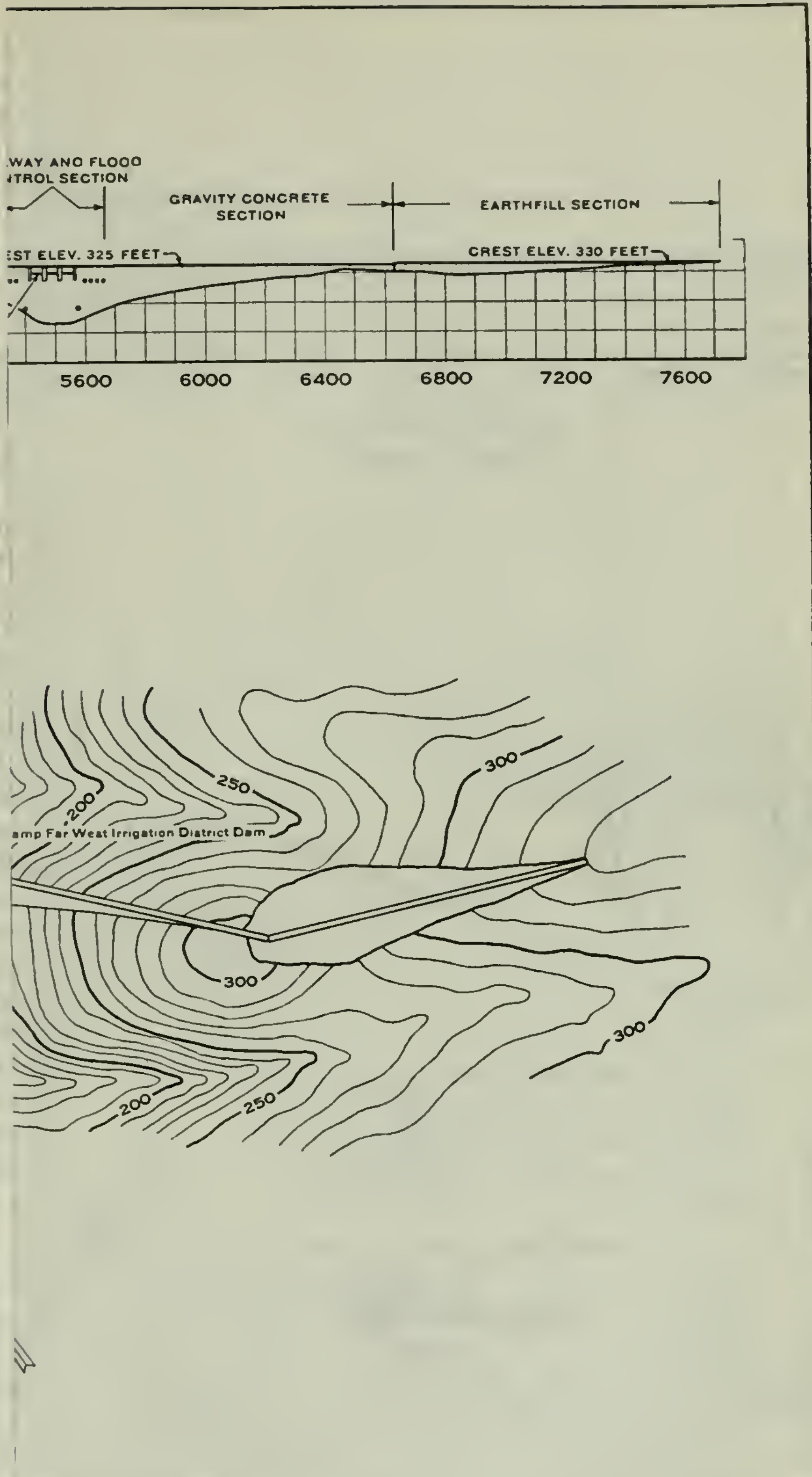
PLATE XXXIII

Camp Far West Dam Site on Bear River

The dam would consist of three sections. The main section across the river channel and up the slopes on both sides would be of the gravity concrete type. This section would be 2120 feet in length. At each end of this concrete section there would be an earth fill section extending along the ridge to an elevation 10 feet above the maximum water surface in the reservoir. The section at the right abutment would be 4500 feet in length and the one at the left abutment would be 1100 feet in length. The layout for the dam is shown on Plate XXXIV, "Camp Far West Reservoir on Bear River."

The main section of the dam would have a curved alignment at the right abutment to fit the topography of the site. The central portion of the dam across the stream channel would contain the spillway section and would be of the gravity concrete overflow type. The entire concrete dam would rest on firm rock which would require excavation of all the overlying soil and the decomposed rock. There would be a cut-off wall at the upstream toe, beneath which the foundation rock would be sealed by grouting. The foundation also would be drained by a row of deep drainage wells, just downstream from upper cut-off wall, which would be connected to a gallery in the dam.

Gravel for the concrete for the dam could be obtained from dredge tailings in the channel downstream from the dam, and sand could be obtained from the Yuba River at Marysville. For the transportation of materials, a 6.5 mile railroad could be constructed to the site from Sheridan.



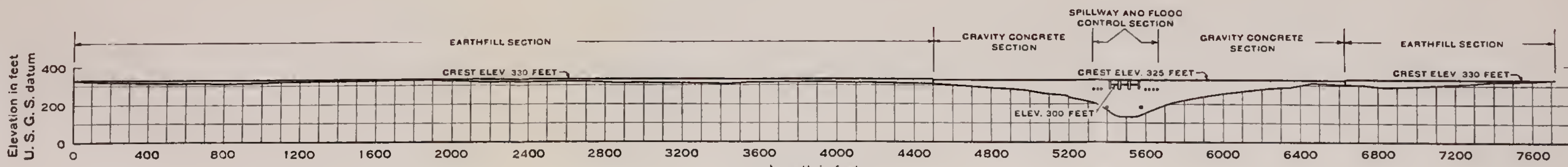
CAMP FAR WEST RESERVOIR

ON

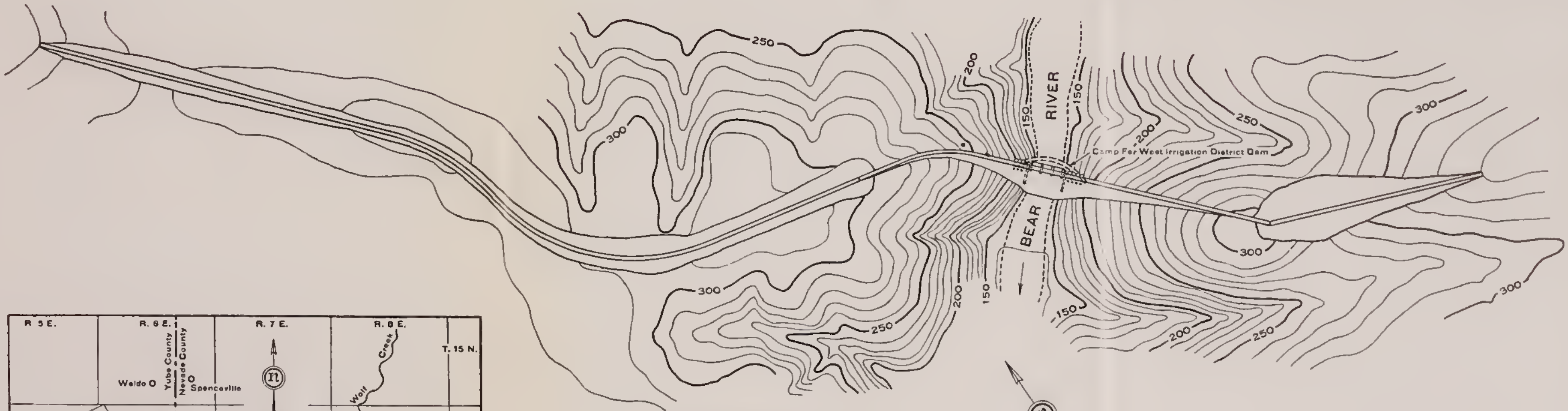
BEAR RIVER

WITH

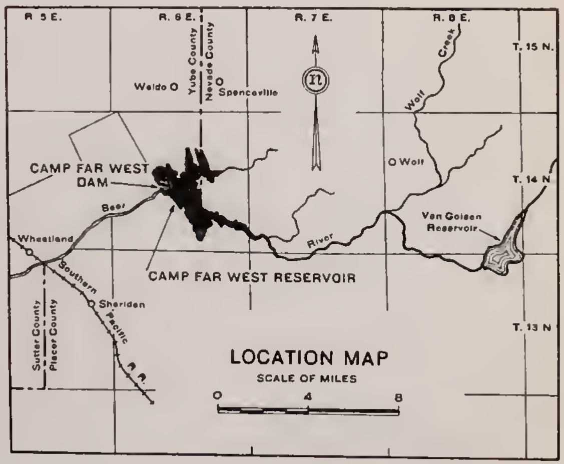
FLOOD CONTROL FEATURES



PROFILE OF DAM
LOOKING UPSTREAM



GENERAL PLAN OF DAM



CAMP FAR WEST RESERVOIR

ON

BEAR RIVER

WITH

FLOOD CONTROL FEATURES

Diversion of the stream flow during the excavation for the foundation in the stream channel could be accomplished by the use of the present dam as an upstream coffer dam with pipe extensions of the present outlets to carry the water below a coffer dam downstream from the excavations for the new dam.

The spillway as previously stated, would be located in the section of the dam across the stream channel. It would have an over-all length of 140 feet and a capacity of 40,000 second-feet. Flow over it would be controlled by three hydraulically operated steel segmental drum gates 40 feet in length and 20 feet high, set in the crest. These gates would be separated by ten-foot concrete piers in which the operating mechanism would be located. The water from the spillway would flow over the downstream face of the dam into the main river channel which, on account of the rock formation, would require no protection.

Outlets through the dam would be provided for controlling floods. These outlets would have a capacity of 20,000 second-feet with the water in the reservoir drawn down a sufficient depth to give the reserve storage space required for controlling floods to this amount. There would be seven openings ten feet square, spaced 20 feet center to center and located 50 feet below the top of the dam. Flow through each outlet would be controlled by a caterpillar type self-closing sluice gate, at the upstream face of the dam, which would be protected by steel trash racks mounted in a semicircular concrete structure extending to the top of the dam.

Two other outlets would be provided at a depth of 125 feet below the top of the dam to be used for sluiceways and the discharge of irrigation water. These outlets would be 50 inches in diameter and would be lined with steel. Flow through each outlet would be controlled by a caterpillar-type sluice gate, at the upstream face of the dam, and also by an auxiliary slide valve, near the inlet, operated from a chamber within the dam. One outlet also would be provided with a 50-inch balanced needle valve at its outlet end to give more accurate regulation of the releases. Each caterpillar gate would be protected by steel trash racks set in a semicircular concrete structure and would operate in a concrete enclosed gate well extending to the top of the dam.

Yield of Reservoir in Water for Irrigation.—A study was made to estimate the amounts of water that would have been made available at the dam site for irrigation, with the reservoir operated primarily for this use, in each of the years from 1889 to 1929, and the amount of this yield that would have been new water. The study was made by the methods described in the fore part of this chapter. In making it the entire capacity of the reservoir was utilized in the years of deficiency in supply. The study indicates that a seasonal irrigation draft of 192,000 acre-feet would have been obtainable with a maximum deficiency of 23 per cent in the driest year and an average of two per cent for the period. The seasonal yield in new water would have been 130,000 acre-feet, with corresponding deficiencies.

Flood Control.—Flood control on the Bear River is not of as great importance as on the other major streams along the east side of the Sacramento Valley as its peak flows are not as large. Some damage to the lands and flood control works along the Bear River occurs from

Diversion of the stream flow during the excavation for the foundation in the stream channel could be accomplished by the use of the present dam as an upstream coffer dam with pipe extensions of the present outlets to carry the water below a coffer dam downstream from the excavations for the new dam.

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Yield of Reservoir in Water for Irrigation.—A study was made to estimate the amounts of water that would have been made available at the dam site for irrigation, with the reservoir operated primarily for this use, in each of the years from 1889 to 1929, and the amount of this yield that would have been new water. The study was made by the methods described in the fore part of this chapter. In making it the entire capacity of the reservoir was utilized in the years of deficiency in supply. The study indicates that a seasonal irrigation draft of 192,000 acre-feet would have been obtainable with a maximum deficiency of 23 per cent in the driest year and an average of two per cent for the period. The seasonal yield in new water would have been 130,000 acre-feet, with corresponding deficiencies.

Flood Control.—Flood control on the Bear River is not of as great importance as on the other major streams along the east side of the Sacramento Valley as its peak flows are not as large. Some damage to the lands and flood control works along the Bear River occurs from maximum floods, however, and control to smaller amounts, therefore, would benefit lands adjacent to the river and also would have some effect in increasing the degree of protection along the lower Feather and Sacramento rivers.

Curves on Plate VIII and data in Table 32 in Chapter VI show the probable frequency of occurrence of flood flows of certain amounts at the Van Trent gaging station, which is practically the same location as the Camp Far West dam site. The reservoir spaces required at that point to control flood flows which are expected to occur at different intervals of time, to certain specified amounts below the dam, are shown by the curves on Plate X and the data in Table 35, in the same chapter.

The control of floods to a flow of 20,000 second-feet below the dam, exceeded once in 100 years on the average, would require 50,000 acre-feet of reserve storage space, which would be held in reserve in accordance with the rule given in Chapter VI.

The effect of holding this reserve space for controlling floods is best illustrated by showing its effect on two of the largest floods of record. The flood of March 19, 1907, with a maximum mean daily discharge of 25,800 second-feet, would have been controlled to 20,000 second-feet flow by the use of 11,500 acre-feet of reserve storage space. The flood of January 14, 1909, with a maximum mean daily discharge of 25,300 second-feet and a crest of 29,600 second-feet, would have required 15,300 acre-feet of storage space for its control to 20,000 second-feet. It may be seen, therefore, that the space which would be reserved would control floods much larger than any of which there is definite knowledge.

Cost of Reservoir.—An estimate of the cost of the reservoir was made as generally outlined in the fore part of this chapter and includes all of the items which have been briefly described in the foregoing paragraphs. The items included under miscellaneous in the cost estimate are a construction railroad from the Southern Pacific railroad to the dam site, a railroad spur to the gravel pit, a permanent camp, and cleaning up after construction. No power plant is proposed in connection with this reservoir. The estimated cost of the reservoir is shown in Table 93.

TABLE 93

COST OF CAMP FAR WEST RESERVOIR WITH FLOOD CONTROL FEATURES

Height of dam, 180 feet. Capacity of reservoir, 151,000 acre-feet.
Capacity of overflow spillway, 40,000 second-feet.
Capacity of flood control outlets, 20,000 second-feet.

Exploration and core drilling		$20,000
Diversion works utilizing existing dam		10,000
Clearing reservoir site		130,000
Excavation for dam, 245,000 cu. yds. at $1 to $5	$676,000	
Mass concrete, 465,000 cu. yds. at $6.75 to $9	3,157,000	
Earthfill, 280,000 cu. yds. at $0.50	140,000	
Reinforced concrete, 10,300 cu. yds. at $12 to $24	135,000	
Spillway gates	72,000	
Irrigation outlets and sluiceway	36,000	
Flood control features	96,000	
Drilling and grouting foundation	50,000	
		4,362,000
Lands and improvements flooded		262,000
Miscellaneous		245,000
Subtotal		$5,029,000
Administration and engineering, 10 per cent		503,000
Contingencies, 15 per cent		754,000
Interest during construction based on a rate of 4.5 per cent per annum		214,000
Total cost of dam and reservoir		$6,500,000

The annual cost of the dam and reservoir estimated on the bases given in the fore part of this chapter and the capital cost given in Table 93 would be $403,000.

American River Unit.

Unlike the plans of development for the other major streams of the Sacramento River Basin, three major reservoirs on the American River are proposed in the State Water Plan for the development of its water resources. In former plans * for the development of the water resources of the Sacramento Valley, only the Folsom reservoir was needed to regulate the amount of water required from the American River. The Folsom site, however, due to topographic conditions, can not readily be developed to a size adequate to regulate the proportion of the stream's run-off required for the development of the Great Central Valley under the State Water Plan, and two other storage reservoirs higher on the stream are required. The storage reservoirs would be located on the main stream near Folsom, on the North Fork near Auburn, and on the South Fork near Coloma. They are called the Folsom, Auburn, and Coloma reservoirs, respectively. There are in addition to the storage reservoirs, sites for two power drops, one below each of the two upper reservoirs, which could be developed in connection with the storage projects, and a site for a reregulating afterbay below the Folsom reservoir. One power drop would be located on the North Fork below the mouth of Pilot Creek, and the other on the South Fork below the mouth of Webber Creek. Each was named for the creek which it would be near. The Folsom afterbay dam would be located just above the highway bridge at Folsom. The locations of the reservoir and power features are shown on Plate XXXV, "American River Unit."

A report ** on the proposed development of the American River was made in 1929 for the Joint Legislative Committee of 1927 on Water Resources, and the State Department of Finance. This report analyzed the proposed hydroelectric project of the American River Hydroelectric Company and showed the service obtainable from the development in flood control, salinity control and irrigation. The present report analyzes the American River unit of the State Water Plan without reference to any development proposed by other interests.

The first requirement of the major storage reservoirs on the American River would be to supply water for the irrigation of the lands lying within the American River water service area described in Chapter V. This supply, however, would be only about one-third of the ultimate net run-off of the stream and, therefore, since studies that were made indicate that all of the water which can be economically developed in the Sacramento River Basin by the operation of the State Water Plan will ultimately be required for the full development of the Great Central Valley, the three major storage reservoirs on the American River will be required to develop as large a proportion of

* Bulletin No. 9, "Supplemental Report on Water Resources of California," Division of Engineering and Irrigation, 1925.
Bulletin No. 12, "Summary Report on the Water Resources of California and a Coordinated Plan for their Development," Division of Engineering and Irrigation, 1927.

** Bulletin No. 24, "A Proposed Major Development on American River," Division of Water Resources, 1929.

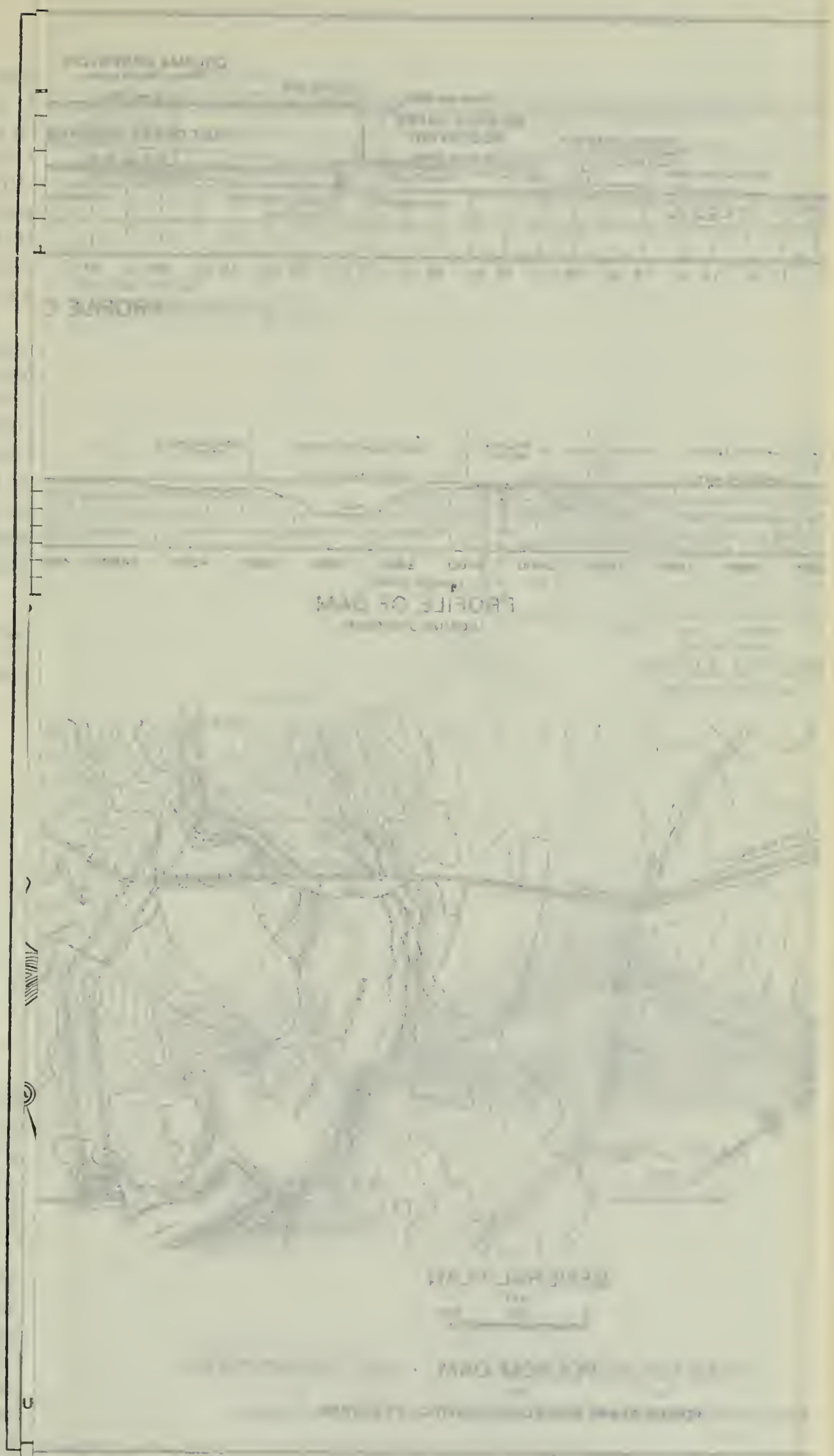
the water resources of the stream as practicable for this purpose. The water regulated by these reservoirs which would be surplus to the irrigation supply for the American River water service area would be required for a supplemental irrigation supply for the Dry Creek and Cosumnes, Mokelumne and Calaveras River water service areas which would have insufficient supplies from their local streams, for salinity control and irrigation in the Sacramento-San Joaquin Delta, and for exportation to the San Joaquin Valley and San Francisco Bay Basin to supplement local supplies in those areas for irrigation and industrial uses.

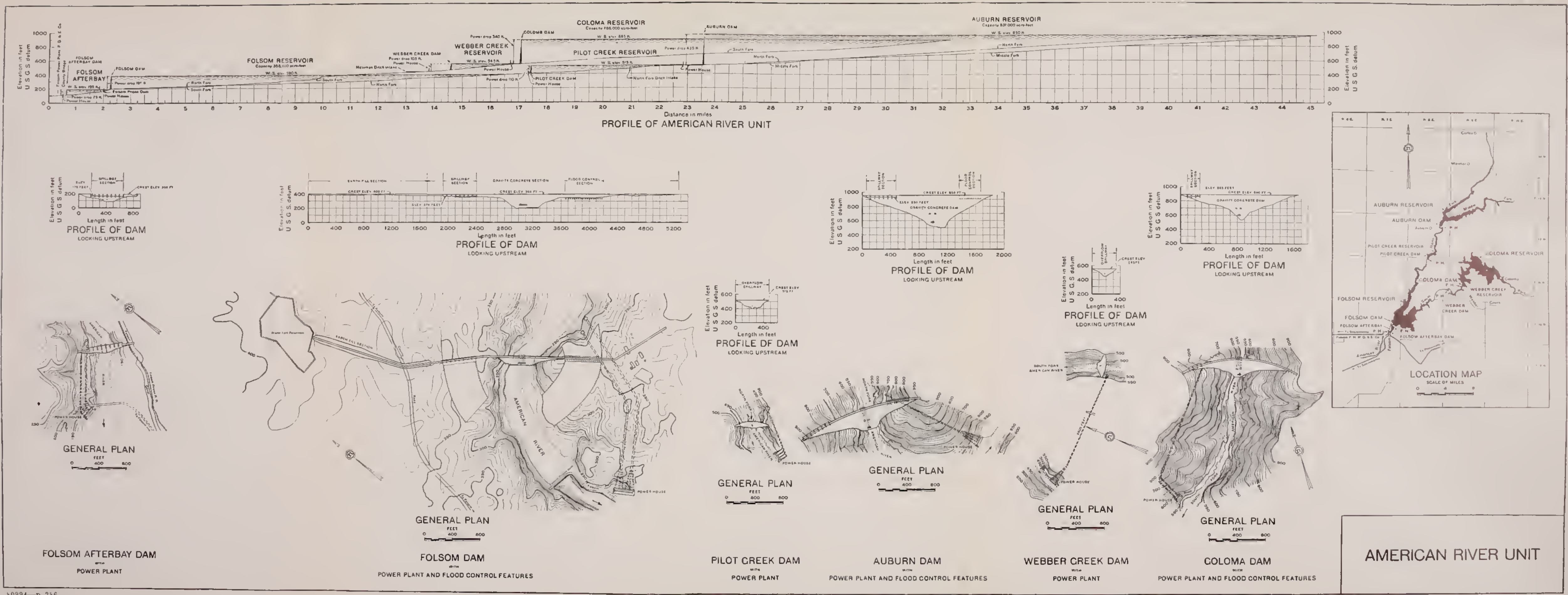
Water Supply.—The gaging station having the longest record on the American River is located at the highway bridge at Fairoaks. Discharge records have been obtained at this station by the United States Geological Survey since October, 1904. A brief description of the watershed above this station is given in Chapter II. Other principal gaging stations are maintained by the Geological Survey near East Auburn, Colfax and Camino on the Middle, North and South Forks of the American River, respectively. Discharge records obtained at these stations and records of diversions and storage obtained by other agencies, were used in estimating the full natural run-offs at these gaging stations during the period of stream discharge records. In estimating these run-offs, the methods described briefly in Chapter II were used.

The monthly full natural run-offs at the Fairoaks gaging station for the 25-year period of record, 1904–1929, were obtained from the recorded run-offs by adding the estimated diversions by the Pilot Creek, Towle or Lake Valley, El Dorado, Webber Creek, Nigger Hill, North Fork, and Natomas ditches and the Alder Creek pumping plant; by adding water stored in and subtracting water released from the Twin Lakes, Silver Lake, Medley Lakes, Webber Creek and Lake Valley reservoirs; by subtracting water diverted into the watershed from Echo Lake; by subtracting water diverted into the river from the tailrace of the Wise power plant; and by adding estimated return flow to the river. The seasonal full natural run-offs at the Fairoaks gaging station are given in Table 5 in Chapter II.

The monthly full natural run-offs of the North Fork above its junction with the Middle Fork were estimated from the records obtained by the United States Geological Survey at the gaging station near Colfax for the 18-year period 1911–1929. The monthly full natural run-offs for the period of record were estimated from the measured run-offs by adding water stored in and subtracting water released from Lake Valley reservoir, and adding the net diversion from the watershed by the Towle or Lake Valley canal during the period each was in operation.

The monthly full natural run-offs of the Middle Fork above its junction with the North Fork were estimated from the records obtained by the United States Geological Survey at the gaging station near East Auburn, which is at the quarry of the Pacific Portland Cement Company, for the 18-year period 1911–1929. The monthly full natural run-offs for the period of record were estimated from the measured run-offs by adding the estimated amount of water diverted by the Pilot Creek Ditch.




COLOMA RESERVOIR
AUBURN RESERVOIR
AUBURN DAM
COLOMA DAM
WEBBER CREEK RESERVOIR
FOLSOM RESERVOIR
FOLSOM AFTERBAY
FOLSOM DAM
FOLSOM AFTERBAY DAM
PILOT CREEK RESERVOIR
PILOT CREEK DAM
WEBBER CREEK DAM
Elevation in feet U S G S datum
Distance in miles
PROFILE OF AMERICAN RIVER UNIT
PROFILE OF DAM
LOOKING UPSTREAM
Length in feet
GENERAL PLAN
FEET
AMERICAN RIVER
POWER HOUSE
LOCATION MAP
SCALE OF MILES
FOLSOM AFTERBAY DAM
POWER PLANT
FOLSOM DAM
POWER PLANT AND FLOOD CONTROL FEATURES
PILOT CREEK DAM
POWER PLANT
AUBURN DAM
POWER PLANT AND FLOOD CONTROL FEATURES
WEBBER CREEK DAM
POWER PLANT
COLOMA DAM
POWER PLANT AND FLOOD CONTROL FEATURES
AMERICAN RIVER UNIT

The monthly full natural run-offs of the South Fork were estimated from the records obtained by the United States Geological Survey at a station near Placerville from August, 1911, to July, 1920, and at the station near Camino from November, 1922, to September, 1929. The monthly full natural run-offs for the period of record were estimated from the measured run-offs by adding the estimated diversions by the Eldorado Irrigation Ditch; by adding water stored in and subtracting water released from the Twin Lakes, Medley Lakes and Silver Lake reservoirs; and by subtracting water diverted into the watershed from Echo Lake.

The variation in seasonal run-off from the American River watershed is shown by the values in Table 5 in Chapter II. The maximum seasonal full natural run-off in the 40-year period 1889–1929 occurred in 1889–1890 with a run-off of 8,749,000 acre-feet and the minimum was 543,000 acre-feet in 1923–1924, a variation of from 285 per cent to 18 per cent of the mean seasonal run-off for the same 40-year period.

The average monthly distribution of the run-off, as determined from the estimated monthly full natural run-offs at the Fairoaks gaging station, is shown in Table 94.

TABLE 94

AVERAGE MONTHLY DISTRIBUTION OF RUN-OFF OF AMERICAN RIVER AT FAIROAKS

Month	Average full natural run-off	
	In acre-feet	In per cent of mean seasonal
January	294,000	9.58
February	349,000	11.37
March	487,000	15.87
Apr l	558,000	18.18
May	607,000	19.78
June	383,000	12.48
July	111,000	3.62
August	25,100	0.82
September	17,500	0.57
October	31,400	1.02
November	68,000	2.21
December	138,000	4.50
Totals	3,069,000	100.00

The variation in mean daily flow at Fairoaks is indicated by the maximum recorded discharge of 120,000 second-feet with a crest flow of 184,000 second-feet on March 25, 1928, and 105,000 second-feet with a crest of 119,000 second-feet on March 19, 1907; and the minimum mean daily recorded flow of about five second-feet on several days in July and August, 1924.

Folsom Reservoir on American River.—The site for the dam which would create the Folsom reservoir is located in Section 24, Township 10 North, Range 7 East, M. D. B. and M., about two miles upstream from the town of Folsom and one mile below the junction of the North and South forks. The left abutment would lie within the boundaries of Folsom Prison.

The area of the drainage basin tributary to this site is 1875 square miles. This is 98 per cent of the area above the Fairoaks gaging station

The monthly full natural run-offs of the South Fork were estimated from the records obtained by the United States Geological Survey at a station near Placerville from August, 1911, to July, 1920, and at the station near Camino from November, 1922, to September, 1929. The monthly full natural run-offs for the period of record were estimated from the measured run-offs by adding the estimated diversions by the Eldorado Irrigation Ditch; by adding water stored in and subtracting water released from the Twin Lakes, Medley Lakes and Silver Lake reservoirs; and by subtracting water diverted into the watershed from Echo Lake.

The variation in seasonal run-off from the American River watershed is shown by the values in Table 5 in Chapter II. The maximum seasonal full natural run-off in the 40-year period 1889–1929 occurred in 1889–1890 with a run-off of 8,749,000 acre-feet and the minimum was 543,000 acre-feet in 1923–1924, a variation of from 285 per cent to 18 per cent of the mean seasonal run-off for the same 40-year period.

The average monthly distribution of the run-off, as determined from the estimated monthly full natural run-offs at the Fairoaks gaging station, is shown in Table 94.

TABLE 94

AVERAGE MONTHLY DISTRIBUTION OF RUN-OFF OF AMERICAN RIVER AT FAIROAKS

Month	Average full natural run-off	
	In acre-feet	In per cent of mean seasonal
January	294,000	9.58
February	349,000	11.37
March	487,000	15.87
Apr l	558,000	18.18
May	607,000	19.78
June	383,000	12.48
July	111,000	3.62
August	25,100	0.82
September	17,500	0.57
October	31,400	1.02
November	68,000	2.21
December	138,000	4.50
Totals	3,069,000	100.00

The variation in mean daily flow at Fairoaks is indicated by the maximum recorded discharge of 120,000 second-feet with a crest flow of 184,000 second-feet on March 25, 1928, and 105,000 second-feet with a crest of 119,000 second-feet on March 19, 1907; and the minimum mean daily recorded flow of about five second-feet on several days in July and August, 1924.

Folsom Reservoir on American River.—The site for the dam which would create the Folsom reservoir is located in Section 24, Township 10 North, Range 7 East, M. D. B. and M., about two miles upstream from the town of Folsom and one mile below the junction of the North and South forks. The left abutment would lie within the boundaries of Folsom Prison.

The area of the drainage basin tributary to this site is 1875 square miles. This is 98 per cent of the area above the Fairoaks gaging station and about nine per cent of the mountain and foothill area of the Sacramento River Basin. The run-off at the dam site, however, is greater than 98 per cent of that at the gaging station since the 44 square mile drainage area between the two points is not as productive of run-off as the area above the dam site.

Water Supply.—The full natural, ultimate net, and present net run-offs at the Folsom dam site were estimated by months for the 40-year period 1889–1929.

The monthly full natural run-offs at the dam site were estimated from those at the Fairoaks gaging station by subtracting the estimated run-offs from the area between these points. The run-offs from the latter portion of the watershed were estimated from the ratios of areas multiplied by mean seasonal precipitations on those areas, to be 7.27 per cent of the run-offs from the intermediate watershed lying between the Fairoaks, Colfax, East Auburn and Placerville gaging stations. Curves were first constructed for each month to show the relation of the full natural run-offs at the Colfax gaging station to those at Fairoaks, using the stream discharge records for a common period at both stations. Similar curves were drawn for the East Auburn and Placerville stations and, from the three sets of curves, for the intermediate area between the three upper stations and Fairoaks. Another curve was drawn showing the relationship of the run-offs from the portion of the watershed between the Folsom dam site and Fairoaks to those at the latter point. With the monthly run-off at Fairoaks as an index, the amount was obtained from this curve which when subtracted from the amount used as the index would give the monthly full natural run-off at the Folsom dam site.

The monthly ultimate net run-offs at the dam site were estimated from the monthly full natural run-offs by subtracting the diversions from all tributaries for the ultimate irrigation of lands both within the watershed and those lying outside of the watershed which it is estimated would be irrigated by American River water; by subtracting water which would be stored in and adding water which would be released from Lake Valley, Silver Lake, Twin Lakes, Medley Lake, and Webber Creek reservoirs and a number of other reservoirs now proposed and others which it is estimated would be required to furnish water for the irrigation uses mentioned in the first item; by adding water diverted into the watershed from Echo Lake and Wise power house; and by adding the return flow from the area which would be ultimately irrigated within the watershed both by American River water and by water imported from other streams.

The present net run-offs were estimated in the same manner as the ultimate net except that present diversions, storages, importations, and return flows were used.

The estimated seasonal full natural, ultimate net, and present net run-offs at the Folsom dam site are shown in Table 95.

Selection of Capacity of Reservoir.—The height selected for the Folsom dam is 190 feet. The Folsom reservoir created by this dam, if it were the only major reservoir unit on the American River, would not give as great a yield in water regulated for irrigation use as the run-off of the stream would warrant. Since, however, there are two other good reservoir sites, Auburn and Coloma, on the main forks of the river at relatively low elevations, it would not be necessary to construct a higher dam at Folsom than can be best adapted to the topography of and conditions at the site.

TABLE 95

SEASONAL RUN-OFFS OF AMERICAN RIVER AT FOLSOM DAM SITE, 1889-1929

Season	Full natural run-off, in acre-feet	Present net run-off, in acre-feet	Ultimate net run-off, in acre-feet
1889–1890	8,660,000	8,670,000	8,530,000
1890–1891	1,543,000	1,553,000	1,412,000
1891–1892	2,031,000	2,040,000	1,900,000
1892–1893	4,207,000	4,216,000	4,076,000
1893–1894	2,947,000	2,956,000	2,816,000
1894–1895	5,135,000	5,145,000	5,005,000
1895–1896	3,546,000	3,556,000	3,415,000
1896–1897	3,049,000	3,058,000	2,918,000
1897–1898	938,000	948,000	807,000
1898–1899	1,847,000	1,857,000	1,716,000
1899–1900	3,278,000	3,288,000	3,147,000
1900–1901	3,379,000	3,388,000	3,248,000
1901–1902	2,579,000	2,589,000	2,448,000
1902–1903	2,501,000	2,511,000	2,371,000
1903–1904	5,350,000	5,360,000	5,220,000
1904–1905	2,161,000	2,171,000	2,031,000
1905–1906	4,804,000	4,814,000	4,674,000
1906–1907	5,740,000	5,749,000	5,609,000
1907–1908	1,519,000	1,529,000	1,389,000
1908–1909	4,576,000	4,586,000	4,446,000
1909–1910	3,585,000	3,595,000	3,454,000
1910–1911	5,510,000	5,520,000	5,379,000
1911–1912	1,333,000	1,343,000	1,202,000
1912–1913	1,506,000	1,515,000	1,375,000
1913–1914	4,006,000	4,016,000	3,876,000
1914–1915	3,137,000	3,147,000	3,007,000
1915–1916	3,910,000	3,919,000	3,779,000
1916–1917	2,908,000	2,918,000	2,778,000
1917–1918	1,498,000	1,508,000	1,368,000
1918–1919	2,216,000	2,226,000	2,086,000
1919–1920	1,463,000	1,473,000	1,333,000
1920–1921	3,180,000	3,190,000	3,050,000
1921–1922	3,264,000	3,274,000	3,134,000
1922–1923	2,733,000	2,743,000	2,602,000
1923–1924	540,000	550,000	415,000
1924–1925	2,703,000	2,713,000	2,573,000
1925–1926	1,382,000	1,392,000	1,251,000
1926–1927	3,630,000	3,640,000	3,499,000
1927–1928	2,506,000	2,515,000	2,375,000
1928–1929	1,144,000	1,154,000	1,013,000
40-year means, 1889–1929	3,049,000	3,058,000	2,918,000
20-year means, 1909–1929	2,608,000	2,618,000	2,477,000
10-year means, 1919–1929	2,255,000	2,264,000	2,124,000
5-year means, 1924–1929	2,273,000	2,283,000	2,142,000

With the coordinated operation of the Auburn and Coloma reservoirs, hereinafter described, constructed to the sizes selected, and the Folsom reservoir with a 190-foot dam, a yield of 1,933,000 acre-feet per season with a maximum deficiency of 32 per cent in the driest year, would have been available in the 40-year period 1889–1929. This yield is equivalent to 66 per cent of the average ultimate net run-off at the Folsom dam site during the same 40-year period. This is a higher percentage of yield than would have been obtained on any other stream in the Sacramento Valley, except the Sacramento River at Red Bluff, during the same period. This yield is also about 2.5 times the gross allowance required for the American River water service area so that even with the height of dam selected for the Folsom reservoir a large amount of water would be available from the American River unit for irrigation in areas outside of its own water service area and for salinity control.

A dam higher than 190 feet could be constructed at the Folsom site but such a dam would be much longer than the one for the height selected. It also would cross the reservoir of the North Fork Ditch Company and the reservoir would flood the canal of this company and the Natomas Canal to such depths that they would have to be completely reconstructed at higher elevations or converted to enclosed conduits, or their operation would have to be changed by furnishing them with water from the Folsom reservoir, by pumping, during low stages of the reservoir. Also, several more and higher auxiliary dams would be required for reservoirs with main dams higher than 190 feet.

Taking into consideration the disadvantages of constructing a dam higher than 190 feet at Folsom and the very satisfactory yield that could be obtained with a dam 190 feet high, this height has been selected for the Folsom dam.

Reservoir Site.—The lands that would have to be acquired for the Folsom reservoir include both agricultural and grazing lands, with the area used for the latter being the larger. There are no towns within the area, the only settlement being that at Mormon Island.

TABLE 96

AREAS AND CAPACITIES OF FOLSOM RESERVOIR

Height of dam, in feet (5-foot freeboard)	[1]Water surface elevation of reservoir, in feet	Area of water surface, in acres	Capacity of reservoir, in acre-feet
80	280	920	29,000
90	290	1,150	39,500
100	300	1,400	52,200
110	310	1,600	67,700
120	320	1,980	85,600
130	330	2,350	107,300
140	340	2,800	133,000
150	350	3,300	163,800
160	360	3,900	200,000
170	370	4,610	242,500
180	380	5,460	293,800
190	390	6,460	355,000

[1] United States Geological Survey datum.

The other improvements that would be affected would be the North Fork, Natomas and Nigger Hill ditches and several miles of electric transmission line, telephone lines, and county roads. The North Fork Ditch takes out of the North Fork of the American River about 18.7 miles upstream from the dam site. The Natomas Canal takes out of the South Fork about 10.7 miles upstream from the dam site but does not follow the course of the stream to the site. The Natomas Canal would require relocation at a higher elevation for a portion of its length to give it clearance above the high water in the reservoir. The North Fork Ditch would require some protection, and the replacement of several flumes. A Pacific Gas and Electric Company steel tower single circuit electric transmission line crosses the reservoir site on the South Fork of the river. This would require five miles of relocation to take it out of the reservoir area. Six and three-fourths miles of county roads, together with the telephone lines paralleling them, also would have to be relocated.

A topographic survey of the Folsom reservoir site was made by the American River Hydroelectric Company in 1927 in connection with a proposed development at this site, and a map was drawn from this survey by the company with a contour interval of ten feet. The water surface areas measured from this map and the computed capacities of the reservoir are shown in Table 96.

Dam and Power Plant.—A survey of the dam site also was made by the American River Hydroelectric Company in 1927. A topographic map drawn from this survey at a scale of one inch equals 100 feet, with contour intervals of two and five feet, was used in laying out and estimating the costs of the Folsom dam and power plant.

A geological examination of the site was made and the report covering it, together with data on the location and logs of test holes drilled at the site by the American River Hydroelectric Company, may be found in Appendix E. The explorations indicate that the foundation is granite and suitable for a gravity concrete dam.

PLATE XXXVI

Folsom Dam Site on American River

With the 190-foot height of dam selected for this site, the flow line would be at elevation 390 feet United States Geological Survey datum and the top of the concrete dam at elevation 395 feet. The layout for this dam is shown on Plate XXXV. The main dam across the river would consist of a gravity concrete section with an earth fill section on the right abutment. Two auxiliary dams would be required in saddles on the rim of the reservoir. These auxiliary dams would be constructed of rolled earth fill with a rip rap facing. One of these dams would be 465 feet in length and fifteen feet high at its highest point, including a ten-foot freeboard, and the other would be 1200 feet in length with a maximum height of fifteen feet. The concrete section of the main dam would be 3570 feet in length, extending from the left abutment across the river channel to a point about 1250 feet beyond the edge of the river on the right side. It would include outlets for flood control and irrigation water release and also an overflow spillway. From the end of this concrete section to the right end of the dam, a distance of 1700 feet, the section would be of rolled earth fill. This earth fill section would have a concrete facing on the upstream side and a concrete cut-off wall along the upstream toe.

The concrete dam would rest on good firm granite which would require the removal of considerable amounts of decomposed surface rock and overlying soil. There would be a cut-off wall at the upstream toe, beneath which the foundation rock would be sealed by grouting. The foundation would be drained by a row of drainage wells, just downstream from the upstream cut-off wall, which would be connected to a gallery in the dam.

Diversion of the stream flow during the excavation for the foundation in the river channel and the construction of the lower portion of the dam would be accomplished by gravel fill coffer dams with steel sheet-piling core and cut-off walls above and below the excavation. The stream flow would be diverted through a concrete lined horseshoe shaped tunnel which would have a capacity of 5000 second-feet.

The spillway would be of the gravity concrete overflow type located in the main dam on the right bank of the stream. It would have a discharging capacity of 100,000 second-feet and the flow over it would be controlled by eight 50-foot hydraulically operated steel segmental drum gates sixteen feet in height set in the crest. These gates would be separated by concrete piers ten feet in width in which the operating mechanism would be located.

Flood control outlets would be provided through the concrete section of the main dam, on the left bank. These outlets would have a capacity of 100,000 second-feet with the water in the reservoir drawn down a sufficient depth to give the reserve space required for controlling floods to this amount. There would be eighteen openings fourteen feet square, spaced 30 feet center to center and located 60 feet below the top of the dam. Flow through each opening would be controlled by a caterpillar type self-closing sluice gate at the upstream face of the dam. Each gate would be protected by steel trash racks mounted in a semicircular concrete tower extending to the top of the dam from which point the gate would be operated.

Another battery of outlets to be operated for the release of irrigation water and as sluiceways would be located at a distance of 145 feet below the top of the dam. This battery would consist of five circular openings 98 inches in diameter lined with steel. Flow through each outlet would be controlled by a caterpillar type self-closing sluice gate at the upstream face of the dam, operated from the top of the dam, and a short distance below the inlet end, by an auxiliary slide gate operated from a chamber inside of the dam. Also, in order that a more accurate regulation of the irrigation releases might be obtained, one of the outlets would be equipped with a 98 inch balanced needle valve at its discharging end. Each caterpillar type gate would be protected by steel trash racks set in a semicircular concrete structure and would be operated in a concrete enclosed gate well extending to the top of the dam.

Channels would be excavated in the rock on the two banks of the river to carry the water discharged from the flood control outlets and spillway into the river channel below the dam. Each channel would be concrete lined for a short distance from the toe of the dam.

The power house would be located on the left bank of the stream about 800 feet below the Folsom Prison Diversion Dam and on the bank of the Folsom Canal. This power house location would be about one-half mile downstream from the main Folsom dam. Water would be conveyed to the power house from the reservoir by two concrete lined horseshoe shaped tunnels 19.2 feet in diameter. Each tunnel, at a distance of about 400 feet from the power house, would divide into three steel pipe penstocks 11.5 feet in diameter which would carry the water to the turbines in the power house. These pipes would be laid in separate concrete lined tunnels 15.5 feet in diameter. Water would enter each main tunnel through a concrete gate tower over a vertical concrete lined shaft. Water would enter the tower through several openings, flow through each of which would be controlled by a caterpillar type sluice gate operated from the top of the tower. Each gate would be protected by steel trash racks and would operate in a concrete enclosed gate well extending to the top of the tower.

Studies made to estimate the economic installation of generating equipment for this plant indicate that with a load factor of 0.75 and a power factor of 0.80 the total installed generator capacity should be 100,000 kilovolt amperes. This would be divided equally among six generators, each of which would be direct connected to a vertical shaft variable head reaction turbine. The power house would be of steel and concrete construction. Transformers and protective equipment would be of the outdoor type.

Yield of Reservoir in Water for Irrigation.—A study was made to estimate the amounts of water that would have been made available annually, during the 40-year period 1889–1929, at the dam site, for irrigation use, with the reservoir operated primarily for supplying irrigation water, and the amount of this yield that would have been new water. This study was made by the method described in the fore part of this chapter. It indicated that a seasonal irrigation draft of 800,000 acre-feet would have been obtainable with the Folsom reservoir operating alone. This draft would have had a maximum deficiency of 35 per cent in the driest year and an average of 2 per cent for the period. The yield in new water would have been 666,000 acre-feet with the same maximum deficiency.

Flood Control.—The control of floods on the American River by the Folsom, Auburn, and Coloma reservoirs has been described in a previous report* by this Division.

The data in Table 32 in Chapter VI show the probable frequency of occurrence of flood flows of certain amounts at the Fairoaks gaging station. The reservoir space required at this point to control flood flows which are expected to occur at different intervals of time, to

* Bulletin No. 24, "A Proposed Major Development on American River," Division of Water Resources, 1930, Chapter VI.

certain specified amounts below the gaging station are shown by the data in Table 35, in the same chapter.

By reserving 175,000 acre-feet of space in the Folsom reservoir, it may be seen from Table 35 that flood flows could be controlled to 100,000 second-feet at Fairoaks, exceeded one day in 100 years on the average. The effect of this control on the design of protective works along the American River has been described in Chapter VI. With the use of the Auburn and Coloma reservoirs for flood control, still greater reductions in flow or an increase in the average length of the period in which these flows would be exceeded, could be accomplished.

The effect of holding reserve space for controlling floods in the Folsom reservoir alone may be illustrated by applying the regulation to two of the largest floods of record. The largest flood, that of March, 1928, with a maximum mean daily discharge of 120,000 second-feet and a peak flow of 184,000 second-feet, would have been reduced to a maximum flow of 100,000 second-feet by the use of only 48,500 acre-feet of the reserve space. The flood of March, 1907, with a maximum mean daily flow of 105,000 second-feet and a peak flow of 119,000 second feet, would have required only 10,000 acre-feet for its control to a maximum flow of 100,000 second-feet.

Cost of Reservoir and Power Plant.—The estimate of the cost of the Folsom reservoir, as set forth in Table 97, was made as generally outlined in the fore part of this chapter and includes all of the items which have been briefly described in the foregoing paragraphs. The items included under miscellaneous in the cost estimate are a construction railroad from the Southern Pacific railroad to the dam site, a short railroad spur to the gravel pit, a permanent camp and cleaning up after construction.

TABLE 97

COST OF FOLSOM RESERVOIR WITH FLOOD CONTROL FEATURES

Height of dam, 190 feet. Capacity of reservoir, 355,000 acre-feet.
Capacity of overflow spillway, 100,000 second-feet.
Capacity of flood control outlets, 100,000 second-feet.

Exploration and core drilling		$30,000
Diversion of river during construction		109,000
Clearing reservoir site		162,000
Excavation for dam, 389,000 cu. yds. at $1 to $5	$877,000	
Mass concrete, 510,000 cu. yds. at $6.30	3,213,000	
Reinforced concrete, 5700 cu. yds. at $15 to $23.50	99,000	
Earthfill section main dam	44,000	
Auxiliary earth dams	43,000	
Spillway gates	160,000	
Spillway and flood control channels	200,000	
Irrigation outlets and sluiceways	188,000	
Flood control features	486,000	
Drilling and grouting foundation	81,000	
		5,391,000
Lands and improvements flooded		1,157,000
Miscellaneous		155,000
Subtotal		$7,004,000
Administration and engineering, 10 per cent		700,000
Contingencies, 15 per cent		1,051,000
Interest during construction, based on a rate of 4.5 per cent per annum		745,000
Total cost of dam and reservoir		$9,500,000

The estimated cost of the power plant with an installed generator capacity of 100,000 kilovolt amperes, including the inlet structure, tunnel, penstocks and power house is given in Table 98.

TABLE 98

COST OF POWER PLANT FOR FOLSOM RESERVOIR

Installed capacity, 100,000 kilovolt amperes.
Power factor = 0.80. Load factor = 0.75.

Intake structure	$202,000
Penstocks	1,582,000
Building and equipment	2,575,000
Subtotal	$4,359,000
Administration and engineering, 10 per cent	436,000
Contingencies, 15 per cent	654,000
Interest during construction, based on a rate of 4.5 per cent per annum	251,000
Total cost of power plant	$5,700,000

The total estimated capital cost of the Folsom reservoir and its power plant would be $15,200,000.

The annual costs of the reservoir and power plant estimated on the bases given in the fore part of this chapter and for the capital costs given in Table 97 and Table 98, would be $601,000 and $452,000, respectively, or a total of $1,053,000.

Folsom Afterbay on American River.—With the Folsom reservoir operating for the generation of hydroelectric energy, the amount of water released through the power plant would vary throughout the day and week, unless the plant were operated on a unity load factor. If the water released for power generation is to be used for irrigation, these fluctuating flows should be converted to uniform ones by reregulation in an afterbay reservoir located between the tail race of the plant and the point of irrigation diversion.

Below the Folsom dam site, the American River flows through a rocky gorge to the town of Folsom. There are several acceptable sites for low dams in this section of the river. The one selected for the afterbay is located about 800 feet above the highway bridge at the town of Folsom. The capacity of the afterbay selected exceeds that required for reregulation but the additional height of dam is economically justified for the creation of head for the generation of power.

Reservoir Site.—The reservoir would be about 1½ miles in length, would have an average width of about 500 feet, and would extend upstream to the power plant of the Folsom reservoir. The maximum water surface elevation would be limited to 195 feet to avoid flooding the railroad from the town of Folsom to the State Prison.

Dam and Power Plant.—A map of the American River Canyon, at a scale of one inch equals 400 feet, with a contour interval of ten feet, drawn from a survey made by the State in 1925, was used for laying out the Folsom afterbay dam and power plant and for estimating the capacities of the afterbay.

The dam would have a height of 84 feet and a length along the crest of 860 feet. The stream bed at the site is about 200 feet wide. The dam would be of the gravity concrete overflow type with the spillway section located in the center of the structure. The abutments would be of the gravity concrete type with a freeboard of ten feet. No special geological investigation has been made of the site. It appears to be of a good quality of granitic rock exposed at the stream bed and without excessive overburden or decomposition.

PLATE XXXVII

Folsom Afterbay Dam Site on American River

The spillway would have a total length of 470 feet and a discharging capacity of 190,000 second-feet. Flow over it would be controlled by eight 50-foot hydraulically operated steel segmental drum gates 25 feet high separated by ten-foot concrete piers in which the operating mechanism would be located. There also would be a similar gate 15 feet by 60 feet across the power canal capable of discharging 13,000 second-feet.

Two sluiceways five feet in diameter, lined with steel, would be provided at a depth of 70 feet below the top of the dam. Flow through each outlet would be controlled by a caterpillar type self-closing sluice gate operated from the top of the dam. This gate would be protected by steel trash racks set in a semicircular concrete structure and would operate in a concrete enclosed gate well extending to the top of a spillway pier.

During the period of construction the stream would be diverted around the dam site. This would be accomplished by means of coffer dams and tunnels. The tunnels would be used afterwards as conduits to the power plant.

The layout of the dam and power plant is shown on Plate XXXV. The power house would be located at the edge of the river on the right bank about 850 feet below the dam and would be a reinforced concrete and steel structure founded on bedrock. The conduit from the reservoir to the plant would consist of two concrete lined horse-shoe shaped tunnels 17.4 feet in diameter. Each tunnel would divide into two steel penstocks 154 inches in diameter, a short distance from the power house. Water would be admitted to the tunnels through reinforced concrete gate towers similar to those for the Folsom power plant. The generating equipment would consist of four 6250 kilovolt ampere generators direct connected to low head vertical shaft reaction turbines. The power plant would operate on a load factor of 1.00 and have an estimated plant efficiency of 75 per cent.

Power Output.—The only yield of the afterbay would be in power output from the reregulated water from the Folsom reservoir. The seasonal and monthly variations of this power would be dependent upon the releases from the Folsom reservoir since water from this afterbay would be used for the generation of power without holdover storage of more than one or two days. The only studies made of the power output from this afterbay are those made in connection with the output from the operation of the entire American River unit. These studies are discussed later in this chapter.

Cost of Reservoir and Power Plant.—The cost of the Folsom afterbay and power plant were estimated by the method generally outlined in the fore part of this chapter and are shown in Table 99.

TABLE 99

COST OF FOLSOM AFTERBAY AND POWER PLANT

Height of dam, 84 feet.
Installed capacity of power plant, 25,000 kilovolt amperes.
Power factor = 0.80. Load factor = 1.00.

Dam and Reservoir.		
Exploration and core drilling		$10,000
Diversion of river during construction		10,000
Excavation for dam, 45,000 cu. yds. at $2.50 to $5	$178,000	
Mass concrete, 86,000 cu. yds. at $6.30	542,000	
Reinforced concrete, 1,000 cu. yds. at $15.50	16,000	
Spillway gates	340,000	
Sluiceways and canal outlet	40,000	
Drilling and grouting foundation	19,000	
		1,135,000
Lands flooded		5,000
Subtotal		$1,160,000
Administration and engineering, 10 per cent		116,000
Contingencies, 15 per cent		174,000
Interest during construction based on a rate of 4.5 per cent per annum		50,000
Total cost of dam and reservoir		$1,500,000
Power Plant.		
Intake structure		$135,000
Penstocks		267,000
Building and equipment		1,375,000
Lands and improvements		400,000
Subtotal		$2,177,000
Administration and engineering, 10 per cent		218,000
Contingencies, 15 per cent		327,000
Interest during construction based on a rate of 4.5 per cent per annum		78,000
Total cost of power plant		$2,800,000
Total cost of dam, reservoir and power plant		$4,300,000

The annual cost of the afterbay and power plant estimated on the bases outlined in the fore part of this chapter would be $300,000. Of this, the annual cost of the dam and reservoir would be $94,000 and of the power plant $206,000.

Auburn Reservoir on North Fork of American River.—The dam site for the Auburn reservoir is located in Section 11, Township 12 North, Range 8 East, M. D. B. and M., 1.4 miles downstream from the junction of the North and Middle forks and almost due east of the city of Auburn.

The area of the drainage basin tributary to this site is 965 square miles or 50.4 per cent of the total area above the Fairoaks gaging station. The watershed is rough mountainous land extending to the crest of the Sierra Nevada. It is the most productive portion of the American River Basin in run-off. The Middle Fork joins the North Fork within the reservoir site so that the drainage areas of both of these forks above the city of Auburn are tributary to the reservoir.

TABLE 100

SEASONAL RUN-OFFS OF NORTH FORK OF AMERICAN RIVER AT AUBURN DAM SITE, 1889-1929

Season	Full natural run-off, in acre-feet	Present net run-off, in acre-feet	Ultimate net run-off, in acre-feet
1889-1890	5,107,000	5,095,000	4,945,000
1890-1891	925,000	913,000	762,000
1891-1892	1,217,000	1,205,000	1,055,000
1892-1893	2,545,000	2,533,000	2,382,000
1893-1894	1,770,000	1,758,000	1,607,000
1894-1895	3,047,000	3,035,000	2,884,000
1895-1896	2,097,000	2,085,000	1,934,000
1896-1897	1,859,000	1,847,000	1,696,000
1897-1898	561,000	549,000	399,000
1898-1899	1,116,000	1,104,000	954,000
1899-1900	1,988,000	1,976,000	1,825,000
1900-1901	2,043,000	2,031,000	1,881,000
1901-1902	1,560,000	1,549,000	1,398,000
1902-1903	1,510,000	1,499,000	1,348,000
1903-1904	3,252,000	3,241,000	3,070,000
1904-1905	1,285,000	1,273,000	1,122,000
1905-1906	2,830,000	2,818,000	2,667,000
1906-1907	3,458,000	3,446,000	3,296,000
1907-1908	909,000	897,000	746,000
1908-1909	2,662,000	2,650,000	2,500,000
1909-1910	2,211,000	2,199,000	2,048,000
1910-1911	3,269,000	3,257,000	3,106,000
1911-1912	786,000	775,000	624,000
1912-1913	904,000	892,000	742,000
1913-1914	2,353,000	2,341,000	2,190,000
1914-1915	1,896,000	1,884,000	1,733,000
1915-1916	2,351,000	2,339,000	2,188,000
1916-1917	1,747,000	1,735,000	1,584,000
1917-1918	904,000	892,000	741,000
1918-1919	1,344,000	1,332,000	1,181,000
1919-1920	881,000	869,000	718,000
1920-1921	1,917,000	1,905,000	1,754,000
1921-1922	1,977,000	1,965,000	1,814,000
1922-1923	1,649,000	1,637,000	1,487,000
1923-1924	332,000	320,000	178,000
1924-1925	1,649,000	1,637,000	1,486,000
1925-1926	846,000	834,000	683,000
1926-1927	2,224,000	2,212,000	2,062,000
1927-1928	1,546,000	1,534,000	1,383,000
1928-1929	684,000	672,000	522,000
40-year means, 1889-1929	1,830,000	1,818,000	1,667,000
20-year means, 1909-1929	1,573,000	1,562,000	1,411,000
10-year means, 1919-1929	1,370,000	1,359,000	1,209,000
5-year means, 1924-1929	1,390,000	1,378,000	1,227,000

Water Supply.—The full natural, ultimate net and present net run-offs at the Auburn dam site were estimated for the 40-year period 1889-1929, by months.

The monthly full natural run-off curves drawn for the Colfax, East Auburn and Placerville gaging stations, showing the relation of the run-offs at these stations to those at Fairoaks, as described under the water supply for the Folsom reservoir, were again used. The curves for the intermediate area between the three upper stations and Fairoaks also were used. The run-off from the area between Colfax and East Auburn gaging stations and the Auburn dam site was estimated to be 13.12 per cent of that from the total intermediate area. Another set of monthly full natural run-off curves for the Auburn dam site were drawn by combining the curves for the Colfax and East Auburn gaging stations and 13.12 per cent of the run-off from the intermediate area. Those curves show the relation of monthly run-off at the Auburn dam site to that at Fairoaks. With the run-offs at the latter point as indices, the monthly full natural run-offs at the dam site were taken from the curves.

The monthly ultimate net run-offs at the dam site were estimated from the monthly full natural run-offs, by subtracting water diverted for the ultimate irrigation of lands within the watershed above Auburn; by subtracting water stored in Lake Valley reservoir; by subtracting water which would be stored in and adding water which would be released from a number of reservoirs now proposed and others which would be necessary to furnish water for the ultimate irrigation of lands within the watershed and foothill lands lying outside that would be served by water from the North and Middle forks; and by adding the return flow from the area which ultimately would be irrigated within the watershed. Water required for use on the foothill areas outside of the watershed would pass through the Auburn reservoir and would be available for the generation of power at its power plant but would not be available for reregulation in the Folsom reservoir.

The monthly present net run-offs were estimated in the same manner as the ultimate net except that present diversions, storage and return flows were used. In this case, the present diversion by the North Fork Ditch would pass through the Auburn reservoir but would not be available to the Folsom reservoir.

The estimated seasonal full natural, ultimate net and present net run-offs at the Auburn dam site are shown in Table 100.

Reservoir Site.—The lands that would have to be acquired for the Auburn reservoir lie in the river channel and on steep rocky slopes. There are no towns and very few people live within the reservoir area. The major improvements that would be flooded are the quarry of the Pacific Portland Cement Company, the branch railroad running to it from Auburn, a portion of the State highway from Auburn to Placerville, and a portion of the county road from Auburn to Forest Hill.

A topographic survey of the reservoir site was made by the American River Hydroelectric Company in 1928 and a map was drawn from this survey by the company at a scale of one inch equals 400 feet, with a contour interval of 20 feet. The water surface areas measured from this map and the computed capacities are shown in Table 101.

Dam and Power Plant.—A survey of the dam site also was made by the American River Hydroelectric Company in 1928. A topographic map drawn from this survey at a scale of one inch equals 100 feet, with a contour interval of 10 feet, was used in laying out and estimating the costs of the Auburn dam and power plant.

The site is topographically favorable for a dam somewhat over 440 feet in height. The stream channel at the site is 150 feet wide and at 440 feet above low water the canyon is only 1800 feet wide. No core drillings or other explorations of the site were made but a detailed geological examination was made, the report on which may be found in Appendix E. The geologist has classified the foundation rock at the site as amphibolite schist and states that the site is an excellent one, with foundations satisfactory for a major structure. Considerable excavation would be required, however, to obtain firm unweathered rock for the foundation and also to remove a fairly deep soil covering.

TABLE 101

AREAS AND CAPACITIES OF AUBURN RESERVOIR

Height of dam, in feet (5-foot freeboard)	[1]Water surface elevation of reservoir, in feet	Area of water surface, in acres	Capacity of reservoir, in acre-feet
30	540	86	900
50	560	148	3,300
70	580	203	6,800
90	600	283	11,600
110	620	426	18,700
130	640	597	29,000
150	660	774	42,700
170	680	968	60,100
190	700	1,244	82,200
210	720	1,467	109,300
230	740	1,692	140,900
250	760	1,937	177,200
270	780	2,200	218,600
290	800	2,508	265,700
310	820	2,804	318,800
330	840	3,143	378,200
350	860	3,480	444,500
370	880	3,830	517,600
390	900	4,206	598,000
410	920	4,575	686,000
430	940	4,945	781,000
440	950	5,130	831,000
450	960	5,441	884,000

[1] United States Geological Survey datum.

Estimates of cost were made for four heights of dam from 290 to 440 feet at 50-foot intervals. The detailed estimate and layout for only one of these heights, 440 feet, are shown in this report. The features of this dam are typical of those of the dams of other heights and are described herein for illustration. The layout for this dam is shown on Plate XXXV.

The dam would be of the gravity concrete type slightly arched in plan. There would be a cut-off wall at the upstream toe, beneath which the foundation rock would be sealed by grouting. The foundation would be drained by a row of drainage wells, just downstream from the upstream cut-off wall, which would be connected to a gallery in the dam.

Diversion of the stream flow during the excavation for the foundation and the construction of the lower portion of the dam would be accomplished by means of rock fill coffer dams with earth blankets placed above and below the excavation in the stream bed. The diverted water would be carried around the excavation by a concrete lined horseshoe shaped tunnel having a capacity of 4000 second-feet.

The spillway would be located in the right abutment of the dam and would have a discharging capacity of 120,000 second-feet. It would be divided into seven openings and the flow through each would be controlled by a hydraulically operated steel segmental drum gate 50 feet long and 20 feet high. Ten-foot concrete piers in which the operating mechanism would be located, would separate these gates. The water from the spillway would be allowed to reach the stream channel by flowing over the bedrock surface.

PLATE XXXVIII

Auburn Dam Site on North Fork of American River

Outlets would be provided in the left abutment of the dam for flood control. These outlets would have a capacity of 50,000 second-feet with the water in the reservoir drawn down a sufficient depth to give the reserve storage space required for controlling floods to this amount. There would be sixteen openings each ten feet square spaced 20 feet center to center and located 45 feet below the top of the dam. Flow through each outlet would be controlled by a caterpillar type self-closing sluice gate at the upstream face of the dam operated from the top of the dam. Each gate would be protected by steel trash racks mounted in a semicircular concrete tower extending to the top of the dam.

Another battery of outlets to be used both for the release of irrigation water and as sluiceways, would be provided in the section of the dam over the stream channel. This battery would consist of four circular openings 78 inches in diameter, lined with steel. Two of these outlets would be at a depth of 240 feet below the top of the dam and the other two would be at a depth of 370 feet. Flow through each outlet would be controlled by a caterpillar type sluice gate at the upstream face of the dam, and auxiliary control would be provided by a slide gate, operated from a chamber inside of the dam, near the upstream face. Each caterpillar type gate would be protected by steel trash racks mounted in a semicircular concrete structure and would operate in a concrete enclosed gate well extending to the top of the dam. In order to obtain more accurate regulation of the irrigation releases, one of the lower outlets would be equipped with a 78-inch balanced needle valve at the discharging end.

The power house would be located below a bend in the river 2400 feet downstream from the dam. Water would be conveyed to it from the reservoir by a concrete lined horseshoe shaped tunnel 15.7 feet in diameter contructed through the point of the mountain forming the bend. At a distance of 200 feet from the power house, the tunnel would divide into four steel pipe penstocks 98 inches in diameter which would carry the water to the turbines in the power house. These steel pipes would be laid in separate concrete lined tunnels 12.2 feet in diameter. Water would enter the main tunnel through a concrete gate tower similar to that described for the Folsom power plant. It is estimated that the economic capacity of the generating equipment to be placed in the power house, with a load factor of 0.75 and a power factor of 0.80, would be 85,000 kilovolt amperes. This would be divided equally among four units. Each generator would be direct connected to a vertical shaft variable head reaction turbine. The power house would be of concrete and steel construction. Transformers and protective equipment would be of the outdoor type.

Yield of Reservoir in Water for Irrigation.—Studies were made to estimate the amounts of water that would have been made available at the dam site for irrigation use, with the reservoir operated primarily for this purpose, in each of the years from 1889 to 1929, and the amounts of these yields that would have been new water. These studies were made for the four heights of dam previously mentioned, by the methods described in the fore part of this chapter. The total yield and the yield in new water for each of these four heights, are given in Table 104. In making these studies, the entire capacity of the reservoir was utilized in the years of deficiency in supply. The yields are those that would have been obtained with a maximum seasonal deficiency not exceeding 35 per cent and an average for the 40-year period not exceeding two per cent.

Flood Control.—Under the heading of ''Flood Control'' in the Folsom reservoir description, reference is made to the discussion of this subject for the American River in Bulletin No. 24 of the Division of Water Resources. It is shown in that bulletin that 175,000 acre-feet of reservoir space is required to control flows at Fairoaks to a maximum of 100,000 second-feet exceeded one day in 100 years on the average.

An increased degree of protection could be obtained along the river below Folsom by utilizing space in the Auburn reservoir for flood control. Any space so provided in this reservoir could be considered as the equivalent of space in the Folsom reservoir, if, with a flood of a given occurrence at Folsom reservoir, there is assurance that a flow would occur at the Auburn reservoir large enough to fill the space allotted for flood control in that reservoir. Thus, if 90,000 acre-feet of space were reserved in the Auburn reservoir and 175,000 acre-feet were reserved in the Folsom reservoir, there would be an aggregate space of 265,000 acre-feet utilizable for flood control. With this space all available in the Folsom reservoir it would be possible to control the flow in the American River at Fairoaks to 76,000 second-feet exceeded one day in 100 years on the average. Folsom reservoir alone with 175,000 acre-feet of space would control flows to 76,000 second-feet exceeded about one day in 25 years on the average. It is estimated that a flood of a volume that would be exceeded one day in 25 years on the average at Folsom reservoir, would have sufficient flow at Auburn reservoir to fill the entire space of 90,000 acre-feet allotted in that reservoir. Consequently, it is believed that it would be possible to control the flow of the American River below Folsom to 76,000 second-feet exceeded one day in 100 years on the average, with 175,000 acre-feet of space in Folsom reservoir and 90,000 acre-feet of space in Auburn reservoir, there being an assurance that the space in Auburn reservoir would be entirely filled by a flood of the magnitude that would be exceeded one day in 100 years on the average.

In a similar manner, it was estimated that with the above amounts of space in Folsom and Auburn reservoirs it would be possible to control the flow at Fairoaks to 89,000 second-feet exceeded one day in 250 years on the average.

Cost of Reservoir and Power Plant.—Estimates of the cost of the Auburn reservoir were prepared for the four heights of dam previously mentioned. These estimates were made as generally outlined in the fore part of this chapter and include all of the items, except the power plant, which have been briefly described in the foregoing paragraphs. The costs are listed in Table 104.

A somewhat detailed estimate for the reservoir having a 440-foot dam is given in Table 102. In this table, the items included under miscellaneous are a permanent camp and cleaning up after construction. The same items and similar unit prices to those shown in Table 102 were used in estimating the costs of reservoirs with other heights of dam.

TABLE 102

COST OF AUBURN RESERVOIR WITH FLOOD CONTROL FEATURES

Height of dam, 440 feet. Capacity of reservoir, 831,000 acre-feet.
Capacity of spillway, 120,000 second-feet.
Capacity of flood control outlets, 50,000 second-feet.

Exploration and core drilling		$30,000
Diversion of river during construction		100,000
Clearing reservoir site		318,000
Excavation for dam, 619,000 cu. yds. at $2.50 to $5	$1,719,000	
Mass concrete, 2,132,000 cu. yds. at $6.50	13,858,000	
Reinforced concrete, 3800 cu. yds. at $15 to $23	65,000	
Spillway gates	210,000	
Irrigation outlets and sluiceways	222,000	
Flood control features	231,000	
Drilling and grouting foundation	42,000	
		16,347,000
Lands and improvements flooded		855,000
Miscellaneous		50,000
Subtotal		$17,700,000
Administration and engineering, 10 per cent		1,770,000
Contingencies, 15 per cent		2,655,000
Interest during construction based on a rate of 4.5 per cent per annum		1,875,000
Total cost of dam and reservoir		$24,000,000

The estimated cost of the 85,000 kilovolt ampere power plant previously described in connection with the 440-foot dam, is shown in Table 103.

TABLE 103

COST OF POWER PLANT FOR AUBURN RESERVOIR WITH 440-FOOT DAM

Installed capacity, 85,000 kilovolt amperes.
Power factor = 0.80. Load factor = 0.75.

Intake structure	$201,000
Penstocks	495,000
Building and equipment	2,280,000
Subtotal	$2,976,000
Administration and engineering, 10 per cent	298,000
Contingencies, 15 per cent	446,000
Interest during construction based on a rate of 4.5 per cent per annum	180,000
Total cost of power plant	$3,900,000

The total estimated capital cost of the Auburn reservoir with a 440-foot dam, and its power plant, would be $27,900,000.

The annual cost of each reservoir without a power plant was estimated on the bases given in the fore part of this chapter and is given in Table 104. The annual costs of the Auburn reservoir and power plant based on the capital costs given in Tables 102 and 103 are estimated to be $1,429,000 and $323,000, respectively, or a total of $1,752,000.

Comparison of Sizes of Reservoir.—The principal use of the reservoirs on the American River would be for flood control and the regulation of water for irrigation and salinity control. Although the salinity control demands would vary somewhat from those for irrigation, and the costs per acre-foot of water for the two purposes would be different, they are comparable as to relative costs of regulated water from the reservoirs. Comparisons of reservoirs of different capacities at the Auburn site, therefore, were made on the basis of the cost of storage, the costs of the total seasonal irrigation yield and yield in new water, the cost of the reservoir per acre-foot increase in each of these items, and the annual costs for irrigation water for both the total yield and the yield in new water. These items are given in tabular form in Table 104, and the comparisons are shown graphically on Plate XXXIX, "Cost of Reservoir Capacity and Unit Yield of Water for Irrigation From Auburn Reservoir." The capital costs do not include the costs of power features and the annual costs are gross costs from which no deductions have been made for revenue from the sale of electric energy. The generation of such energy, however, is economically justified since the revenue from its sale would be more than sufficient to cover the annual costs of the power features. The net revenue, therefore, would help to defray the other costs of the project, thereby reducing the costs per acre-foot of total seasonal irrigation yield and yield in new water set forth in Table 104.

The seasonal irrigation yields shown in Table 104 are those which would have been available at the Auburn dam site. A study also was made to estimate the seasonal irrigation yields at Folsom with the Auburn reservoir having a 440-foot dam operated as the only major unit on the American River. The maximum irrigation yields, with deficiencies similar to those shown in Table 104, estimated in this study, are those which would have been available at Folsom with the Auburn reservoir operated to supplement the unregulated flows at that point. With this method of operation, the total seasonal irrigation yield at Folsom would have been 1,135,000 acre-feet and the yield in new water 1,001,000 acre-feet. The annual cost per acre-feet of total irrigation yield would have been $1.26 and the cost per acre-foot of new water $1.43.

Selection of Capacity of Reservoir.—The Auburn reservoir alone would have insufficient yield to serve as an initial unit in the Sacramento River Basin and, therefore, has been used only as one of the reservoirs of the American River unit. Each of the storage reservoirs of this unit, however, was studied independently with the idea of selecting the most economical size. The data in Table 104 and the curves on Plate XXXIX indicate that the cost per acre-foot of yield

TABLE 104

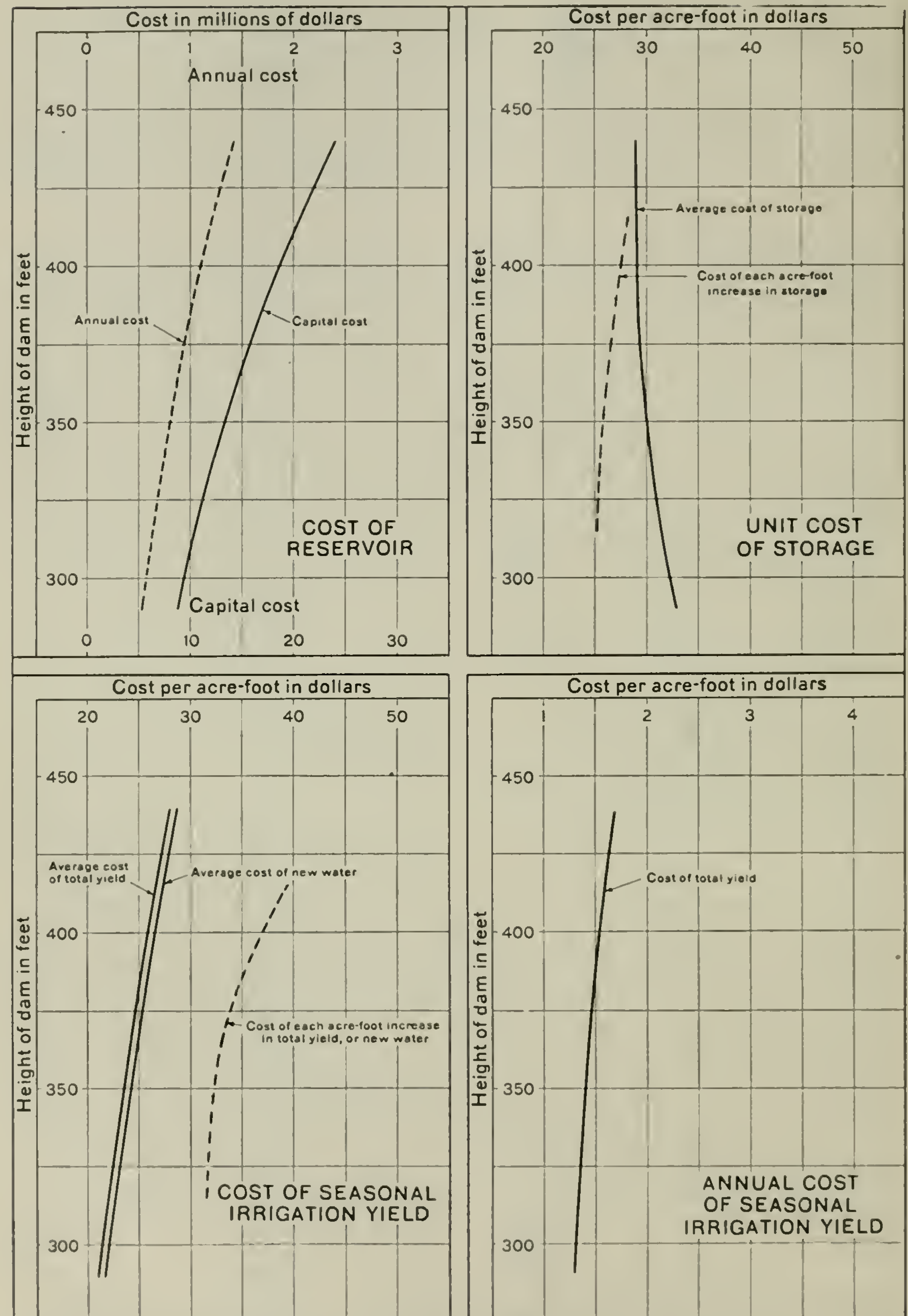
COST OF RESERVOIR CAPACITY AND UNIT YIELD OF WATER FOR IRRIGATION FROM AUBURN RESERVOIR

With Flood Control Features and Without Power Plant

Height of dam, in feet	Elevation of water surface, in feet	Capacity of reservoir, in acre-feet	Seasonal irrigation yield[1]		Cost of reservoir		Capital cost, per acre-foot						Annual cost per acre-foot of irrigation yield	
							Total storage	Increase in storage	Irrigation yield		Increase in irrigation yield			
			Total yield, in acre-feet	New water, in acre-feet	Capital	Annual			Total yield	New water	Total yield	New water	Total yield	New water
290	800	266,000	420,000	405,000	$8,800,000	$541,000	$33 10		$21 00	$21 70			$1 29	$1 34
340	850	412,000	537,000	522,000	12,500,000	757,000	30 30	$25 30	23 30	23 90	$31 60	$31 60	1 41	1 45
390	900	598,000	686,000	671,000	17,400,000	1,044,000	29 10	26 30	25 40	25 90	32 90	32 90	1 52	1 56
440	950	831,000	853,000	838,000	24,000,000	1,429,000	28 90	28 30	28 10	28 60	39 50	39 50	1 68	1 71

[1] Entire capacity of reservoir utilized in years of deficiency in supply. Yields shown are based on run-off for the 40-year period 1889-1929, and are those which would have been available at the dam site. Each yield would have had a maximum seasonal deficiency not exceeding 35 per cent and an average deficiency for the 40-year period not exceeding two per cent.

PLATE XXXIX



COST OF RESERVOIR CAPACITY AND UNIT YIELD OF WATER FOR IRRIGATION FROM AUBURN RESERVOIR in irrigation water from the Auburn reservoir would increase as the height of dam, or size of reservoir, is increased. The rate of increase in cost is not great, however, and the annual cost of yield per acre-foot is lower for any height of dam than it is for any major reservoir unit of the State Water Plan in the Sacramento River Basin except the Kennett, Folsom and Coloma reservoirs, and is very little higher than for any of these.

The lower right hand curve on Plate XXXIX indicates that the rate of increase in annual cost is almost constant up to a height of dam of 390 feet and then increases slightly for higher dams. With a dam 390 feet high, the total seasonal irrigation yield would be only 41.2 per cent of the mean seasonal ultimate net run-off at the dam site for the 40-year period 1889–1929. With a 440-foot dam, this yield would be increased to 51.2 per cent and the annual cost of irrigation water would be increased only 20 cents per acre-foot. The 440-foot height of dam, therefore, was selected for the Auburn reservoir.

Pilot Creek Reservoir on North Fork of American River.—With the Auburn reservoir constructed and operated for the generation of hydroelectric energy, the flow in the river below the tail race of the power plant would be subject to large daily and weekly fluctuations. However, as Auburn reservoir probably would not be constructed prior to the construction of Folsom reservoir, and as any irrigation diversion that would be made between the two sites could be provided for without reregulation, it is believed that no afterbay would be necessary between the reservoirs for reregulation.

There is, however, a fall in the river between the Auburn power house site and the high water level in the Folsom reservoir of about 125 feet, and the development of 110 feet of this potential head as a power drop, by the construction of a dam at the Pilot Creek site about one-half mile below the mouth of Pilot Creek and about three miles upstream from Rattlesnake Bridge, would be economically justified with the Auburn reservoir constructed.

Water Supply.—The water available for power generation would be the same as the releases and spill from the Auburn reservoir less the diversions for the irrigation of the area lying between the American and Bear rivers, which it is estimated would receive its supply from the American River above the Pilot Creek dam. These diversions would include the present rights of the North Fork Ditch. The possible increment to the flow, originating on the area between the Auburn and Pilot Creek dams, was not included in estimating the power output at the Pilot Creek dam.

Reservoir Site.—The reservoir would be about six miles long and would lie entirely within the canyon of the North Fork of the American River. The dam would be constructed high enough to back water up to the tail race of the Auburn power plant at an elevation of 515 feet. The lands that would be flooded are of small value. The intake of the North Fork Ditch Company's canal and about 3.5 miles of canal would be submerged. Provision would be made for furnishing a water supply to the canal by constructing an outlet through the dam to discharge into the existing canal below the dam. This procedure would eliminate relocating the canal and maintenance charges thereon above the dam.

Dam and Power Plant.—A survey of the dam site was made by the American River Hydroelectric Company in 1928. A topographic map drawn from this survey at a scale of one inch equals 100 feet, with a contour interval of ten feet, was used in laying out and estimating the costs of Pilot Creek dam and power plant.

The site for the dam is topographically favorable not only for the proposed dam but also for one of considerably greater height. There have been no borings or other explorations of the foundation for the dam but a geological examination of the site and its vicinity was made. The geological report on the site appears in Appendix E. The canyon walls rise at steep angles from the narrow streambed and the rock is reported by the geologist to be a massive amphibolite. The streambed is comparatively free from gravel and firm rock should be found at shallow depths.

PLATE XL

Pilot Creek Dam Site on North Fork of American River

The dam would be of the gravity concrete overflow type for its entire length. No provision would be made for crest gates. During periods of flood flows, this would cause backwater on the Auburn power plant with a resulting slight decrease of head at that plant and a corresponding increase of head at the Pilot Creek plant. The dam would be 110 feet high and have a crest length of about 470 feet. The foundation would be sealed by grouting, and drainage wells would be drilled just downstream from the upstream toe of the dam and connected to a gallery in the dam.

The stream flow would be diverted during construction in a manner similar to that described for Auburn dam.

With a depth of water of 20 feet over the crest of the dam, the discharging capacity would be comparable to that of Auburn dam, or 170,000 second-feet.

The layout for the dam and power plant are shown on Plate XXXV. The power house would be located on the left bank of the river about 500 feet below the dam. Water would be conveyed to it by a concrete lined horseshoe-shaped tunnel 16.1 feet in diameter which, opposite the power house, would divide into four steel pipe penstocks 98 inches in diameter, laid down the face of the canyon side to the power house. Water would enter the tunnel through a concrete gate structure having two caterpillar-type sluice gates for controlling the flow. It is estimated that the capacity of the plant, with a load factor of 0.75 and a power factor of 0.80, should be 25,000 kilovolt amperes. This would be divided equally among four generators each of which would be direct connected to a vertical shaft reaction turbine. The power house building would be of steel and concrete construction. Transformers and protective equipment would be of the outdoor type.

Power Output.—The yield from this unit would be electric energy generated by part of the water passing Auburn reservoir. The seasonal and monthly variations of this energy would be dependent upon the releases from that reservoir since the released water would be used for the generation of power without holdover storage. The only studies of the electric energy output from the Pilot Creek plant were those made in connection with the output from the operation of the entire American River unit. These studies are discussed later in this chapter.

Cost of Reservoir and Power Plant.—The cost of the Pilot Creek unit was estimated by the methods generally outlined in the fore part of this chapter and is shown in Table 105.

TABLE 105

COST OF PILOT CREEK RESERVOIR AND POWER PLANT

Height of dam, 110 feet.
Installed capacity of power plant, 25,000 kilovolt amperes.
Power factor = 0.80. Load factor = 0.75.

Dam and Reservoir		
Exploration and core drilling		$10,000
Diversion of river during construction		50,000
Clearing reservoir site		16,000
Excavation for dam, 35,000 cu. yds. at $2.50 to $5	$123,000	
Mass concrete, 91,000 cu. yds. at $6.50	592,000	
Drilling and grouting foundation	12,000	
		$727,000
Lands and improvements flooded		25,000
Construction railroad, permanent camp and clean-up after construction		100,000
Subtotal		$928,000
Administration and engineering, 10 per cent		93,000
Contingencies, 15 per cent		139,000
Interest during construction based on a rate of 4.5 per cent per annum		40,000
Total cost of dam and reservoir		$1,200,000
Power Plant		
Intake structure		$35,000
Penstocks		251,000
Building and equipment		875,000
Subtotal		$1,161,000
Administration and engineering, 10 per cent		116,000
Contingencies, 15 per cent		174,000
Interest during construction based on a rate of 4.5 per cent per annum		49,000
Total cost of power plant		$1,500,000
Total cost of dam, reservoir and power plant		$2,700,000

The annual costs of the Pilot Creek reservoir and power plant, computed on the bases outlined in the fore part of this chapter, would be a total of $197,000. Of this, the annual cost of the dam and reservoir would be $71,000 and of the power plant, $126,000.

Coloma Reservoir on South Fork of American River.—Two sites for a dam to creat the Coloma reservoir were surveyed and the geology studied. One of these sites is located about six miles and the other about nine miles downstream from the settlement of Coloma. The upper site is underlain with a serpentine rock, which is considered unsuitable for the foundation of a major dam, and was not considered further in the investigation leading up to this report. The lower site was found to be suitable, both geologically and topographically for a high concrete dam and much superior to the upper site. The lower site, therefore, was selected for the Coloma dam. This site is located in Section 28, Township 11 North, Range 9 East, M. D. B. and M.

The area of the drainage basin tributary to the site contains 708 square miles or 37 per cent of the total area above the Fairoaks gaging station. This area is nearly all rough mountainous land. The stream rises at the crest of the Sierra Nevada at elevations up to over 10,000 feet. This area contributes about one-third of the total run-off of the American River.

Water Supply.—The full natural, ultimate net and present net run-offs at the Coloma dam site were estimated for the 40-year period 1889–1929, by months.

The monthly full natural run-off curves for the Colfax, East Auburn and Placerville gaging stations and for the intermediate area between these three stations and the Fairoaks station, showing the relation of the run-off at the station and from the intermediate area to that at Fairoaks, as described under the water supply for the Folsom reservoir, were used for estimating the run-off at the Coloma dam site. The run-off from the area between the Placerville gaging station and the Coloma dam site was estimated to be 27.45 per cent of that from the total intermediate area. Another set of monthly full natural run-off curves for the Coloma dam site was drawn by combining the curves for the Placerville gaging station and 27.45 per cent of the run-off from the intermediate area. These curves show the relation of the run-off at the dam site to that at Fairoaks. With the run-offs at the latter point as indices, the monthly full natural run-offs at the dam site were taken from the curves.

The monthly ultimate net run-offs at the dam site were estimated by correcting the monthly full natural run-offs by subtracting the ultimate diversions through the El Dorado Irrigation District Canal; by subtracting water which would be stored in and adding water which would be released from Silver Lake, Twin Lakes, and Medley Lakes reservoirs and a number of other reservoirs now proposed and others which it is estimated would be required to furnish irrigation water; by subtracting diversions for irrigation in the watershed; by adding water diverted into the watershed from Echo Lake; and by adding return flow from the area which ultimately would be irrigated within the watershed.

The monthly present net run-offs were estimated in the same manner as the ultimate net except that present diversions, storage and return flows were used.

The estimated seasonal full natural, ultimate net and present net run-offs at the Coloma dam site are given in Table 106.

TABLE 106

SEASONAL RUN-OFFS OF SOUTH FORK OF AMERICAN RIVER AT COLOMA DAM SITE, 1889-1929

Season	Full natural run-off, in acre-feet	Present net run-off, in acre-feet	Ultimate net run-off, in acre-feet
1889-1890	2,868,000	2,856,000	2,806,000
1890-1891	563,000	551,000	501,000
1891-1892	739,000	728,000	677,000
1892-1893	1,442,000	1,430,000	1,380,000
1893-1894	1,029,000	1,018,000	967,000
1894-1895	1,734,000	1,722,000	1,672,000
1895-1896	1,285,000	1,273,000	1,223,000
1896-1897	1,053,000	1,041,000	991,000
1897-1898	344,000	333,000	282,000
1898-1899	665,000	653,000	603,000
1899-1900	1,128,000	1,116,000	1,066,000
1900-1901	1,168,000	1,157,000	1,106,000
1901-1902	903,000	892,000	841,000
1902-1903	871,000	859,000	809,000
1903-1904	1,820,000	1,808,000	1,758,000
1904-1905	760,000	748,000	698,000
1905-1906	1,708,000	1,696,000	1,646,000
1906-1907	1,940,000	1,928,000	1,878,000
1907-1908	544,000	532,000	482,000
1908-1909	1,534,000	1,523,000	1,472,000
1909-1910	1,151,000	1,139,000	1,089,000
1910-1911	1,888,000	1,876,000	1,826,000
1911-1912	509,000	497,000	447,000
1912-1913	552,000	540,000	490,000
1913-1914	1,370,000	1,358,000	1,308,000
1914-1915	1,109,000	1,097,000	1,047,000
1915-1916	1,327,000	1,315,000	1,265,000
1916-1917	1,034,000	1,023,000	972,000
1917-1918	542,000	530,000	480,000
1918-1919	778,000	767,000	717,000
1919-1920	543,000	531,000	481,000
1920-1921	1,069,000	1,058,000	1,007,000
1921-1922	1,153,000	1,142,000	1,091,000
1922-1923	948,000	936,000	886,000
1923-1924	193,000	182,000	132,000
1924-1925	936,000	924,000	874,000
1925-1926	483,000	471,000	421,000
1926-1927	1,215,000	1,203,000	1,153,000
1927-1928	834,000	823,000	772,000
1928-1929	430,000	418,000	368,000
40-year means, 1889-1929	1,054,000	1,042,000	992,000
20-year means, 1909-1929	903,000	891,000	841,000
10-year means, 1919-1929	780,000	769,000	718,000
5-year means, 1924-1929	780,000	768,000	718,000

Reservoir Site.—The lands that would have to be acquired for the Coloma reservoir include only about 1550 acres that is either cultivated or suitable for cultivation, of which about 250 acres is in orchard. The remainder of the lands lie principally in gulches and on steep rocky slopes covered by small tree growth, and are used for grazing. The principal improvements that would be flooded are the old town of Coloma, the settlement of Lotus, about eight miles of the State highway between Auburn and Placerville, and about two miles of the county road from Shingle Springs to Coloma. The roads could be relocated and the towns either abandoned or moved to elevations above the flow line.

A topographic survey of the Coloma reservoir site was made by the American River Hydroelectric Company in 1928 and a map was drawn from this survey by the company at a scale of one inch equals 1000 feet, with a contour interval of 25 feet. The water surface areas measured from this map and the computed capacities of the reservoir are shown in Table 107.

TABLE 107

AREAS AND CAPACITIES OF COLOMA RESERVOIR

Height of dam, in feet (5-foot freeboard)	[1]Water surface elevation of reservoir, in feet	Area of water surface, in acres	Capacity of reservoir, in acre-feet
60	600	125	2,000
80	620	205	5,000
100	640	315	11,000
120	660	465	20,000
140	680	710	32,000
160	700	1,150	50,000
180	720	1,670	80,000
200	740	2,295	120,000
220	760	2,955	172,000
240	780	3,590	236,000
260	800	4,150	312,000
280	820	4,670	402,000
300	840	5,235	500,000
320	860	5,825	613,000
340	880	6,420	733,000
345	885	6,565	766,000
360	900	7,000	865,000
380	920	7,580	1,011,000
385	925	7,725	1,049,000

[1] United States Geological Survey datum.

Dam and Power Plant.—A survey of the dam site was made by the State in 1930. A topographic map drawn from this survey at a scale of one inch equals 100 feet, with a contour interval of ten feet, was used in laying out and estimating the costs of the Coloma dam and power plant.

The site is topographically favorable for a dam higher than the maximum height of 385 feet investigated. There have been no borings or other explorations of the foundation for the dam but a geological examination of the site and its vicinity was made, the report on which may be found in Appendix E. The geologist has classified the foundation rock at the site as amphibolite, which is a satisfactory rock for the foundation for a high concrete dam. A portion of the site is overlaid with a soil covering and some of the surface rock is weathered and broken. A moderate amount of excavation in the stream bed and rather deep excavations on the two abutments would be required to obtain firm unweathered rock for the foundation for the dam.

Estimates of cost were made for four heights of dam ranging from 255 feet to 385 feet at intervals of 50, 40 and 40 feet, respectively. A detailed estimate and layout for only one of these heights, 345 feet, are shown in this report. The features of this dam are typical of those of the dams of other heights and are described herein for illustration. The layout for this height of dam is shown on Plate XXXV.

The dam would be of the gravity concrete type arched in plan to fit the topography of the site. There would be a cut-off wall at the upstream toe, beneath which the rock would be sealed by grouting.

The foundation would be drained by a row of drainage wells, just downstream from the upstream cut-off wall, which would be connected to a gallery in the dam.

PLATE XLI

Coloma Dam Site on South Fork of American River

Diversion of the stream flow during the excavation for the foundation and the construction of the lower portion of the dam would be accomplished by means of rockfill coffer dams with clay blankets placed above and below the excavation in the stream bed. The diverted water would be carried around the excavation by a concrete lined horseshoe shaped tunnel having a capacity of 2000 second-feet.

The spillway would be located in the main dam near the right abutment and would have a discharging capacity of 50,000 second-feet. Flow over the crest would be controlled by three hydraulically operated steel segmental drum gates 50 feet in length and 20 feet high. These gates would be separated by ten-foot piers in which the operating mechanism would be located. The water from the spillway would be allowed to reach the stream channel by flowing over the rock surface of the canyon wall which would be left unprotected.

The spillway also would be used for the discharge of regulated flow for flood control. The control of floods by this reservoir would require 35,000 acre-feet of space which would be obtainable in the top five feet of the reservoir. This would leave a 15-foot head for the discharge of water over the spillway which is sufficient for the regulated flow of 30,000 second-feet.

Four outlets would be provided through the dam in the section over the stream channel. These outlets would be used for the release of irrigation water and as sluiceways. They would be circular openings, 70 inches in diameter, lined with steel. Two of these outlets would be at a depth of 190 feet below the top of the dam and the other two would lie at a depth of 290 feet. Flow through each outlet would be controlled by a caterpillar type sluice gate, at the upstream face of the dam, and auxiliary control would be provided by a slide gate, a short distance below the inlet, operated from a chamber inside of the dam. Each caterpillar type gate would be protected by steel trash racks mounted in a semicircular concrete structure and would operate in a concrete enclosed gate well extending to the top of the dam. Also, in order to obtain a more accurate control of the irrigation releases, one of the lower openings would be equipped with a 70-inch balanced needle valve at its discharging end. Water from these openings would be discharged over the face of the dam into the stream channel.

The power house would be located on the right bank of the stream about 2000 feet downstream from the dam. Water would be conveyed to it from the reservoir by a concrete lined horseshoe shaped tunnel 12.1 feet in diameter which, at a point opposite the power house, would divide into two steel pipe penstocks leading to the turbines in the power house. These steel pipes would be 106 inches in diameter and would be laid in separate horseshoe shaped concrete lined tunnels. Water would enter the main tunnel through a concrete gate tower over a vertical concrete lined shaft similar to that described for the Folsom reservoir.

Studies made to estimate the economic installation of generating equipment for this plant indicate that with a load factor 0.75 and a power factor of 0.80, the total installed generator capacity should be 40,000 kilovolt amperes. This would be divided equally between two generating units each of which would be direct connected to a vertical shaft variable head reaction turbine. The power house would be of steel and concrete construction. Transformers and protective equipment would be of the outdoor type.

Yield of Reservoir in Water for Irrigation.—Studies were made to estimate the amounts of water that would have been made available at the dam site for irrigation use, with the reservoir operated primarily for this use, in each of the years from 1889 to 1929, and the amounts of these yields that would have been new water. These studies were made for the four heights of dam previously mentioned by the methods described in the fore part of this chapter. The total yields and the yields in new water for these four heights of dam, as shown by these studies, are given in Table 110. In making these studies, the entire capacity of the reservoir was utilized in the years of deficiency in supply. The yields are those that would have been obtained with a maximum seasonal deficiency not exceeding 35 per cent and an average for the 40-year period not exceeding two per cent.

Flood Control.—Under the heading of "Flood Control" in the Folsom reservoir description, reference is made to the discussion of this subject for the American River in Bulletin No. 24 of the Division of Water Resources. It also is shown in that section that 175,000 acre-feet of reservoir space is required to control flows at Fairoaks to a maximum of 100,000 second-feet exceeded one day in 100 years on the average. It also has been shown in the flood control description for the Auburn reservoir that with 175,000 acre-feet of reserve space in the Folsom reservoir and 90,000 acre-feet in the Auburn reservoir, flows at Fairoaks could be controlled to 76,000 second-feet exceeded one day in 100 years on the average or 89,000 second-feet exceeded one day in 250 years on the average.

A still greater reduction in flood flow at Fairoaks could be obtained by holding some space in reserve in the Coloma reservoir. Any space so provided in the Coloma reservoir could be considered as the equivalent of space in the Folsom reservoir, if, with a flood of a given frequency at Folsom reservoir, there is assurance that a flow would occur at Coloma reservoir of sufficient magnitude to fill the space allotted for flood control in that reservoir. Since, however, the flood flows from the South Fork are not large, it is estimated that only 35,000 acre-feet of space should be reserved in the Coloma reservoir. This space combined with that which would be reserved in Folsom and Auburn reservoirs would total 300,000 acre-feet. This space if all available at Folsom reservoir would control flows at Fairoaks to 80,000 second-feet exceeded one day in 250 years on the average.

It has already been stated that it is estimated that the space reserved in the Auburn reservoir could be considered as equivalent to the same space at Folsom for the control of floods exceeded one day in 25 years on the average. The 175,000 acre-feet of reserve space in Folsom reservoir alone would control the flows at Fairoaks to 80,000 second-feet exceeded one day in about 26 years on the average and the 265,000 acre-feet in the Folsom and Auburn reservoirs would give the same controlled flow exceeded one day in about 135 years on the average. It has been estimated that with a flow exceeded one day in 135 years on the average at Folsom, the flow at Coloma reservoir would fill the space allotted for flood control in that reservoir. Consequently, it is believed that it would be possible to control the flow of the American River below Folsom reservoir to 80,000 second-feet exceeded one day in 250 years with 175,000 acre-feet of reserve space in Folsom reservoir, 90,000 acre-feet in Auburn reservoir and 35,000 acre-feet in Coloma reservoir, there being an assurance that the space in the two upper reservoirs would be entirely used in a flood of the magnitude exceeded one day in 250 years on the average.

Cost of Reservoir and Power Plant.—Estimates of the cost of the Coloma reservoir were prepared for the four heights of dam previously mentioned. These estimates were made as generally outlined in the fore part of this chapter and include all of the items, except the power plant, which have been briefly described in the foregoing paragraphs. The costs are listed in Table 110.

A somewhat detailed estimate is given in Table 108 for the reservoir having a 345-foot dam. In this estimate the items included under miscellaneous are a construction railroad from the Southern Pacific railroad, a permanent camp and cleaning up after construction. The same items and similar unit prices to those shown in Table 108 were used in estimating the costs for reservoirs with other heights of dam.

TABLE 108

COST OF COLOMA RESERVOIR

Height of dam, 345 feet. Capacity of reservoir, 766,000 acre-feet.
Capacity of spillway, 50,000 second-feet.

Exploration and core drilling		$30,000
Diversion of river during construction		85,000
Clearing reservoir site		164,000
Excavation for dam, 417,000 cu. yds. at $1 to $5	$1,083,000	
Mass concrete, 1,048,000 cu. yds. at $6.50	6,812,000	
Reinforced concrete, 2600 cu. yds. at $15.50 to $23.50	46,000	
Spillway gates	90,000	
Irrigation outlets and sluiceways	154,000	
Drilling and grouting foundation	39,000	
		$8,224,000
Lands and improvements flooded		1,290,000
Miscellaneous		310,000
Subtotal		$10,103,000
Administration and engineering, 10 per cent		1,010,000
Contingencies, 15 per cent		1,515,000
Interest during construction, based on a rate of 4.5 per cent per annum		771,000
Total cost of dam and reservoir		$13,400,000

The estimated cost of the power plant with an installed generating capacity of 40,000 kilovolt amperes, described in connection with the 345-foot dam, is shown in Table 109.

TABLE 109

COST OF POWER PLANT FOR COLOMA RESERVOIR WITH 345-FOOT DAM

Installed capacity, 40,000 kilovolt amperes.
Power factor = 0.80. Load factor = 0.75.

Intake structure	$113,000
Penstocks	471,000
Building and equipment	1,350,000
Subtotal	$1,934,000
Administration and engineering, 10 per cent	193,000
Contingencies, 15 per cent	290,000
Interest during construction based on a rate of 4.5 per cent per annum	83,000
Total cost of power plant	$2,500,000

The total estimated capital cost of the Coloma reservoir with a 345-foot dam, and its power plant, would be $15,900,000.

The annual cost of each reservoir without a power plant has been estimated on the bases described in the fore part of this chapter and is given in Table 110. The annual costs of the Coloma reservoir and power plant based on the capital costs given in Tables 108 and 109 are estimated to be $798,000 and $201,000, respectively, or a total of $999,000.

Comparison of Sizes of Reservoir.—The principal use of the reservoirs on the American River would be for flood control and the regulation of water for irrigation and salinity control.

Although the salinity control demands would vary somewhat from those for irrigation, and the costs per acre-foot of water for the two purposes would be different, they are comparable as to relative costs of regulated water from the reservoirs. Comparisons of reservoirs of different capacities at the Coloma site, therefore, were made on the bases of the cost of storage, the cost of the total seasonal irrigation yield and the yield in new water, the cost of the reservoir per acre-foot increase in each of these items and the annual cost for irrigation water for both the total yield and the yield in new water. These items are given in tabular form in Table 110 and the comparisons are shown

TABLE 110

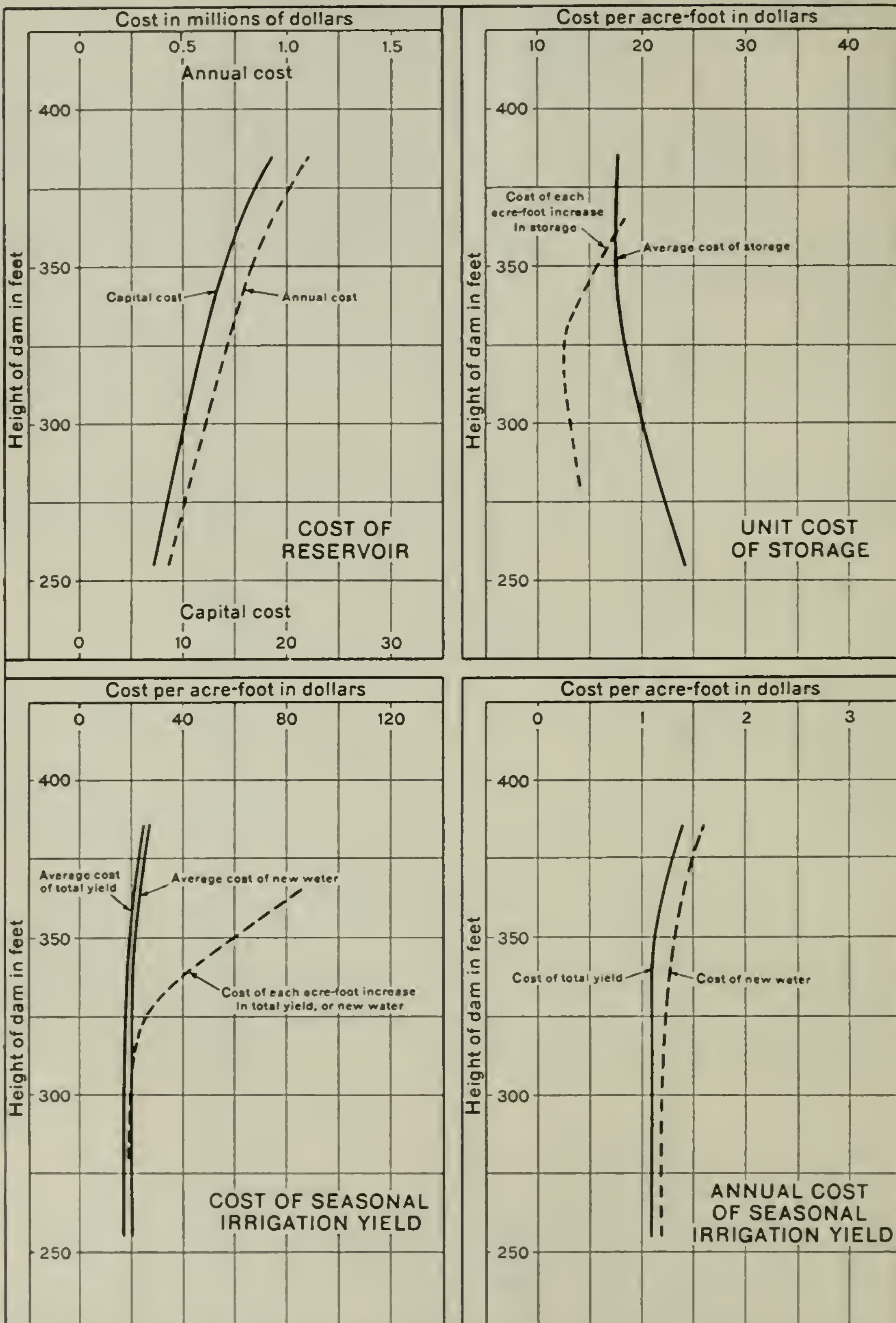
COST OF RESERVOIR CAPACITY AND UNIT YIELD OF WATER FOR IRRIGATION FROM COLOMA RESERVOIR

With Flood Control Features and Without Power Plant

Height of dam, in feet	Elevation of water surface, in feet	Capacity of reservoir, in acre-feet	Seasonal irrigation yield[1]		Cost of reservoir		Capital cost, per acre-foot						Annual cost per acre-foot of irrigation yield	
							Total storage	Increase in storage	Irrigation yield		Increase in irrigation yield			
			Total yield, in acre-feet	New water, in acre-feet	Capital	Annual			Total yield	New water	Total yield	New water	Total yield	New water
255	795	293,000	417,600	345,600	$7,100,000	$432,000	$24 20		$17 00	$20 50			$1 03	$1 25
								$14 10			$19 10	$19 10		
305	845	534,000	595,200	523,200	10,500,000	628,000	19 70		17 60	20 10			1 06	1 20
								12 50			25 40	25 40		
345	885	766,000	709,500	637,500	13,400,000	798,000	17 50		18 90	21 00			1 12	1 25
								18 40			86 00	86 00		
385	925	1,049,000	770,000	698,000	18,600,000	1,101,000	17 70		24 20	26 60			1 43	1 58

[1] Entire capacity of reservoir utilized in years of deficiency in supply. Yields shown are based on run-off for the 40-year period 1889-1929 and are those which would have been available at the dam site. Each yield would have had a maximum seasonal deficiency not exceeding 35 per cent and an average deficiency for the 40-year period not exceeding two per cent.

PLATE XLII



COST OF RESERVOIR CAPACITY AND UNIT YIELD OF WATER FOR IRRIGATION FROM COLOMA RESERVOIR graphically on Plate XLII, "Cost of Reservoir Capacity and Unit Yield of Water for Irrigation from Coloma Reservoir." The capital costs do not include the costs of power features and the annual costs are gross costs from which no deductions have been made for revenue from the sale of electric energy. The generation of such energy, however, is economically justified since the revenue from its sale would be more than sufficient to cover the costs of the power features. The net revenue, therefore, would help to defray the other costs of the project, thereby reducing the costs per acre-foot of total seasonal irrigation yield and yield in new water set forth in Table 110.

The seasonal irrigation yields shown in Table 110 are those which would have been available at the Coloma dam site. A study also was made to estimate the seasonal irrigation yields at Folsom with the Coloma reservoir having a 345-foot dam operated as the only major unit on the American River. The maximum irrigation yields, with deficiencies similar to those shown in Table 110, estimated in this study, are those which would have been available at Folsom with the Coloma reservoir operated to supplement the unregulated flows at that point. With this method of operation, the total seasonal irrigation yield at Folsom would have been 908,000 acre-feet and the yield in new water 774,000 acre-feet. The annual cost per acre-feet of total irrigation yield would have been $0.88 and the cost per acre-foot of new water $1.03.

Selection of Capacity of Reservoir.—The Coloma reservoir alone would have insufficient yield to serve as an initial unit in the Sacramento River Basin and therefore has been considered only as one of the reservoirs of the American River unit in the plans for ultimate and initial developments. Each of the storage reservoirs of this unit, however, was studied independently for the purpose of selecting the most economical size.

The data in Table 110 and the curves on Plate XLII indicate that for heights of dam greater than 345 feet the unit annual cost of irrigation water increases quite rapidly and that the annual cost for water at this height is practically the same as for lower heights. The reservoir with this height of dam also would have given a yield in irrigation water equal to 71.5 per cent of the mean seasonal ultimate net run-off of the South Fork of the American River above the dam site for the 40-year period 1889–1929. The seasonal irrigation yield could have been increased about 60,000 acre-feet, or to 77.6 per cent of the 40-year mean seasonal ultimate net run-off, by building a 385-foot dam. This additional yield would have had an average capital cost of $86 per acre-foot which is a higher cost than the same yield could be obtained for in other major reservoirs of the State Water Plan. The 345-foot height of dam, therefore, was selected for the Coloma reservoir.

Webber Creek Reservoir on South Fork of American River.—With the Coloma reservoir constructed and operated for the generation of hydroelectric energy, the flow in the river below the tailrace of the power plant would be subject to large daily and weekly fluctuations. However, as Coloma reservoir probably would not be constructed prior to the construction of Folsom reservoir, and as any irrigation diversion that would be made between the two sites could be provided for without reregulation, it is believed that no afterbay would be necessary between the reservoirs for reregulation.

There is, however, a fall in the river between the Coloma power house and the high water level in the Folsom reservoir of about 155 feet and the development of 105 feet of this potential head as a power drop, by the construction of a dam at the Webber Creek site about one mile below the mouth of Webber Creek, would be economically justified with the Coloma reservoir constructed.

Water Supply.—The water available for power generation would be the same as the releases and spill from the Coloma reservoir. No diversions for irrigation would be made between Coloma and Webber Creek dam sites, the intake of the Natomas Canal being about one and one-half miles below the Webber Creek dam. The releases from Coloma reservoir would be augmented by run-offs from Webber Creek, but these were neglected in all studies of estimated power output.

Reservoir Site.—The reservoir would extend up the canyon of the South Fork 2.5 miles to the Coloma dam and also a short distance up Webber Creek. The dam would be constructed high enough to back water up to the tailrace of the Coloma power plant at an elevation of 545 feet. The lands that would be flooded are of little value. No improvements are located within the reservoir site.

Dam and Power Plant.—A survey of the dam site was made by the American River Hydroelectric Company in 1928. A topographic map drawn from this survey at a scale of one inch equals 100 feet, with a contour interval of ten feet, was used in laying out and estimating the costs of the Webber Creek reservoir dam and power plant. There have been no core drillings or other explorations of the foundation for the dam but a geological examination of the site and its vicinity was made.

PLATE XLIII

Webber Creek Dam Site on South Fork of American River the report on which may be found in Appendix E. The stream bed is narrow and the side walls rise abruptly. The rock is a dark green rock of granitoid texture being of igneous origin.

The dam would be of the gravity concrete overflow type for its entire length and would not be provided with crest gates. During periods of flood flows, water would back up on the Coloma power plant with a resulting slight decrease of head at this plant and a corresponding increase at the Webber Creek plant. The dam would be 85 feet high and 340 feet long. The foundation would be sealed by grouting and drainage wells would be drilled just downstream from the upstream toe of the dam and connected to a gallery in the dam.

The stream would be diverted during construction in a manner similar to that described for Coloma dam.

With a depth of water over the crest of the dam of about 11 feet, the discharging capacity would be comparable to that of Coloma dam, or 50,000 second-feet.

The layout for the dam and power plant are shown on Plate XXXV. The power house would be located on the left bank of the river about 0.8 mile below the dam. Water would be conveyed to it by a concrete-lined horseshoe shaped tunnel 14.1 feet in diameter which opposite the power house, would divide into two steel pipe penstocks, 122 inches in diameter, laid down the face of the canyon side to the power house. Water would enter the tunnel through a concrete structure having one caterpillar-type sluice gate for controlling the flow. It is estimated that the capacity of the plant, with a load factor of 0.75 and a power factor of 0.80, should be 20,000 kilovolt amperes. This would be divided equally between two generators each of which would be direct connected to a vertical shaft reaction turbine. The power house would be of steel and concrete construction. Transformers and protective equipment would be of the outdoor type. The plant would be operated as one of the units of the American River unit which is discussed later in this chapter.

Power Output.—The yield from this unit would be electric energy output from water passing the dam, most of which would be that regulated by the Coloma reservoir. The seasonal and monthly variations of this power would be dependent upon the releases from the Coloma reservoir since there would be no holdover storage in the Webber Creek reservoir. The only studies of the electric energy output from this reservoir are those made in connection with the output from the operation of the entire American River unit. These studies are discussed later in this chapter.

Cost of Reservoir and Power Plant.—The cost of the Webber Creek unit was estimated by the methods generally outlined in the fore part of this chapter and is shown in Table 111.

The annual cost of the Webber Creek reservoir and power plant computed on the bases outlined in the fore part of this chapter would be a total of $183,000. Of this, the annual cost of the dam and reservoir would be $41,000 and of the power plant features, $142,000.

TABLE 111

COST OF WEBBER CREEK RESERVOIR AND POWER PLANT

Height of dam, 85 feet. Installed capacity, 20,000 kilovolt amperes. Power factor = 0.80. Load factor = 0.75.

Dam and Reservoir		
Exploration and core drilling		$10,000
Diversion of river during construction		50,000
Clearing reservoir site		5,000
Excavation for dam, 26,000 cu. yds. at $2.50 to $5	$99,000	
Mass concrete, 49,000 cu. yds. at $6.50	319,000	
Drilling and grouting foundation	8,000	
		426,000
Lands and improvements flooded		10,000
Construction railroad, permanent camp, and clean-up after construction		40,000
Subtotal		$541,000
Administration and engineering, 10 per cent		54,000
Contingencies, 15 per cent		81,000
Interest during construction based on a rate of 4.5 per cent per annum		24,000
Total cost of dam and reservoir		$700,000
Power Plant		
Intake structure		$20,000
Penstocks		652,000
Building and equipment		720,000
Subtotal		$1,392,000
Administration and engineering, 10 per cent		139,000
Contingencies, 15 per cent		209,000
Interest during construction based on a rate of 4.5 per cent per annum		60,000
Total cost of power plant		$1,800,000
Total cost of dam, reservoir and power plant		$2,500,000

Operation and Cost of American River Unit.—The American River unit comprises the Folsom, Auburn, Coloma, Pilot Creek and Webber Creek reservoirs and the Folsom afterbay together with their hydroelectric power plants. The aggregate storage capacity of the American River unit would be 1,952,000 acre-feet distributed among the three major or storage reservoirs as follows: Folsom 355,000 acre-feet, Auburn 831,000 acre-feet and Coloma 766,000 acre-feet.

The total available power drop within the unit would be from the maximum water surface elevations of Auburn and Coloma reservoirs, which would be 950 feet and 885 feet, respectively, to the tailrace elevation of the Folsom afterbay which would be 115 feet. Of these amounts, it would be feasible to utilize the following: North Fork, 545 feet; South Fork, 445 feet; main stream, 270 feet; or a total of 815 feet for the North Fork water and 715 feet for the South Fork water. This would be distributed among the reservoirs as follows: Auburn, 435 feet; Pilot Creek, 110 feet; Coloma, 340 feet; Webber Creek, 105 feet; Folsom, 195 feet; and Folsom afterbay, 75 feet.

The power plant installation at each power drop of the American River unit would be as follows:

Auburn	85,000 kilovolt amperes
Pilot Creek	25,000 kilovolt amperes
Coloma	40,000 kilovolt amperes
Webber Creek	20,000 kilovolt amperes
Folsom	100,000 kilovolt amperes
Folsom afterbay	25,000 kilovolt amperes
Total	295,000 kilovolt amperes

Water Supply.—In the foregoing studies of the Folsom, Auburn and Coloma reservoirs, an estimate was made of the water supply available at each dam site. In estimating the supply for the Folsom reservoir, it was assumed that no water would be stored in the Auburn or Coloma reservoirs, as this supply was to be used for estimating the yield of the Folsom reservoir when operating as the only major reservoir unit on the American River.

In the studies for determining the yields of the American River unit, however, the reservoirs were operated coordinately and the water supply for each reservoir was determined accordingly. The supplies for the Auburn and Coloma reservoirs were taken the same as when the reservoirs were studied alone. The supply for the Folsom reservoir was taken as the run-off from the area between the Folsom and Auburn and Coloma dam sites plus the releases and spills from the Auburn and Coloma reservoirs, less diversions between the two upper dam sites and the Folsom reservoir.

Yields of Unit in Water for Irrigation and in Hydroelectric Energy with Unit Operated Primarily for Irrigation.—A study was made to estimate the amount of water that would have been made available annually during the 40-year period 1889–1929 at the Folsom afterbay, for irrigation use, with Auburn, Coloma and Folsom reservoirs operated primarily for supplying irrigation water, and the amount of this yield that would have been new water. This study was made with the capacities of reservoirs given above, by the method described in the fore part of this chapter. In making the study, the entire capacity of the reservoirs was utilized in the years of deficient supply. The total yield and the yield in new water would have been 1,933,000 acre-feet and 1,799,000 acre-feet, respectively. These yields are those that would have been obtainable with a maximum deficiency not exceeding 32 per cent in the driest year or an average of two per cent for the 40-year period.

A similar study was made using all of the reservoirs, power drops and the afterbay of the unit, operating primarily for irrigation with incidental power during the same 40-year period 1889–1929. This study differed from the previous one in that the entire capacities of the reservoirs were not utilized. It was assumed that the storage reservoirs would have been operated so that the minimum head for power development would have been 50 per cent of the maximum obtainable. It also was assumed that the power plants would have had the same installed capacities as those for the reservoirs operating primarily for the generation of power on a 0.75 load factor, except the Folsom afterbay plant which would have operated on a unity load factor. With this method of operation, the annual yield in irrigation water, with a maximum deficiency of 35 per cent and an average of 1.8 per cent for the period, would have been 1,790,000 acre-feet of which 1,656,000 acre-feet would have been new water. The electric energy would have had a low value on account of there being some months in each year when none would have been generated. However, by a slight modification in releases so that some water would have been available in the months when none was released for irrigation uses, the irrigation yield would have been practically the same and the power value would have been substantially increased. The average annual electric energy output with this modified operation would have been 898,800,000 kilowatt hours. The value of this energy based on the lowest of several estimates of the cost of producing an equivalent amount of electric energy of the same characteristics with a steam-electric plant located in the area of consumption, taking into account the cost of transmission from the point of generation to the load center, as shown in Chapter VIII, was estimated to be $.00256 per kilowatt hour. The average annual return at this value would have been $2,301,000.

Yields of Unit in Hydroelectric Energy and in Water for Irrigation with Unit Operated Primarily for Generation of Power.—A study also was made to estimate the amount of electric energy that would have been developed in the 40-year period 1889–1929 with the entire unit operated primarily for this purpose, and the amount of new water that would have been made available with this method of operation of the reservoir. The study was made by the method described in the fore part of this chapter. All plants except the one at the Folsom afterbay would have been operated on a 0.75 load factor. The plant at Folsom afterbay would have been operated on a unity load factor. The six plants combined would have produced an average annual output of 1,052,400,000 kilowatt hours. The output in the minimum year would have been 721,500,000 kilowatt hours and in the maximum year 1,349,900,000 kilowatt hours. The value of this electric energy was estimated in the same manner as described in the preceding paragraph to be $.00327 per kilowatt hour. The average annual return at this value would have been $3,441,000.

The reservoirs operated primarily for the generation of power also would have made available an annual yield of 658,000 acre-feet of water for irrigation, distributed in accordance with the irrigation demand. This yield would have had a maximum seasonal deficiency of 5.1 per cent and an average for the 40-year period 1889–1929 of two per cent. This yield amounts to 34 per cent of that with the reservoirs operated primarily for irrigation. Of this yield 524,000 acre-feet would have been new water. This is 29 per cent of the yield in new water with the reservoirs operated primarily for irrigation.

TABLE 112

SUMMARY OF CAPITAL AND ANNUAL COSTS OF AMERICAN RIVER UNIT

	Capital cost	*Annual cost*
Auburn dam and reservoir	$24,000,000	$1,429,000
Auburn power plant	3,900,000	323,000
Pilot Creek dam and reservoir	1,200,000	71,000
Pilot Creek power plant	1,500,000	126,000
Coloma dam and reservoir	13,400,000	798,000
Coloma power plant	2,500,000	201,000
Webber Creek dam and reservoir	700,000	41,000
Webber Creek power plant	1,800,000	142,000
Folsom dam and reservoir	9,500,000	601,000
Folsom power plant	5,700,000	452,000
Folsom afterbay dam and reservoir	1,500,000	94,000
Folsom afterbay power plant	2,800,000	206,000
Total cost of dams and reservoir	50,300,000	3,034,000
Total cost of power plants	18,200,000	1,450,000
Total cost of American River unit	68,500,000	4,484,000

Flood Control.—With the reservation of 175,000 acre-feet of space for flood control in the Folsom reservoir, 90,000 acre-feet in the Auburn reservoir and 35,000 acre-feet in the Coloma reservoir, or a total of

300,000 acre-feet of space, it has been shown under the discussion of flood control for the Coloma reservoir that floods could be controlled to a maximum flow of 80,000 second-feet at Fairoaks, exceeded one day in 250 years on the average.

Cost of Unit.—A summary of the capital and annual costs of the component parts of the American River unit is shown in Table 112.

Trinity River Diversion to Sacramento River Basin.

The Trinity River which is the largest tributary of the Klamath River, the most northerly of all California streams, drains an area of 2965 square miles in the northwestern part of the state on the westerly side of the Coast Range. The main stream heads near Mount Eddy, a peak with an elevation of 9034 feet above sea level lying about sixteen miles west of Mount Shasta, and flows in a southwesterly direction for about fifty miles to the town of Lewiston, thence westerly for about sixty miles to its junction with the South Fork of the Trinity, and finally in a northwesterly direction for thirty miles to its junction with the Klamath River near the town of Weitchpec. The drainage basin is rough in character and heavily timbered. The geology of the region is sedimentary with slate and limestone outcrops, and erosion by the streams has cut many deep canyons in these soft formations. There are no large valleys and only a small amount of agricultural land.

The country through which the stream flows has not been developed to any great extent. There are no railroads and very few highways. The population is sparse and the principal industries are mining and lumbering. Agricultural development along both the Trinity and lower Klamath Rivers is small and very little of the flow of either stream will ever be needed for irrigation. The uses for Trinity River water are and will be for the generation of power, gold dredging, placer mining, and to aid in keeping the lower reach of the Klamath River navigable.

Studies made of a plan for the full development of the Great Central Valley show that water which could be diverted to it from the Trinity River would be needed in that valley for irrigation and other uses. It is shown later in this chapter that almost 800,000 acre-feet of water could be diverted each year to the Sacramento River Basin. About one-half of this amount would be required for the ultimate irrigation of the Trinity River water service area, which lies in the plains lands along the west side of the Sacramento Valley from Red Bluff to just below Stony Creek and is an area which could be developed only with Trinity River water. Water from the Trinity River which is not needed for this water service area was shown by studies to be required for irrigation in other parts of the Great Central Valley and for salinity control in the Sacramento-San Joaquin Delta. The Trinity River diversion, therefore, is a necessary unit in the State Water Plan.

In 1924, Messrs. D. C. Henney, W. F. McClure and E. W. Kramer and Major U. S. Grant, 3d, were appointed by the Federal Power Commission to investigate a proposal then before the commission for diverting the water of the Trinity River into the Sacramento Valley for power and irrigation. While this was not exactly the same proposal as contained in the following report, the effect on the Klamath and

Trinity river systems would have been identical. The conclusions of the above board of engineers include the following statements:

a. The full use of Trinity River water makes essential large storage at its headwaters where required storage facilities exist.
b. Potential power of Trinity River water regulated by available storage is slightly greater if flowing down its natural course than if partially diverted.
e. Irrigation possibilities in the Trinity Basin are relatively small and will not be adversely affected by diversion.
f. Diversion of Trinity River water will permit more complete irrigation development in the joint valleys (Sacramento and San Joaquin) than is otherwise possible * * *.
h. The only important industrial use made of Trinity River water is in connection with gold dredging. Diversion will not interfere with this industry. Storage above diversion may flood prospective dredging lands in the reservoir site (Fairview site); which fact does not justify delay in reservoir construction.
i. Navigation is confined to Klamath River below the mouth of Trinity. It may be interfered with to a small extent by diversion, which on the other hand may benefit Sacramento navigation.
j. The advantages of diversion greatly outweigh its disadvantages.

In harmony with the above it is recommended:

a. That no power rights be granted to prospective Trinity River water users which will interfere with ultimate diversion of Trinity water to the Sacramento Valley;
b. That any permission to divert water from the Trinity River to the Sacramento Valley provide for the maintenance of a flow of at least 20 second-feet in the Trinity River below the point of diversion.

The run-off from the upper fifty miles of the Trinity River drainage area above Lewiston, including that of Coffee Creek, Swift Creek, Stuart Fork and East Fork, was found to be the only supply that could be economically diverted to the Sacramento Valley. This portion of the Trinity River drainage basin contains 718 square miles, or about 23 per cent of the total area tributary to the stream, and includes some of the best water producing areas in the entire watershed.

Immediately to the east of this area and separated only by a narrow ridge are the headwaters of Clear Creek, a tributary of the Sacramento River. This ridge could be pierced by a tunnel 6.35 miles in length through which the Trinity River water could be diverted to the Sacramento River watershed. The Trinity River lies at a higher elevation than the Sacramento River at the same latitude and this offers an opportunity for power development in making the diversion.

In order to make as much of the water as possible available to the Sacramento River Basin, storage would be required in the vicinity of the point of diversion. Two dam and reservoir sites were surveyed and investigated and comparative estimates of the cost of constructing storage works at each were made. One of these dam sites is located at the big bend in the river about 2.5 miles above Lewiston and the other at the old Fairview mine about 10.5 miles above the same town. The comparative estimates showed that the Fairview site would be the better for the creation of the amount of storage capacity that would be required and it was adopted for the plan proposed in this report.

Water Supply.—Records available for estimating the run-offs of the Trinity River above Lewiston are the discharge records kept at several points by the United States Geological Survey and records or estimates of diversions obtained from various other sources. The records of most value in making water supply estimates are those kept at the highway bridge at Lewiston where a gage was established August 28, 1911. These records were available for the 18-year period 1911–1929.

The general methods of estimating the full natural, the ultimate net, and the present net run-offs have been given in Chapter II. These same methods were used to estimate the full natural run-offs for the 40-year period 1889–1929 at the Lewiston gaging station and also the full natural and ultimate net run-offs at the Fairview dam site for the same period. Present use was considered to be practically the same as ultimate use so the present net run-offs were assumed the same as the ultimate net run-offs.

The full natural run-offs at the Lewiston gaging station for the period of record were estimated by months by adding to the monthly measured run-offs the estimated diversions from Stuart Fork by the La Grange Flume for use at the La Grange Mine three miles west of Weaverville. This mine was in operation from 1895 to 1920 and the records at Lewiston from 1911 to 1920 were corrected for these diversions. All other diversions in the watershed above Lewiston are for power or mining uses, from which the water returns to the stream, or for small irrigated areas, and were neglected. The seasonal full natural run-offs for the years 1889 to 1911 were estimated from a probable run-off curve plotted by using seasonal rainfall indices, and the seasonal full natural run-offs at Lewiston for the 18-year period. The indices of wetness for Division C were used in drawing this curve and in obtaining the seasonal full natural run-offs for the seasons prior to 1911–1912. The full natural run-off at the Fairview dam site was estimated to be 97 per cent of that at the Lewiston gaging station and, in the studies for diversion, no allowance was made for water which enters the river between the Fairview dam site and the point of diversion about 2½ miles above Lewiston. The monthly distribution of the run-off in the years prior to stream flow records was assumed the same as the average for the years having records. This distribution is shown in Table 114.

The monthly ultimate net run-offs at the dam site were obtained from the monthly full natural run-offs by subtracting a constant flow of 75 second-feet, or as much thereof as could have been obtained from the estimated natural flow of Stuart Fork, either for mining or power development. A deduction also was made from the releases from the reservoir for a steady flow of 20 second-feet in the river below Lewiston to care for prior rights. This latter amount of water would have been available for the generation of power at the dam but not for diversion to the Sacramento Valley.

The seasonal full natural and ultimate net run-offs at the Fairview dam site are shown in Table 113.

The variation in the seasonal run-offs from the area above Fairview is shown by the values in Table 113. The maximum seasonal full natural run-off in the 40-year period occurred in 1889–1890 with a run-off of 3,315,000 acre-feet and the minimum was 248,000 acre-feet in 1923–1924, a variation of from 276 per cent to 20.6 per cent of the mean seasonal run-off for the 40-year period.

The average monthly distribution of the run-off as determined from the estimated monthly full natural run-offs at the Fairview dam site during the 40-year period 1889–1929 is shown in Table 114.

TABLE 113

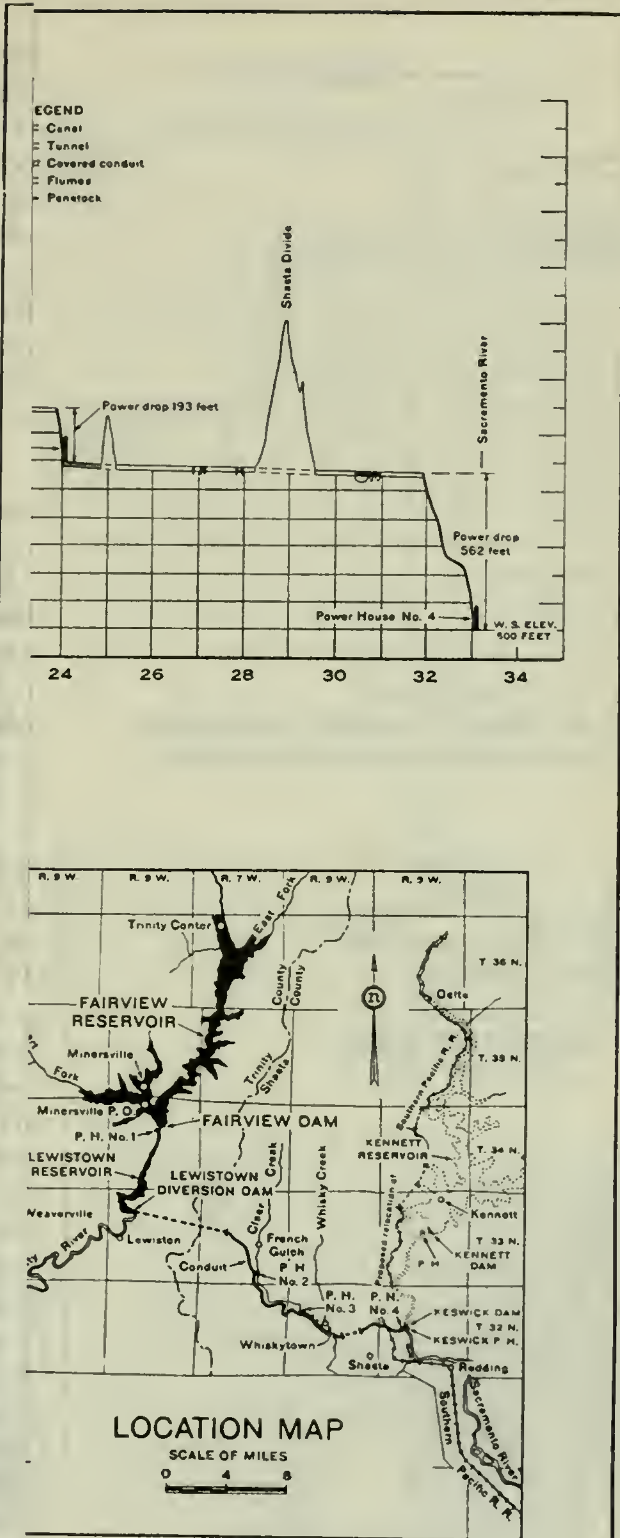
SEASONAL RUN-OFFS OF TRINITY RIVER AT FAIRVIEW DAM SITE, 1889-1929

Season	Full natural run-off, in acre-feet	Ultimate net run-off, in acre-feet
1889-1890	3,315,000	3,248,000
1890-1891	677,000	630,000
1891-1892	804,000	755,000
1892-1893	1,040 000	986,000
1893-1894	2,653,000	2,588,000
1894-1895	712,000	665,000
1895-1896	1,507,000	1,447,000
1896-1897	1,289,000	1,232,000
1897-1898	399,000	360,000
1898-1899	498,000	457,000
1899-1900	1,004,000	952,000
1900-1901	1,532,000	1,472,000
1901-1902	923,000	871,000
1902-1903	1,133,000	1,078,000
1903-1904	3,113,000	3,046,000
1904-1905	1,371,000	1,312,000
1905-1906	1,460,000	1,402,000
1906-1907	1,930,000	1,868,000
1907-1908	687,000	640,000
1908-1909	1,585,000	1,524,000
1909-1910	890,000	839,000
1910-1911	954,000	902,000
1911-1912	972,000	920,000
1912-1913	1,013,000	958,000
1913-1914	1,896,000	1,839,000
1914-1915	2,012,000	1,957,000
1915-1916	1,410,000	1,356,000
1916-1917	616,000	575,000
1917-1918	578,000	535,000
1918-1919	1,082,000	1,032,000
1919-1920	391,000	354,000
1920-1921	1,670,000	1,611,000
1921-1922	729,000	687,000
1922-1923	638,000	594,000
1923-1924	248,000	217,000
1924-1925	1,394,000	1,338,000
1925-1926	752,000	708,000
1926-1927	1,698,000	1,639,000
1927-1928	984,000	932,000
1928-1929	492,000	450,000
40-year means, 1889-1929	1,201,000	1,149,000
20-year means, 1909-1929	1,021,000	972,000
10-year means, 1919-1929	900,000	853,000
5-year means, 1924-1929	1,064,000	1,013,000

TABLE 114

AVERAGE MONTHLY DISTRIBUTION OF RUN-OFF OF TRINITY RIVER AT FAIRVIEW DAM SITE

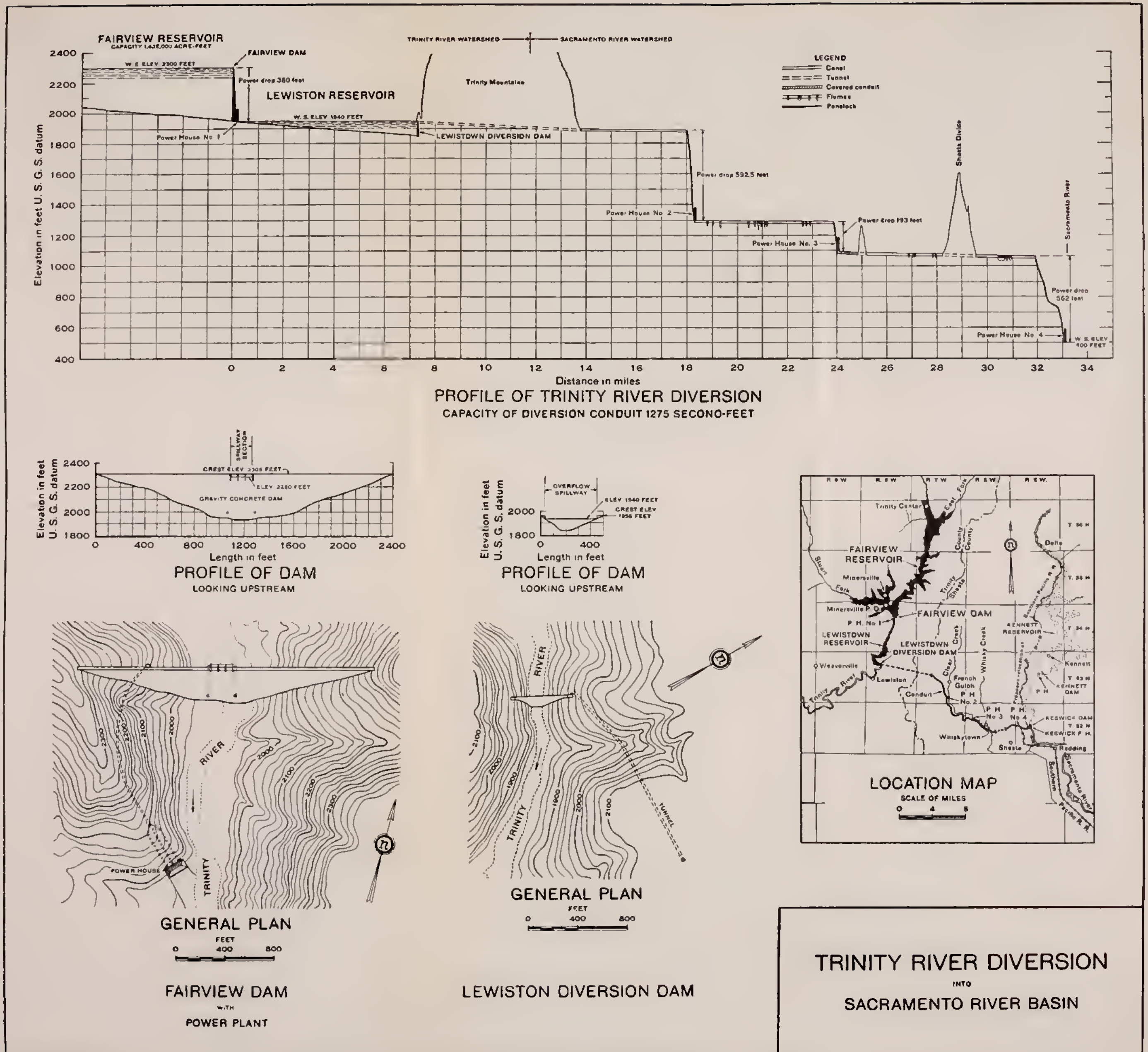
Month	Average full natural run-off	
	In acre-feet	In per cent of mean seasonal
January	83,900	6.99
February	144,200	12.01
March	169,600	14.12
April	229,200	19.08
May	255,400	21.27
June	136,800	11.39
July	41,700	3.47
August	12,900	1.07
September	10,500	0.88
October	15,300	1.27
November	47,600	3.96
December	53,900	4.49
Total	1,201,000	100.00



TRINITY RIVER DIVERSION

INTO

SACRAMENTO RIVER BASIN



TRINITY RIVER DIVERSION
INTO
SACRAMENTO RIVER BASIN

Plan of Development.—A number of plans were studied for the diversion of the Trinity River water to the Sacramento River Basin in order to obtain the one which would deliver this water into the basin at the lowest net annual cost per acre-foot. Since the utilization of the head between the two rivers for the generation of power is an important item, many plans of power development were analyzed in connection with these studies. One of these plans appeared to be better than any other studied and therefore was adopted for the development proposed in this report. The adopted plan, hereinafter described, is shown on Plate XLIV, "Trinity River Diversion into Sacramento River Basin." It is practically the same plan as that formerly proposed* for this diversion.

Fairview Reservoir.—The run-off of Trinity River would be regulated by a storage reservoir with a dam at the Fairview site. This dam would be 365 feet in height and would create a storage capacity of 1,436,000 acre-feet. It is believed that for a good many years after the completion of the development, water would be released from the reservoir in accordance with the demand for power in northern and central California as shown in Table 64. The maximum releases would be made in August, the month of maximum power demand, and would be at the rate of 2570 acre-feet per day or an average discharge of 1295 second-feet.

An area of 11,200 acres of land would be flooded by the proposed 365-foot dam. This land is for the most part rocky side hill grazing land but there are some areas in the upper end of the reservoir of fairly good agricultural land. The timber within the reservoir area is of very little value. No active mines would be flooded and any gold dredging land within the reservoir probably will have been worked over before the reservoir would be built. There are some ranch buildings and improvements within the area, and two county roads and paralleling telephone lines which would be flooded would require relocation above the flow line. Assessed land values in the reservoir range from $1 to $17 per acre with an average of $5.50.

A topographic survey of the Fairview reservoir site was made by the State in 1922 and a map was drawn from this survey at a scale of one inch equals 1000 feet, with a contour interval of 50 feet. The water surface areas measured from this map and the computed capacities of the reservoir are shown in Table 115.

It is estimated that the mean annual net evaporation from the reservoir surface would be distributed by months as shown in Table 63.

A survey of the Fairview dam site was made by the state in 1930 and a topographic map drawn from this survey at a scale of one inch equals 200 feet with a contour interval of 20 feet was used in laying out and estimating the costs of the Fairview dam and power plant No. 1.

No core drilling or other explorations were made at the site. A few borings made in the stream channel by a dredging company to determine the depth of the gravel were available, however, and the mine tunnels in the vicinity and the rock outcrops in the stream bed and on the slopes of the sides of the canyon give a good opportunity

* Bulletin No. 12, "Summary Report on the Water Resources of California and a Coordinated Plan for Their Development," Division of Engineering and Irrigation, 1927.

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* Bulletin No. 12, "Summary Report on the Water Resources of California and a Coordinated Plan for Their Development," Division of Engineering and Irrigation, 1927.

TABLE 115

AREAS AND CAPACITIES OF FAIRVIEW RESERVOIR

Height of dam, in feet (5-foot freeboard)	[1]Water surface elevation of reservoir, in feet	Area of water surface, in acres	Capacity of reservoir, in acre-feet
0	1,940	0	0
15	1,950	10	100
65	2,000	460	11,800
115	2,050	1,370	57,500
165	2,100	2,820	162,000
215	2,150	4,160	337,000
265	2,200	6,000	591,000
315	2,250	8,310	949,000
365	2,300	11,180	1,436,000

[1] United States Geological Survey datum.

for determining the character of the rock which would form the foundation for the dam. A detailed geological examination of all of the dam sites in the vicinity of the old Fairview mine was made and the report may be found in Appendix D. The geological examinations indicate that the rock is suitable for the foundation for a dam of any type. It is a metaandesite of the same character as that at the Kennett dam site on the Sacramento River. The right abutment of the dam would rest against a projecting ridge and on account of the narrow section of this ridge near its outer end, the dam was located to abut against the heavier section near its junction with the main slope of the canyon wall.

PLATE XLV

Fairview Dam Site on Trinity River

Rock fill, gravel fill, and gravity concrete types of dam were considered for this site. Comparative estimates indicated that with the sections proposed for the two former types, the cost would be as much if not more than with a concrete section. There is also some doubt as to the suitability of the rock in the vicinity for a rock fill, and as to there being sufficient gravel for a gravel fill. Furthermore, both of the latter types also offer greater difficulty in handling stream flow during construction. The gravity concrete section, therefore, was adopted for the estimates in this report. However, more detailed study might reveal that another type of dam would be feasible and less costly, and ample and suitable material available for its construction. The layout for the dam is shown on Plate XLIV. It would be straight in plan, 365 feet high and 2400 feet long.

A considerable amount of excavation of the overlying soil and decomposed rock and the gravel in the river channel would be required to obtain a good firm rock foundation. There would be a cut-off wall at the upstream toe, beneath which the rock would be sealed by grouting. The foundation would be drained by a row of drainage wells, just downstream from the upper cut-off wall, which would be connected to a gallery in the dam.

Diversion of the stream flow during the excavation for and construction of the lower portion of the dam in the stream channel would be accomplished by gravel or rock fill coffer dams with steel sheet piling core walls, above and below the excavation. Water would be conveyed around the excavation by a concrete-lined horseshoe-shaped tunnel which would have a capacity of 5000 second-feet.

The spillway would be located in the main dam near its center and would have a discharging capacity of 50,000 second-feet. This section of the dam would be of the gravity concrete overflow type. The flow over the spillway would be controlled by three hydraulically operated steel segmental drum gates 50 feet long and 20 feet high set in the crest of the spillway section. The gates would be separated by 10-foot piers in which the operating mechanism would be located.

There would be no flood control outlets in the dam. Control of floods by the Fairview reservoir is not proposed since the Trinity River floods would have no effect on flood control works in the Sacramento Valley, as the discharge to the valley would be limited to the capacity of the diversion tunnel, and it is not believed that flood control is necessary for the protection of lands along the Trinity River.

The only outlets through the dam would be two circular openings 300 feet below the top of the dam which would be used both for sluices and for releasing water when the power house was not in operation. These openings would be 66 inches in diameter and lined with steel. Flow through each outlet would be controlled by a caterpillar type self-closing sluice gate, at the upstream face of the dam, operated from the top of the dam. The gate would be protected by steel trash racks set in a semicircular concrete structure and would operate in a concrete enclosed gate well extending to the top of the dam. Each outlet would be further controlled by a slide gate a short distance from the inlet end, operated from a chamber inside of the dam. Also, in order to give more accurate regulation of the releases, one outlet would be equipped with a 66-inch balanced needle valve at its discharging end.

Water discharged from the spillway and sluiceways would flow over the downstream face of the dam into a concrete lined channel in the streambed.

Power Plant No. 1.—Water released from the Fairview reservoir would pass through power house No. 1 which would be located on the right bank of the stream about 1300 feet below the dam. The water would be conveyed to it from the reservoir by a concrete lined horseshoe shaped tunnel, 12.5 feet in diameter, located under the right abutment of the dam. Near the power house this tunnel would divide into three steel pipe penstocks, 90 inches in diameter, leading to the turbines. These pipes would be laid in separate concrete lined horseshoe shaped tunnels 11.5 feet in diameter. Water would enter the main tunnel through a concrete gate tower over a vertical concrete lined shaft. Flow into the tower would be controlled by caterpillar type self-closing sluice gates operated from the top of the tower and protected by steel trash racks and concrete enclosed gate wells. The power plant would be operated on a load factor of 0.60 and have a power factor of 0.80 and a total installed capacity of 62,000 kilovolt amperes. This would be divided equally among three generators each of which would be direct connected to a vertical shaft variable head reaction turbine. The power house would be of concrete and steel construction. Transformers and protective equipment would be of the outdoor type.

Lewiston Reservoir.—A diversion dam would be built at the Lewiston site about 2.5 miles above the town of Lewiston. Surveys of the Lewiston reservoir and dam sites were made by the State in 1926. A topographic map of the reservoir site was drawn from this survey at a scale of one inch equals 1000 feet, with a contour interval of 25 feet, and a topographic map of the dam site drawn at a scale of one inch equals 200 feet, with a contour interval of ten feet, was used in laying out and estimating the cost of the Lewiston diversion dam. The dam would be of the gravity concrete overflow type without crest gates. The crest would be at the level of the tail water of plant No. 1 and would be 98 feet above low water below the dam. It would be essentially a diversion dam but the pond between it and the Fairview dam also would serve as an afterbay to reregulate the variable discharge from plant No. 1 to the desired flow for diversion. A minimum of twenty second-feet of water would be allowed to pass this dam at all times for downstream uses. The layout for this dam also is shown on Plate XLIV.

Diversion Tunnel.—The water to be diverted to the Sacramento River Basin would enter a tunnel constructed through the Trinity Mountains, at the left abutment of the Lewiston dam. This tunnel would have a concrete lined horseshoe shaped section 12.9 feet in diameter and would be 6.35 miles in length. It would have a capacity of 1275 second-feet, which would be the draft in the month of maximum power demand with the project operated primarily for the generation of power. This same capacity would be maintained for all conduits from the Lewiston dam to the last power house in the system, on the Sacramento River. The tunnel would terminate in French Gulch, a tributary of Clear Creek.

Power Plant No. 2.—At the end of the diversion tunnel in French Gulch, the water would be turned into a concrete lined canal which would carry it 4.14 miles along the sides of the French Gulch and Clear Creek canyons to a point near Tower House, where it would pass through steel pipe penstocks to power house No. 2. The power drop at this point would be 592.5 feet. This plant would operate on a unity daily load factor. It would have an installed generator capacity of

59,000 kilovolt amperes. The power house would be similar in construction to power house No. 1.

Power Plant No. 3.—The water on leaving the turbines of plant No. 2 would be collected in another open conduit and carried through a concrete lined canal, with flumes across streams and ravines, along the right side of the Clear Creek Canyon, a distance of 5.59 miles to power plant No. 3 near Oak Bottom on the Redding-Weaverville highway. At this plant, the power drop would be 193 feet. The water would be carried from the canal to the turbines through steel pipe penstocks. This plant also would operate on a unity daily load factor. It would have an installed generator capacity of 19,000 kilovolt amperes.

Power Plant No. 4.—The water from power house No. 3 would flow through a covered conduit along the bed of Clear Creek for a distance of 0.84 mile, then through a tunnel for 0.26 mile and then into a concrete lined canal, which, with flumes across streams entering Clear Creek from the north, would carry it 3.2 miles to a tunnel 1.15 miles in length under the Shasta Divide, at a point near the State highway crossing. Below the Shasta Divide tunnel, the water would again flow through a concrete lined canal, and one long flume across a draw, a distance of 2.67 miles to the head of the penstocks leading to power house No. 4. These penstocks would be steel pipes and would be 1.1 miles in length. The power house would be located on the right bank of the Sacramento River a short distance downstream from Keswick afterbay dam site. This plant also would operate on a unity daily load factor. The power drop would be 562 feet and the installed generator capacity of the plant, 53,000 kilovolt amperes.

Alternate Plan.—As an alternate for the plan just described, power plant No. 4 and the conduit to it could be omitted and the water after passing through plant No. 3 could be reregulated in a reservoir on Clear Creek. The other units of the plan would remain the same.

There is a site for a reregulating reservoir, which also could be used to regulate the run-off of Clear Creek, near the settlement of Whiskytown. This site has been studied and although it appears to be expensive, future conditions may show that is is desirable to use it for storage and omit the power development east of the Shasta Divide.

If the alternate plan were used, water diverted to the Sacramento River Basin in accordance with the power demand schedule could be reregulated to make it available under an irrigation demand schedule, thereby making more water available for this latter use. In the studies made with the adopted plan, about half of the water diverted from the Trinity River would be available in accordance with the irrigation demand and the remainder would be used only for the development of power or for this use, salinity control and the improvement of navigation on the Sacramento River.

Yields of Trinity River Diversion in Hydroelectric Energy and in Water for Irrigation—Diversion Operated Primarily for Generation of Power.—It is probable that for a good many years after its construction, the Trinity River diversion would be operated as a power project and that releases would be made from Fairview reservoir on this basis.

These releases would be distributed by months in accordance with the power demand shown in Table 64.

A study was made to estimate the amount of electric energy that would have been developed in each of the years from 1889 to 1929 with the reservoir operated primarily for this purpose, and the amount of new water that would have been made available in the Sacramento River Basin with the project operated in this way. The net run-off at the Fairview dam site was used in making these studies. The water was assumed to have been passed through the diversion conduits and the four power houses previously described and to have been discharged into the Sacramento River at Keswick. In addition to the regular releases, spillwater from the Fairview reservoir would have been utilized up to the capacity of the diversion system and the power plants. The flow of Clear Creek also would have been utilized through plants 3 and 4 when they were not running to capacity on Trinity River water. Plant No. 1 would have been operated on a 0.60 load factor and used for carrying peak loads while the other plants would have been operated on unity daily load factors.

Under this method of operation and with the drawdown in Fairview reservoir such that the head on plant No. 1 would never have been less than 50 per cent of the maximum, the regulated releases from the reservoir would have been 796,000 acre-feet per year and there would have been a deficiency in only one year in the forty, when the draft would have been 736,000 acre-feet, which is a deficiency of 7.5 per cent.

The average annual output of the entire system in hydroelectric energy would have been 1,063,900,000 kilowatt hours, with a maximum output of 1,144,500,000 kilowatt hours in 1904 and a minimum output of 890,300,000 kilowatt hours in 1924. The weighted daily load factor for the complete development would have been 0.87. The value of this energy at the power plants, based on the lowest of several estimates of the cost of producing an equivalent amount of electric energy of the same characteristics with a steam-electric plant located in the area of consumption, taking into account the cost of transmission from the point of generation to the load center, is estimated to be $0.0025 per kilowatt hour. The average annual revenue at this value would have been $2,660,000.

The total yield in irrigation water at Red Bluff with the unregulated run-off of the Sacramento River supplemented by the water diverted from the Trinity River, with the Trinity River diversion operated primarily for the production of electric energy, would have been 2,045,000 acre-feet per year distributed in accordance with the irrigation demand in the Sacramento Valley. This supply would have had a maximum deficiency of 27 per cent in 1924, and an average over the 40-year period 1889–1929 of two per cent. The annual yield in new water would have been 555,000 acre-feet. To make all of the Trinity River water available for irrigation use with this method of operation would require storage or reregulation in a reservoir on the Sacramento River Basin side of the Trinity Mountains.

Yields of Trinity River Diversion in Water for Irrigation and in Hydroelectric Energy—Diversion Operated Under Ultimate Conditions of Irrigation.—The irrigation of the total area along the foothills on the west side of the Sacramento Valley which is indicated on Plate VI as being the area to be supplied with Trinity River water, would require 440,000 acre-feet of water annually, distributed in accordance with the demand in the Sacramento Valley.

To have obtained this irrigation supply, the monthly distribution of water releases from Fairview reservoir would have been similar to, but slightly different from, the distribution when operated primarily for the production of hydroelectric energy, shown in Table 64. With this method of operation, the drafts in January, February, March, November and December would have been reduced slightly and in June, July and August, they would have been increased to the discharging capacity of the power installation, other months being practically the same as in the operation primarily for the generation of power. In June, July and August, additional amounts of water, from which no power would have been obtained, would have been drawn from the reservoir for irrigation use. This water would have been conveyed through the Trinity Mountains tunnel to French Gulch and released to flow down Clear Creek to a point of diversion below plant No. 3, where, with the amount available from the tailrace of this plant, it would have been diverted to the irrigable area.

The diversion of this water would have slightly reduced the energy output from plants Nos. 1, 2 and 3 and would have materially reduced the output of plant No. 4 by depriving that plant of about half of its water supply. With this modified schedule of release, plant No. 4 would have been idle each year from the end of April to the beginning of September. This would have resulted in the character of the power from plant No. 4 being poor but this would have been compensated for in part by the other three plants being operated to capacity during the summer months. It was estimated that the average annual energy output for the 40-year period 1889–1929, with this method of operation, would have been 855,000,000 kilowatt hours.

The irrigation yield would have had a maximum seasonal deficiency of 35 per cent in 1924 if sufficient storage had been retained in Fairview reservoir to maintain a minimum head equal to 50 per cent of the maximum, on plant No. 1.

Cost of Reservoirs and Diversion.—The following estimates of the cost of constructing the diversion were made by the methods generally outlined in the fore part of this chapter. They include all of the items necessary for the construction of the Fairview reservoir, the Lewiston diversion dam and reservoir, all tunnels and conduits, and the four power plants.

The annual cost of each unit of the diversion and power system also was estimated on the bases given in the fore part of this chapter and the amounts are set forth in Table 116.

TABLE 116

SUMMARY OF CAPITAL AND ANNUAL COSTS OF TRINITY RIVER DIVERSION INTO SACRAMENTO RIVER BASIN

Unit—	*Capital cost*	*Annual cost*
Fairview reservoir	$37,000,000	$2,210,000
Power plant No. 1 at Fairview dam	3,500,000	289,000
Lewiston diversion dam and reservoir	900,000	58,000
Conduit from Lewiston diversion dam to power plant No. 2, and power plant No. 2	10,700,000	741,000
Conduit from power plant No. 2 to power plant No. 3, and power plant No. 3	2,400,000	182,000
Conduit from power plant No. 3 to power plant No. 4, and power plant No. 4	7,500,000	538,000
Total cost of Trinity River diversion	$62,000,000	$4,018,000

The details of the estimates of the costs of constructing the foregoing units are shown in Tables 117 to 122, inclusive.

TABLE 117

COST OF FAIRVIEW RESERVOIR

Height of dam, 365 feet. Capacity of reservoir, 1,436,000 acre-feet.
Capacity of spillway, 50,000 second-feet.

Exploration and core drilling		$30,000
Diversion of river during construction		128,000
Clearing reservoir site		224,000
Excavation for dam, 887,000 cu. yd. at $1.50 to $5	$1,496,000	
Mass concrete, 2,630,000 cu. yds. at $9	23,670,000	
Reinforced concrete, 2200 cu. yds. at $21 to $27.50	50,000	
Spillway gates	97,000	
Spillway channel	291,000	
Sluiceways	140,000	
Drilling and grouting foundation	55,000	
		$25,799,000
Lands and improvements flooded		1,068,000
Permanent camps and clean-up after construction		50,000
Subtotal		$27,299,000
Administration and engineering, 10 per cent		2,730,000
Contingencies, 15 per cent		4,095,000
Interest during construction based on a rate of 4.5 per cent per annum		2,876,000
Total cost of dam and reservoir		$37,000,000

TABLE 118

COST OF POWER PLANT No. 1 AT FAIRVIEW DAM

Installed capacity, 62,000 kilovolt amperes.
Power factor = 0.80. Load factor = 0.60.

Intake structure	$76,000
Penstocks and tunnels	600,000
Building and equipment	1,935,000
Subtotal	$2,611,000
Administration and engineering, 10 per cent	261,000
Contingencies, 15 per cent	392,000
Interest during construction based on a rate of 4.5 per cent per annum	236,000
Total cost of power plant	$3,500,000

TABLE 119

COST OF LEWISTON DIVERSION DAM AND RESERVOIR

Height of dam, 98 feet. Overflow dam.
Capacity of spillway, 50,000 second-feet.

Exploration and core drilling		$10,000
Diversion of river during construction		10,000
Clearing reservoir site		25,000
Excavation for dam, 12,000 cu. yd. at $4.50	$54,000	
Mass concrete, 56,000 cu. yds. at $8	448,000	
Drilling and grouting foundation	12,000	
		514,000
Lands and improvements flooded		110,000
Construction road, permanent camp and clean-up after construction		20,000
Subtotal		$689,000
Administration and engineering, 10 per cent		69,000
Contingencies, 15 per cent		103,000
Interest during construction based on a rate of 4.5 per cent per annum		39,000
Total cost of dam and reservoir		$900,000

TABLE 120

COST OF DIVERSION CONDUIT FROM LEWISTON DAM TO POWER PLANT No. 2 NEAR TOWER HOUSE, AND POWER PLANT No. 2

Capacity of conduit, 1275 second-feet.
Installed capacity of power plant, 59,000 kilovolt amperes.
Power factor = 0.80. Load factor = 1.00.

Inlet structure	$15,000
Tunnel	4,951,000
Canal	899,000
Penstocks	420,000
Power house and equipment	1,745,000
Right of way, construction road, permanent camp and clean-up	60,000
Subtotal	$8,090,000
Administration and engineering, 10 per cent	809,000
Contingencies, 15 per cent	1,214,000
Interest during construction based on a rate of 4.5 per cent per annum	588,000
Total cost of conduit and power plant	$10,700,000

TABLE 121

COST OF CONDUIT FROM POWER PLANT No. 2 TO POWER PLANT No. 3 NEAR OAK BOTTOM, AND POWER PLANT No. 3

Capacity of conduit, 1275 second-feet.
Installed capacity of power plant, 19,000 kilovolt amperes.
Power factor = 0.80. Load factor = 1.00.

Inlet structure	$15,000
Canal	740,000
Flumes	110,000
Feeder ditches	90,000
Penstocks	141,000
Power house and equipment	698,000
Right of way, construction road, permanent camp and clean-up	57,000
Subtotal	$1,851,000
Administration and engineering, 10 per cent	185,000
Contingencies, 15 per cent	278,000
Interest during construction based on a rate of 4.5 per cent per annum	86,000
Total cost of conduit and power plant	$2,400,000

TABLE 122

COST OF CONDUIT FROM POWER PLANT No. 3 TO POWER PLANT No. 4 NEAR KESWICK, AND POWER PLANT No. 4

Capacity of conduit, 1275 second-feet.
Installed capacity of power plant, 53,000 kilovolt amperes.
Power factor = 0.80. Load factor = 1.00.

Inlet structure	$15,000
Covered conduit	116,000
Tunnels	1,059,000
Canals	766,000
Flumes	225,000
Penstocks	1,963,000
Power house and equipment	1,590,000
Right of way, construction road, permanent camp and clean-up	71,000
Subtotal	$5,805,000
Administration and engineering, 10 per cent	580,000
Contingencies, 15 per cent	871,000
Interest during construction based on a rate of 4.5 per cent per annum	244,000
Total cost of conduit and power plant	$7,500,000

Millsite Reservoir on Stony Creek.

Two storage reservoirs have been developed on Stony Creek by the United States Bureau of Reclamation to furnish irrigation water for the Orland Project. These reservoirs are the East Park, with a capacity of 51,000 acre-feet, completed in 1911 and the Stony Gorge, with a capacity of 50,200 acre-feet, completed in 1928. These two reservoirs, however, do not give as complete control of the run-off of the stream as is possible and desirable. The Millsite reservoir, therefore, is believed to be a necessary unit of the State Water Plan, for the further control of the run-off from the area between its dam site and the Stony Gorge dam and the water which would spill over the latter dam. The water regulated by this reservoir would practically all be required for irrigation use in the Stony Creek water service area described in Chapter V, which is an area lying at elevations too high to be served by gravity from the Sacramento River. Its only source of supply, therefore, is Stony Creek, or possibly the Trinity River diversion. The area, however, can be served more economically from the reservoirs on Stony Creek than from any other source of supply.

The site for the dam which would create the Millsite reservoir is located in Sections 1 and 12, Township 21 North, Range 6 West, M. D. B. and M., about ten miles downstream from the Stony Gorge dam.

The area of the drainage basin above the dam site is 597 square miles, of which 322 square miles or 54 per cent lies in the uncontrolled area between the site and the Stony Gorge dam. The total area includes about 3 per cent of the mountain and foothill drainage area of the Sacramento River Basin. The watershed is bounded on the west by the Coast Range divide between the Sacramento River Basin and the North Pacific Coast Basin and on the east is separated from the Sacramento Valley by a lower ridge. It runs in a general north and south direction parallel to the Sacramento Valley. Most of the area is of the low mountain or foothill type with some lands suitable for agriculture.

Water Supply.—Only the full natural and ultimate net run-offs at the dam site were estimated. The methods used were the same as those generally described in Chapter II.

Information on the run-off was obtained from records which have been kept by the United States Geological Survey at the station on the main stream near Fruto from 1901 to 1912; at Simpson Bridge station on the main stream (near Orland) from January, 1920, to September, 1929; and at the station on Little Stony Creek near Ladoga from January, 1908, to September, 1929. Records kept by the United States Bureau of Reclamation of storage in and releases from the East Park and Stony Gorge reservoirs were used in converting measured to full natural run-offs.

The full natural run-offs from the entire drainage area of 710 square miles above the mouth of the canyon were first estimated. To obtain these, the full natural run-offs at the Fruto and Simpson Bridge gaging stations were estimated for the period of record at each. The monthly full natural run-offs at the Fruto station were obtained from the measured run-offs by adding the estimated net amounts used for irrigation above the gage, by adding water stored in and subtracting water released from East Park reservoir, by adding evaporation from the reservoir, and by adding seepage losses from released water. The monthly full natural run-offs at Simpson Bridge were obtained from the measured run-offs by adding the estimated net amounts used for irrigation above the gage, by adding water stored in and subtracting water released from the East Park and Stony Gorge reservoirs, by adding evaporation losses from these reservoirs, and by adding seepage losses from water released from the reservoirs. The relation of the flows at the Fruto station to those at Simpson Bridge were established by comparing run-offs at each with the run-offs at the Little Stony Creek station near Ladoga. The run-offs at Simpson Bridge from 1913 to 1919 were estimated from those at the Ladoga station by the use of curves showing the relation of these run-offs established from parallel records. The run-off from the entire drainage area was estimated to be 11.6 per cent greater than that at Simpson Bridge and the monthly run-offs at the mouth of the canyon from 1901 to 1929 were estimated by increasing those at Simpson Bridge by this per cent. The monthly run-offs for the period 1889 to 1901 were estimated from probable run-off curves drawn for each month, as described in Chapter II. Rainfall stations in Division F were used for establishing the indices of wetness.

The full natural run-offs, by months, at the Millsite dam site were estimated from those at the mouth of the canyon by multiplying the run-offs at the latter point by the ratio of the drainage areas, since the rainfall appears to be about uniform over the entire area.

The monthly ultimate net run-offs at the dam site were estimated from the monthly full natural run-offs by making allowances for ultimate conditions of development. In making these estimates, it was assumed that under the plan for ultimate development, the irrigation yield of the East Park reservoir would be used on lands within the watershed above the Millsite dam site and that the irrigation yield of the Stony Gorge reservoir would be exported for use on areas outside of the watershed. The ultimate net run-offs were obtained from the full natural run-offs by subtracting the amounts of water stored in, evaporation from, and releases for irrigation from the East Park and Stony Gorge reservoirs; and by adding the return water from the irrigation in the watershed above the Millsite dam site.

The estimated full natural and ultimate net run-offs at the Millsite dam site are shown in Table 123.

The variations in the seasonal run-offs are shown by the full natural run-offs listed in Table 123. The maximum seasonal full natural run-off in the 40-year period 1889–1929, was 1,213,000 acre-feet in 1889–90 and the minimum was 36,000 acre-feet in 1923–24, a variation of from 281 per cent to 8 per cent of the mean seasonal full natural run-off for the same period.

The average monthly distribution of the run-off, as determined from the full natural run-offs at the dam site, is shown in Table 124.

Estimates of the maximum mean daily flow at the Simpson Bridge station indicate that once in 100 years on an average, a flow of 46,000 second-feet may be expected. Flows past the Fruto gaging station prior to the construction of the East Park Reservoir and the releasing of water from it in the summer for irrigation, were as low as 0.5 of a second-foot.

TABLE 123

SEASONAL RUN-OFFS OF STONY CREEK AT MILLSITE DAM SITE, 1889-1929

Season	Full natural run-off, in acre-feet	Ultimate net run-off, in acre-feet
1889-1890	1,213,000	1,078,000
1890-1891	366,000	314,000
1891-1892	176,000	109,000
1892-1893	569,000	484,000
1893-1894	174,000	118,000
1894-1895	1,106,000	1,016,000
1895-1896	480,000	418,000
1896-1897	343,000	278,000
1897-1898	73,100	45,700
1898-1899	182,000	105,000
1899-1900	293,000	205,000
1900-1901	312,000	247,000
1901-1902	752,000	667,000
1902-1903	611,000	549,000
1903-1904	868,000	790,000
1904-1905	520,000	450,000
1905-1906	575,000	498,000
1906-1907	901,000	839,000
1907-1908	294,000	228,000
1908-1909	1,107,000	1,034,000
1909-1910	305,000	245,000
1910-1911	599,000	509,000
1911-1912	55,200	34,900
1912-1913	125,000	72,800
1913-1914	902,000	787,000
1914-1915	686,000	606,000
1915-1916	453,000	390,000
1916-1917	239,000	173,000
1917-1918	125,000	75,700
1918-1919	224,000	156,000
1919-1920	58,300	37,200
1920-1921	539,000	419,000
1921-1922	218,000	149,000
1922-1923	186,000	128,000
1923-1924	36,000	29,300
1924-1925	428,000	321,000
1925-1926	258,000	191,000
1926-1927	535,000	449,000
1927-1928	317,000	252,000
1928-1929	85,500	51,400
40-year means, 1889-1929	432,000	364,000
20-year means, 1909-1929	319,000	254,000
10-year means, 1919-1929	266,000	203,000
5-year means, 1924-1929	325,000	253,000

TABLE 124

AVERAGE MONTHLY DISTRIBUTION OF RUN-OFF OF STONY CREEK AT MILLSITE DAM SITE

Month	Average full natural run-off	
	In acre-feet	In per cent of mean seasonal
January	106,000	24.51
February	111,000	25.68
March	92,400	21.40
April	47,400	10.97
May	21,000	4.87
June	6,700	1.56
July	1,900	0.45
August	1,400	0.33
September	1,200	0.27
October	1,500	0.35
November	10,600	2.45
December	30,900	7.16
Totals	432,000	100.00

Reservoir Site.—The lands that would have to be acquired for the reservoir are not highly improved. Most of the area would be in the gravel wash stream beds of Stony and Grindstone creeks. There are a few acres of cultivated land and a few small old orchards. Most of the area is useful primarily for grazing, if usable at all. There are only a few buildings within the area and these are of small value. A few miles of county road would be flooded and would require relocation above the flow line of the reservoir.

A topographic survey of the Millsite reservoir site was made by the United States Bureau of Reclamation in connection with storage studies for the Orland Project in 1923, and a map was drawn from this survey at a scale of one inch equals 500 feet, with a contour interval of ten feet. The water surface areas measured from this map and the computed capacities of the reservoir are shown in Table 125.

TABLE 125

AREAS AND CAPACITIES OF MILLSITE RESERVOIR

Height of dam, in feet (5-foot freeboard)	[1]Water surface elevation of reservoir, in feet	Area of water surface, in acres	Capacity of reservoir, in acre-feet
0	548	0	0
25	563	120	800
35	573	270	2,700
45	583	400	6,000
55	593	500	10,600
65	603	630	16,200
75	613	800	23,400
85	623	1,030	32,500
95	633	1,230	44,000
105	643	1,510	57,600
115	653	1,780	74,400
125	663	2,050	93,500
135	673	2,310	115,000

[1] United States Geological Survey datum.

Dam and Appurtenant Works.—The survey of the dam site and explorations of the foundations by diamond drill borings and open test pits also were made by the United States Bureau of Reclamation. A topographic map drawn from this survey at a scale of one inch equals 200 feet, with a contour interval of ten feet, was used in laying out and estimating the cost of the Millsite dam. A geological examination of the site was made by this division, the report on which, together with the logs of the test holes and a map showing their locations, may be found in Appendix E. The formation on which the dam would be founded is conglomerate beds separated by thinner beds of sandstone and shale. The ridge formed by these materials has been cut by Stony Creek and at the stream channel the notch is about 60 feet deep below low water surface and is filled with sand and gravel. The suggested method of preparing the foundation for the dam and the probable amounts of excavation are given in the geologic report.

The dam would be of the reinforced concrete slab-buttress type. It would be 135 feet high above low water and the crest would be 2840 feet in length. The layout and profile of the dam are shown on Plate XLVII, "Millsite Reservoir on Stony Creek."

PLATE XLVI

Millsite Dam Site on Stony Creek

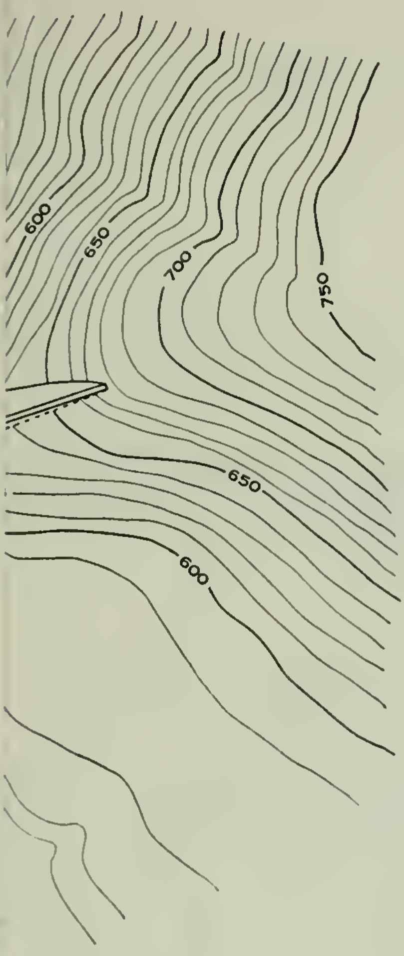
There would be a cut-off wall at the upstream toe, beneath which any seams or voids in the rock would be sealed by pressure grouting for the purpose of preventing seepage under the dam.

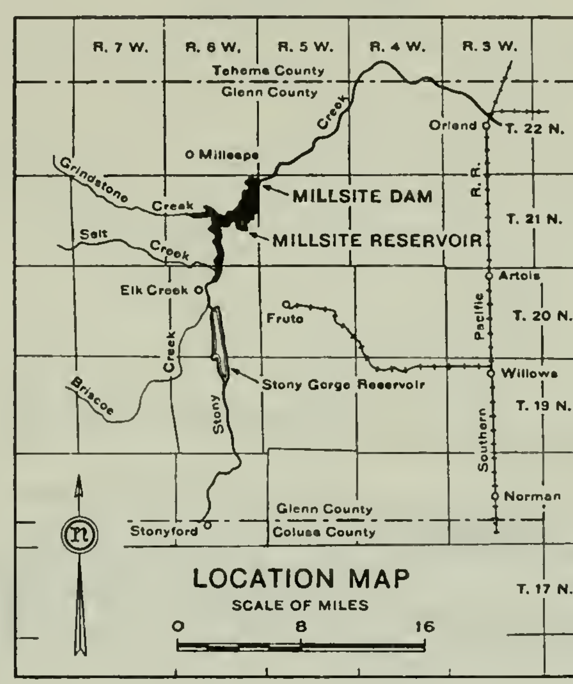
Diversion of the stream flow during the construction of the lower portion of the dam would be accomplished by constructing coffer dams of gravel fill, with steel sheet-piling core and cut-off walls, above and below the excavation. The water would be carried between these dams in a flume.

The spillway would be located in the portion of the dam over the stream channel and would have a capacity of 53,000 second-feet. The flow over the crest would be controlled by five caterpillar type gates which would slide down the inclined surface of the upstream face of the dam when opened. These gates would be 30 feet square and would control an opening 20 feet in depth. They would be operated on concrete piers which would separate them. Water passing over the spillway would flow over the down-stream face of the dam into the stream channel which would be protected by a concrete apron.

There would be two outlet pipes 50 inches in diameter, located at a depth of 130 feet below the top of the dam. These outlets would serve as sluiceways and for the release of irrigation water. Flow through each pipe would be controlled by a slide gate near the inlet end and a 50-inch balanced needle valve at the outlet. Steel trash racks would protect the inlet.

Yield of Reservoir in Water for Irrigation.—A study was made to estimate the amounts of water that would have been made available for irrigation from the Millsite reservoir alone in the 40-year period 1889–1929, with the reservoir operating primarily for this purpose, and the amount of this yield that would have been new water. This study was made by the methods described in the fore part of this chapter. The entire capacity of the reservoir was utilized and the reservoir was operated primarily for supplying irrigation water.

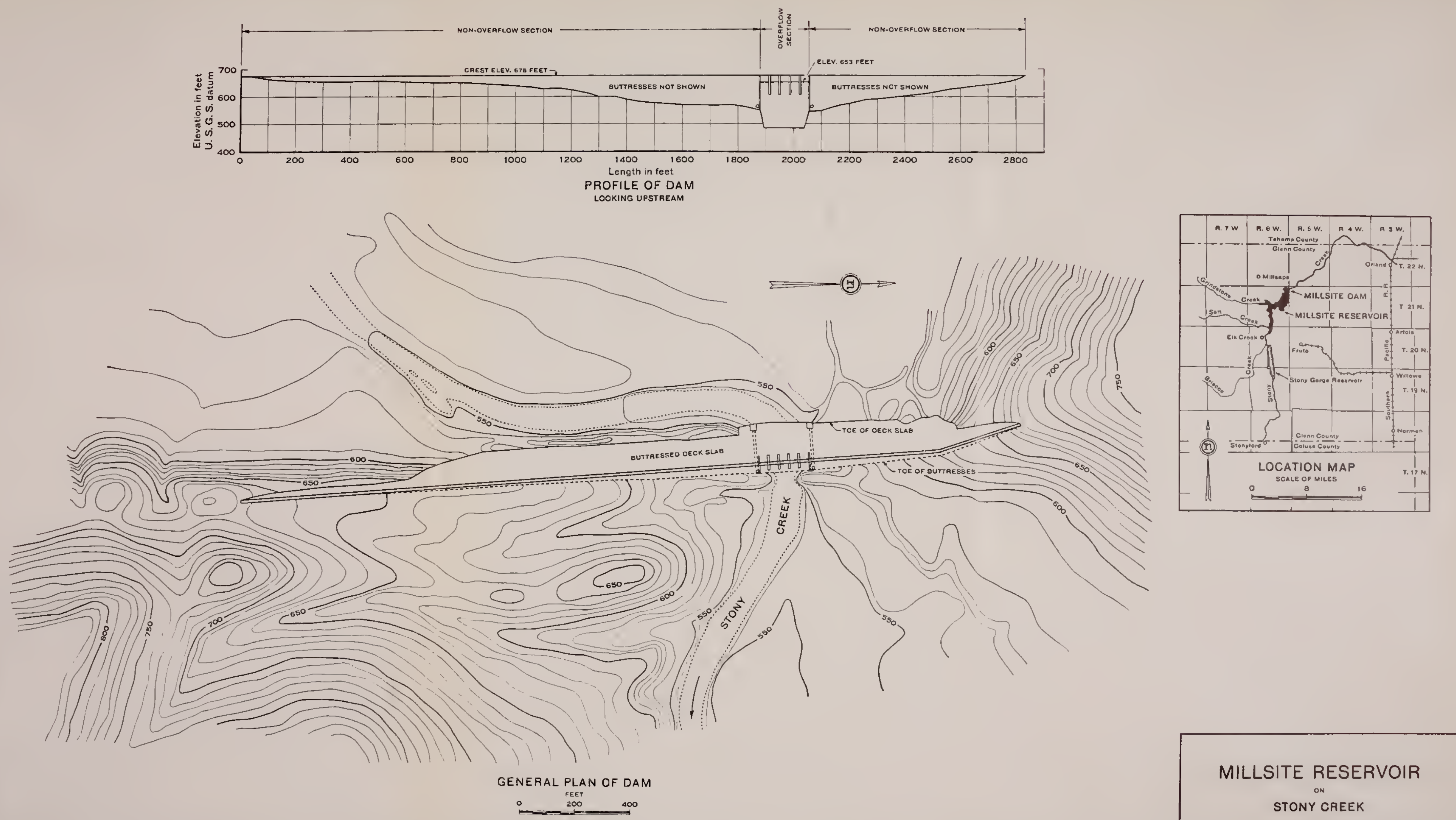




MILLSITE RESERVOIR

ON

STONY CREEK



MILLSITE RESERVOIR
ON
STONY CREEK

The study indicates that a seasonal irrigation draft of 92,000 acre-feet would have been obtainable with a maximum seasonal deficiency of 24.8 per cent in the driest year and an average deficiency for the 40-year period of two per cent. The seasonal yield in new water would have been 77,000 acre-feet with corresponding deficiencies.

Flood Control.—Curves showing the probable frequency of occurrence of flood flows of certain amounts at the Simpson Bridge gaging station near Orland and the amount of reservoir space required to control floods which are expected to occur at certain intervals of time at that point, to selected regulated flows, are shown on Plates VIII and X in Chapter VI.

One of the largest floods of record occurred in the latter part of March and it would be necessary, therefore, to hold the full reserve space until the first of April. Due to the nature of the run-off from the drainage area, there would be insufficient water after this date in some years to fill as much of the reserve space as would have been filled without this reservation for flood control. The irrigation yield of the reservoir would be diminished and no flood control, therefore, has been considered with this reservoir as the full irrigation yield would be required for the area to be watered from this source.

Should flood control on the stream ever be desired, the required storage space could be reserved in the Stony Gorge or Millsite reservoirs, or both, and an equivalent irrigation storage created at one of the other reservoir sites on the stream.

Cost of Reservoir.—The estimate of the cost of the reservoir set forth in Table 126 was made as generally outlined in the fore part of this chapter and includes all of the items which have been briefly described in the foregoing paragraphs. No power plant is proposed in connection with this reservoir.

TABLE 126

COST OF MILLSITE RESERVOIR

Height of dam, 135 feet. Capacity of reservoir, 115,000 acre-feet.
Capacity of spillway, 53,000 second-feet.

Exploration and core drilling		$20,000
Diversion of stream during construction		56,000
Clearing reservoir site		15,000
Excavation for dam, 135,000 cu. yds. at $1 to $2.50	$150,000	
Buttress and slab concrete, 96,000 cu. yds. at $15	1,440,000	
Spillway gates	114,000	
Spillway channel	307,000	
Irrigation outlets	44,000	
Drilling and grouting foundation	65,000	
		2,120,000
Lands and improvements flooded		225,000
Permanent camps and clean-up after construction		20,000
Subtotal		$2,456,000
Administration and engineering, 10 per cent		246,000
Contingencies, 15 per cent		368,000
Interest during construction, based on a rate of 4.5 per cent per annum		130,000
Total cost of dam and reservoir		$3,200,000

The annual cost of the dam and reservoir estimated on the bases given in the fore part of this chapter and the capital cost given in Table 126 would be $212,000.

The study indicates that a seasonal irrigation draft of 92,000 acre-feet would have been obtainable with a maximum seasonal deficiency of 24.8 per cent in the driest year and an average deficiency for the 40-year period of two per cent. The seasonal yield in new water would have been 77,000 acre-feet with corresponding deficiencies.

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Should flood control on the stream ever be desired, the required storage space could be reserved in the Stony Gorge or Millsite reservoirs, or both, and an equivalent irrigation storage created at one of the other reservoir sites on the stream.

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Total cost of dam and reservoir		$3,200,000

The annual cost of the dam and reservoir estimated on the bases given in the fore part of this chapter and the capital cost given in Table 126 would be $212,000.

Capay Reservoir on Cache Creek.

The Capay reservoir site is located in the lower Cache Creek canyon near the line of the valley floor.

There are other reservoir sites in the watershed above the Capay site, the most important of which are Clear Lake, and the Little Indian Valley site on the North Fork of Cache Creek. These sites are in positions to control only a portion of the run-off of the creek but are, nevertheless, important units in the plan to obtain the maximum use of Cache Creek water for the irrigation of lands which can obtain a supply from no other source, since they lie at sufficient elevation to water the higher lands by gravity. The Capay reservoir would serve to regulate any water not used in the upper watershed, or diverted from the upper reservoirs for use on the valley floor. Storage for irrigation has been developed in Clear Lake and the stored water is now used on lands below the mouth of the canyon on the west side of the Sacramento Valley floor. It is proposed in the operation of the State Water Plan to use the water stored in Clear Lake for the irrigation of lands in the foothills along the west side of the Sacramento Valley which are too high to be irrigated from the Capay reservoir, and to use the latter reservoir to irrigate lands on the valley floor now irrigated from Clear Lake, and as much additional land as the reservoir can serve. The Capay reservoir, therefore, is required as a major unit of the State Water Plan to obtain a reasonable conservation of the water of Cache Creek and to furnish water for valley floor lands so that water from the reservoirs higher on the stream may be used for irrigation of lands which otherwise could not be served.

The site for the dam which would create the Capay reservoir is located in Sections 5 and 6, Township 10 North, Range 2 West, M. D. B. and M., about five miles upstream from the town of Capay.

The area of the drainage basin above the dam site is about 996 square miles, which is about 4.7 per cent of the total mountain and foothill area of the Sacramento River Basin. The basin can be divided into two natural divisions, that tributary to Clear Lake, a large natural lake in Lake County, and that from which the run-off is not tributary to the lake. The portion of the basin above the outlet of the lake contains 487 square miles, or 49 per cent of the total area above the dam site. This portion of the watershed contains large areas of lake surface and more or less flat land surrounded by mountains, while the area which does not drain into the lake is all mountainous except for a few small valleys and some flat land in the bottom of the lower Cache Creek canyon. These conditions have a very material effect on the run-off from the Cache Creek watershed.

Water Supply.—Records of the flow of Cache Creek have been kept at Yolo and Lower Lake by the United States Geological Survey for the periods shown in Table 4. Records of the stages of Clear Lake also have been kept since 1913 by the Geological Survey and for a number of years prior to that date by residents around the lake. Records of evaporation from the lake are available for the years 1920, 1924, 1927, and 1928.

The gaging station at Yolo is located several miles from the mouth of the Cache Creek canyon and the run-off at the station is reduced from that at the mouth of the canyon by channel losses and is increased over it by the run-off from 200 square miles of valley floor. It was decided, therefore, to estimate the full natural run-offs and the ultimate net run-offs at the dam site without the direct use of these records. In estimating the full natural run-offs, the drainage area above the dam site was divided into the two areas previously described, that which drains into Clear Lake and the remaining area above the dam site not tributary to the lake. The run-offs from these two areas were estimated separately and added to obtain the run-offs at the dam site for the period 1901 to 1929. The full natural run-offs of the Clear Lake drainage basin were estimated from changes in storage in the lake, outflows from the lake and evaporation from the lake surface. The full natural run-offs from the Cache Creek basin not tributary to the lake were estimated by comparison with the full natural run-offs from the Putah Creek drainage basin above Winters, since these two basins are adjacent and similar in size and character and since the records of Putah Creek run-off are considered to be reliable. The run-offs from the Cache Creek basin below the lake were assumed to bear the same ratio to those from the Putah Creek basin as the ratio of the areas of the two watersheds. Prior to 1901, the run-offs were estimated from probable run-off curves based on the relation of rainfall, or index of seasonal wetness, to run-off, as described in Chapter II.

As previously stated, the full irrigation of the area dependent upon Cache Creek for a supply will require storage at elevations higher than Capay reservoir. This storage was assumed to be provided in Clear Lake, Little Indian Valley, and in the Cache Creek canyon near the mouth of Bear Creek. The full natural run-offs at each of these reservoir sites were estimated, and from them the yields of the reservoirs in irrigation water. Clear Lake was assumed to have the same limitations of operation as have been fixed by court order. The water was released in accordance with the irrigation requirements of the agricultural lands along Cache Creek and on the foothill lands along the west side of the Sacramento Valley north of Cache Creek, under the conditions of ultimate irrigation development of those lands. Estimates also were made of the monthly full natural run-offs from the area between the Bear Creek reservoir, the lowest of the three mentioned above, and the Capay dam site. The ultimate net run-offs, by months, at the Capay dam site were estimated by adding the full natural run-offs from the area between this site and the Bear Creek reservoir site, the spill from the Bear Creek reservoir under the conditions of ultimate development as determined from the irrigation yield studies for the three upper reservoirs, and the return water from the lands that would be ultimately irrigated in the watershed along Cache Creek above the Capay dam site.

The estimated full natural and ultimate net run-offs at the Capay dam site are shown in Table 127.

The variation in the seasonal run-offs is shown by the full natural run-offs listed in Table 127. The maximum seasonal full natural run-off in the 40-year period 1889–1929 was 2,125,000 acre-feet in 1889–90 and the minimum was 59,500 acre-feet in 1897–98, a variation of from 279 per cent to eight per cent of the mean seasonal run-off for the period.

TABLE 127

SEASONAL RUN-OFFS OF CACHE CREEK AT CAPAY DAM SITE, 1889-1929

Season	Full natural run-off, in acre-feet	Ultimate net run-off, in acre-feet
1889-1890	2,125,000	1,540,000
1890-1891	584,000	330,000
1891-1892	558,000	276,000
1892-1893	1,435,000	1,145,000
1893-1894	398,000	162,000
1894-1895	1,450,000	1,132,000
1895-1896	903,000	625,000
1896-1897	813,000	537,000
1897-1898	59,500	6,200
1898-1899	398,000	105,000
1899-1900	813,000	374,000
1900-1901	791,000	522,000
1901-1902	787,000	520,000
1902-1903	672,000	408,000
1903-1904	1,310,000	1,004,000
1904-1905	1,111,000	851,000
1905-1906	1,009,000	701,000
1906-1907	1,247,000	978,000
1907-1908	477,000	208,000
1908-1909	1,632,000	1,340,000
1909-1910	492,000	220,000
1910-1911	815,000	515,000
1911-1912	180,000	20,400
1912-1913	302,000	82,800
1913-1914	1,487,000	1,070,000
1914-1915	1,254,000	971,000
1915-1916	898,000	633,000
1916-1917	437,000	180,000
1917-1918	193,000	39,500
1918-1919	531,000	180,000
1919-1920	93,600	9,800
1920-1921	960,000	495,000
1921-1922	488,000	225,000
1922-1923	523,000	243,000
1923-1924	76,300	9,000
1924-1925	756,000	316,000
1925-1926	681,000	399,000
1926-1927	914,000	615,000
1927-1928	637,000	366,000
1928-1929	183,000	25,400
40-year means, 1889-1929	762,000	484,000
20-year means, 1909-1929	595,000	331,000
10-year means, 1919-1929	531,000	270,000
5-year means, 1924-1929	634,000	344,000

TABLE 128

AVERAGE MONTHLY DISTRIBUTION OF RUN-OFF OF CACHE CREEK AT CAPAY DAM SITE

Month	Average full natural run-off	
	In acre-feet	In per cent of mean seasonal
January	163,000	21.39
February	184,000	24.15
March	153,000	20.08
April	87,800	11.52
May	39,800	5.22
June	17,700	2.32
July	9,900	1.30
August	5,000	0.66
September	4,200	0.55
October	11,000	1.44
November	24,000	3.15
December	62,600	8.22
Totals	762,000	100.00

The average monthly distribution of the run-off as determined from the full natural run-offs at the Capay dam site is shown in Table 128.

Reservoir Site.—The lands that would be flooded in the Capay reservoir site are principally agricultural. Parts of these lands are planted to orchard and nearly all are relatively flat and of good quality. The principal improvements that would be affected, in addition to the buildings and ranch improvements, are the county highway from Woodland to Rumsey and the branch line of the Southern Pacific railroad running up the Capay Valley. The relocation of the road would require the construction of eleven miles of new highway above the flow line of the reservoir. It is doubtful whether it would be necessary to reconstruct the railroad as it would serve only a limited area above the reservoir. The value of the abandoned portion of the line, however, was included in the cost estimate.

A topographic map of the reservoir site filed with this division by H. M. Byllesby and Company in 1930, at a scale of one inch equals 1000 feet, with a contour interval of ten feet, was used in obtaining the water surface areas and computed capacities of the Capay reservoir shown in Table 129.

TABLE 129

AREAS AND CAPACITIES OF CAPAY RESERVOIR

Height of dam, in feet (10-foot freeboard)	[1]Water surface elevation of reservoir, in feet	Area of water surface, in acres	Capacity of reservoir, in acre-feet
65	320	400	4,000
75	330	710	10,000
85	340	1,030	20,000
95	350	1,810	33,000
105	360	2,600	52,000
115	370	3,270	80,000
125	380	3,950	118,000
135	390	4,680	162,000
145	400	5,420	209,000
155	410	6,410	268,000
165	420	7,400	338,000
170	425	7,860	378,000

[1] Datum not known.

Dam and Appurtenant Works.—The topographic map of the reservoir site just referred to also was used in laying out and estimating the costs of the main dam and the two auxiliary dams. There have been no explorations of the foundation for the dams but a geological examination of this site was made, the report on which will be found in Appendix E. The formation on which the dam would be founded is a soft sandy shale overlaid with a soil cover on the abutments and gravel in the stream channel.

The only type of dam considered for this site is an earth fill with a concrete facing and cut-off wall. The main dam would be 170 feet in height and 1130 feet in length. A dam of this height would require two auxiliary dams in saddles lying to the west of the main dam site. One of these would be 75 feet in height and 800 feet in length, and the other 35 feet in height and 4320 feet in length. Both would be of the same type as the main dam. The cut-off walls on all dams would extend

PLATE XLVIII

Capay Dam Site on Cache Creek

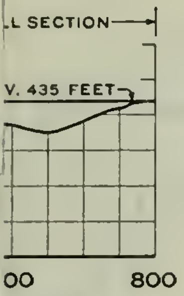
through the soft overlying material and into the shale bedrock for the purpose of preventing seepage under the dams. The layout and profiles of these dams are shown on Plate XLIX, "Capay Reservoir on Cache Creek."

The diversion of the stream flow during construction would be accomplished by a small diversion dam upstream from the main dam site which would divert the water into a tunnel which would afterwards be used for the release of irrigation water and spill from the reservoir.

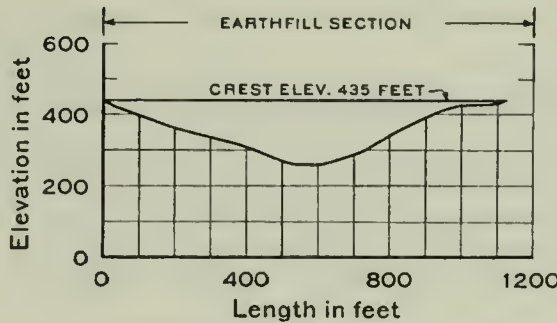
The spillway would be of the vertical shaft and tunnel type through the ridge at the left abutment of the dam. Water would enter the vertical shaft over a gravity concrete overflow spillway constructed in four sections around the top of the shaft. The flow over these spillways would be controlled by four hydraulically operated steel segmental drum gates 10 feet high and 50 feet in length set in recesses in the crest of the spillway. The vertical shaft would be circular in shape and would vary from 28.2 to 22 feet in diameter. The horizontal tunnel would have a concrete-lined horseshoe-shaped section 22 feet in diameter. It would discharge into the stream channel about 400 feet below the downstream toe of the dam.

The irrigation releases from the reservoir would be made through a concrete gate tower 10 feet in diameter in which there would be openings through which the flow would be controlled by slide gates. This tower would discharge into a six-foot diameter concrete-lined horseshoe-shaped tunnel which would connect to the tunnel leading from the spillway.

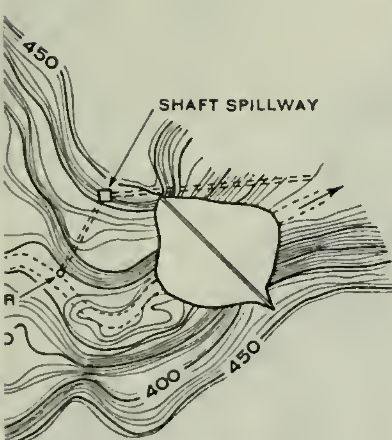
Yield of Reservoir in Water for Irrigation.—A study was made to estimate the amounts of water that would have been made available for irrigation from the Capay reservoir alone in each of the years from 1889 to 1929, if the three upper reservoirs previously described were constructed, and the amounts of these yields that would have been new



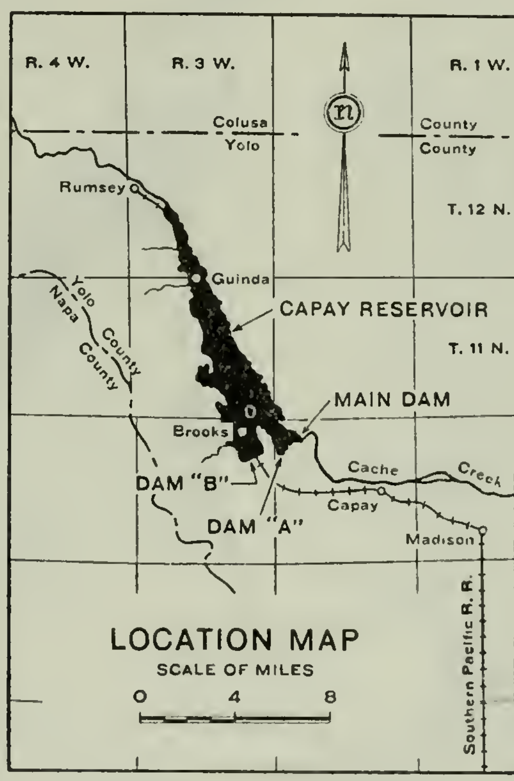
OF DAM "A"
UPSTREAM



PROFILE OF MAIN DAM
LOOKING UPSTREAM

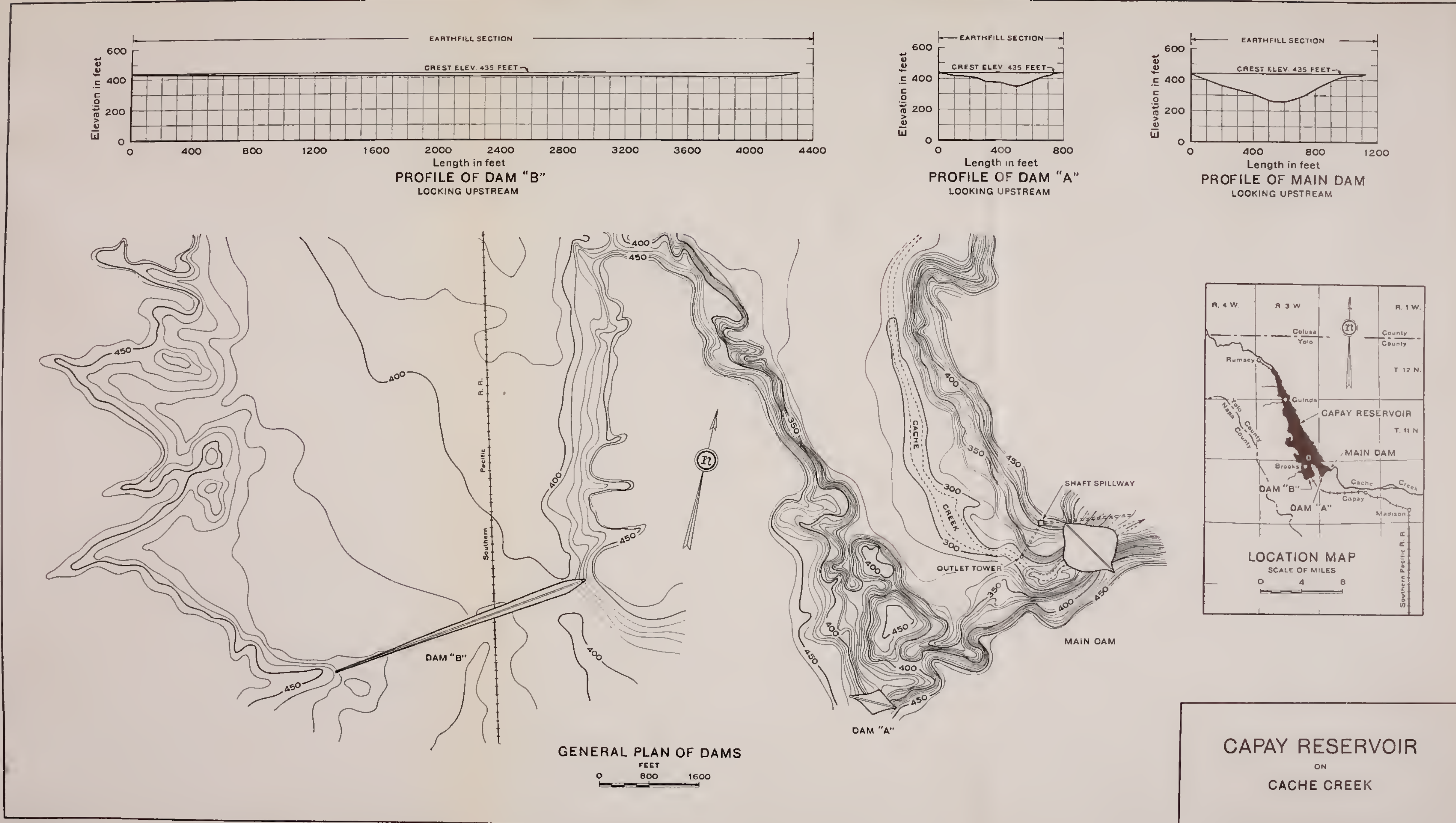


MAIN DAM



LOCATION MAP

CAPAY RESERVOIR
ON
CACHE CREEK



CAPAY RESERVOIR
ON
CACHE CREEK

water. This study was made by the methods described in the fore part of this chapter. The entire capacity of the reservoir was utilized and the reservoir was operated primarily for supplying irrigation water.

The study indicates that a seasonal irrigation draft of 155,000 acre-feet would have been obtainable with a maximum deficiency of 35 per cent in the driest year and an average deficiency for the 40-year period of one per cent. The seasonal yield in new water would have been the same.

Flood Control.—Curves showing the probable frequency of occurrence of flood flows of certain amounts at the Yolo gaging station and the amount of reservoir space required to control floods which are expected to occur at certain intervals of time at this point to selected regulated flows, are shown on Plates VIII and X in Chapter VI.

One of the largest floods of record occurred in the latter part of March and it would be necessary, therefore, to hold the full reserve space in the reservoir until the first of April. Due to the nature of the run-off from the Cache Creek drainage area, there would be insufficient water after this date in some years to fill as much of the reserve space as would have been filled without this reservation for flood control. The irrigation yield of the reservoir would be diminished and flood control, therefore, has not been included in this reservoir.

Should flood control on the stream be desired, the required storage space could be reserved in the Capay reservoir and the irrigation yield decreased from that given above. The irrigation yield could be maintained if additional storage space for irrigation water was provided at one of the upper reservoirs, or at some other reservoir site, to take the place of the reserve space for flood control in the Capay reservoir.

Cost of Reservoir.—An estimate of the cost of the reservoir was made as generally outlined in the fore part of this chapter and includes all of the items which have been briefly described in the foregoing paragraphs. No power plant is proposed in connection with this reservoir. The estimated cost of the reservoir is shown in Table 130.

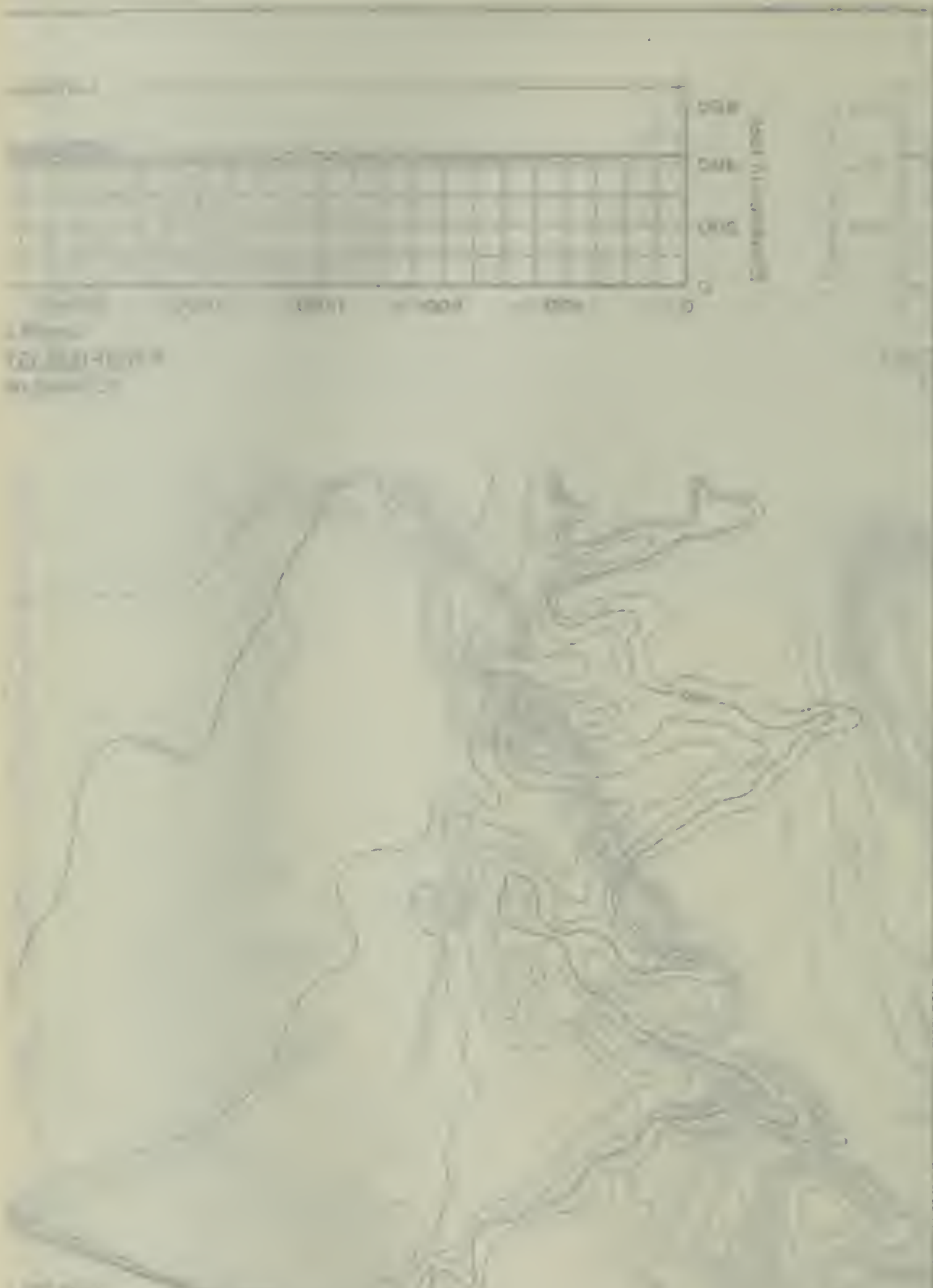
TABLE 130

COST OF CAPAY RESERVOIR

Height of dam, 170 feet. Capacity of reservoir, 378,000 acre-feet.
Capacity of spillway, 25,000 second-feet.

Exploration and core drilling		$10,000
Diversion of stream during construction		5,000
Clearing reservoir site		158,000
Earth fill, 1,825,000 cu. yds. at $0.50	$913,000	
Reinforced concrete, 28,000 cu. yds. at $8.50 to $11.50	274,000	
Excavation for cut-off wall, 14,000 cu. yds. at $1.25	18,000	
Shaft spillway	412,000	
Irrigation outlet	50,000	
		1,667,000
Lands and improvements flooded		2,320,000
Permanent camp and clean-up after construction		30,000
Subtotal		$4,190,000
Administration and engineering, 10 per cent		419,000
Contingencies, 15 per cent		629,000
Interest during construction, based on a rate of 4.5 per cent per annum		262,000
Total cost of dam and reservoir		$5,500,000

The annual cost of the dam and reservoir estimated on the bases given in the fore port of this chapter, and the capital cost given in Table 130, would be $338,000.



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The study indicates that a seasonal irrigation draft of 155,000 acre-feet would have been obtainable with a maximum deficiency of 35 per cent in the driest year and an average deficiency for the 40-year period of one per cent. The seasonal yield in new water would have been the same.

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Should flood control on the stream be desired, the required storage space could be reserved in the Capay reservoir and the irrigation yield decreased from that given above. The irrigation yield could be maintained if additional storage space for irrigation water was provided at one of the upper reservoirs, or at some other reservoir site, to take the place of the reserve space for flood control in the Capay reservoir.

Cost of Reservoir.—An estimate of the cost of the reservoir was made as generally outlined in the fore part of this chapter and includes all of the items which have been briefly described in the foregoing paragraphs. No power plant is proposed in connection with this reservoir. The estimated cost of the reservoir is shown in Table 130.

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Subtotal		$4,190,000
Administration and engineering, 10 per cent		419,000
Contingencies, 15 per cent		629,000
Interest during construction, based on a rate of 4.5 per cent per annum		262,000
Total cost of dam and reservoir		$5,500,000

The annual cost of the dam and reservoir estimated on the bases given in the fore port of this chapter, and the capital cost given in Table 130, would be $338,000.

Monticello Reservoir on Putah Creek.

Since the run-off of Putah Creek is relatively small, the need for a major reservoir unit on this creek would be principally to regulate as large a proportion of the run-off of the stream as economically feasible for the irrigation of lands in the Putah Creek water service area described in Chapter V.

There are four reservoir sites on Putah Creek, the Monticello site at the lower end of the Berryessa Valley, the Upper Monticello site at the upper end of the Berryessa Valley, the Devil's Head site at the Napa-Lake county line, and the Guenoc or Coyote Valley site. Of these sites, the Monticello site is best located for controlling the flow of Putah Creek. The other sites are too limited in size and in tributary drainage area for a major reservoir unit on this stream but could be used for the storage of water for the irrigation of lands in the drainage basin above Monticello.

The site for the dam which would create the Monticello reservoir is located at the Yolo-Napa county line, in Section 29, Township 8 North, Range 2 West, M. D. B. and M., about seven miles west of the town of Winters.

The area of the drainage basin upstream from this site is 620 square miles or about 95 per cent of the area above the United States Geological Survey gaging station on Putah Creek at Winters, and about 3 per cent of the total mountain and foothill area of the Sacramento River Basin. This watershed lies on the easterly slope of the Coast Range and in general is of the low foothill type. There are considerable areas of agricultural land in the Berryessa, Pope, Morgan, Capell, and Coyote valleys and around Middletown. The highest point of the watershed is Mount St. Helena with a peak elevation of 4743 feet.

Water Supply.—Information on the run-off of Putah Creek at the Monticello dam site is gained from the records of stream flow kept by the United States Geological Survey at Winters since September, 1905. The measured monthly run-offs were converted to full natural by adding to them the estimated net amounts of water used for irrigation in the watershed above the gaging station. The estimated monthly run-offs for the period prior to 1905 were obtained from probable run-off curves for each month, using the indices of wetness computed from rainfall records for stations in Division F, as described in Chapter II. The seasonal full natural run-offs at the Winters gaging station are shown in Table 5.

By multiplying the area of the drainage basin above the Winters gage and that above the Monticello dam site by the mean annual rainfall in each respective area, estimated from isohyetal lines, it was estimated that the full natural run-off at the dam site was 94.8 per cent of that at the gaging station. This was called 95 per cent and each month's run-off at the dam site was taken as this percentage of that at Winters.

The monthly ultimate net run-offs at the dam site were obtained from the monthly full natural run-offs by subtracting the net amounts of water required for the irrigation of all of the agricultural lands above the dam site which it is estimated will ultimately be irrigated, and by deducting water stored in and adding water released from the reservoirs to be used for storage of water for this irrigation.

The full natural and ultimate net run-offs at the dam site are shown in Table 131.

TABLE 131

SEASONAL RUN-OFFS OF PUTAH CREEK AT MONTICELLO DAM SITE, 1889-1929

Season	Full natural run-off, in acre-feet	Ultimate net run-off, in acre-feet
1889–1890	1,177,000	1,139,000
1890–1891	329,000	290,000
1891–1892	315,000	277,000
1892–1893	753,000	715,000
1893–1894	205,000	167,000
1894–1895	863,000	824,000
1895–1896	547,000	509,000
1896–1897	481,000	442,000
1897–1898	16,200	13,200
1898–1899	205,000	165,000
1899–1900	481,000	442,000
1900–1901	464,000	426,000
1901–1902	663,000	625,000
1902–1903	338,000	300,000
1903–1904	630,000	591,000
1904–1905	779,000	740,000
1905–1906	554,000	515,000
1906–1907	656,000	618,000
1907–1908	190,000	152,000
1908–1909	838,000	800,000
1909–1910	217,000	178,000
1910–1911	463,000	424,000
1911–1912	54,400	35,300
1912–1913	128,000	87,500
1913–1914	852,000	811,000
1914–1915	675,000	637,000
1915–1916	675,000	636,000
1916–1917	272,000	233,000
1917–1918	86,100	57,900
1918–1919	302,000	261,000
1919–1920	42,800	23,800
1920–1921	487,000	443,000
1921–1922	221,000	182,000
1922–1923	266,000	228,000
1923–1924	39,200	28,800
1924–1925	334,000	294,000
1925–1926	332,000	294,000
1926–1927	520,000	481,000
1927–1928	288,000	250,000
1928–1929	65,400	45,000
40-year means, 1889–1929	420,000	385,000
20-year means, 1909–1929	316,000	282,000
10-year means, 1919–1929	260,000	227,000
5-year means, 1924–1929	308,000	273,000

The variation in the seasonal run-offs at the dam site is shown by the full natural run-offs listed in Table 131. The maximum seasonal full natural run-off in the 40-year period 1889–1929, was 1,177,000 acre-feet in 1889–90 and the probable minimum was 16,200 acre-feet in 1897–98, a variation of from 280 per cent to four per cent of the mean seasonal run-off for the same period.

The average monthly distribution of the run-off as determined from the full natural run-offs at the dam site is shown in Table 132.

The variation in mean daily flow is indicated by the records at Winters. The maximum mean daily flow of 40,000 second-feet occurred on December 31, 1913, with a peak flow of about 60,000 second-feet, and in the late summer of nearly all years there was no flow.

TABLE 132

AVERAGE MONTHLY DISTRIBUTION OF RUN-OFF OF PUTAH CREEK AT MONTICELLO DAM SITE

Month	Average full natural run-off	
	In acre-feet	In per cent of mean seasonal
January	117,800	28.06
February	121,600	28.96
March	72,900	17.35
April	39,900	9 50
May	12,000	2 85
June	3,700	0.88
July	1,600	0.38
August	700	0.16
September	400	0.09
O tober	500	0.12
November	11,900	2.83
December	37,000	8.82
Totals	420,000	100.00

Reservoir Site.—A topographic survey of the Monticello reservoir site was made by the United States Reclamation Service in 1908 and a map was drawn from this survey at a scale of one inch equals 500 feet, with a contour interval of ten feet. The water surface areas measured from this map and the computed capacities of the reservoir are shown in Table 133. The datum for this survey was an assumed one.

TABLE 133

AREAS AND CAPACITIES OF MONTICELLO RESERVOIR

Height of dam, in feet (5 foot freeboard)	[1]Water surface elevat on of reservoir, in feet	Area of water surface, in acres	Capacity of reservoir, in acre-feet
20	20	25	
30	30	52	400
40	40	108	1,200
50	50	131	2,400
60	60	269	4,400
70	70	365	7,600
80	80	504	11,900
90	90	664	17,700
100	100	917	25,600
110	110	1,283	36,700
120	120	1,867	52,400
130	130	2,365	73,600
140	140	2,799	99,400
150	150	3,223	130,000

[1] Assumed datum.

The site is capable of development for a large storage capacity but any water surface higher than elevation 150 feet of the reservoir survey datum would submerge the town of Monticello and a large area of the Berryessa Valley, much of which is planted to orchards and vineyards. Water surfaces lower than this elevation, however, would flood only a small fraction of the main body of agricultural land in the valley. This height, therefore, was selected for the reservoir. The only improvements that would be flooded, in addition to those on the farmed areas, are some county roads. It would require the construction of about 13.5 miles of new road to place these above the flow line of the reservoir.

Dam and Appurtenant Works.—A topographic survey of the Monticello dam site also was made by the United States Bureau of Reclamation in 1908. A map drawn from this survey at a scale of one inch equals 50 feet, with a contour interval of 5 feet, was used in laying out and estimating the cost of Monticello dam.

The dam site is located in a narrow gorge. The stream bed is about 75 feet wide and at elevation 50 feet the gorge is about 275 feet wide. The canyon walls rise precipitously above this elevation for more than 150 feet. A good grade of heavy gray sandstone is exposed on both sides of the canyon to the water's edge, and is apparently covered in the stream channel by only a small depth of loose material. There have been no borings or other explorations of the foundation for the dam but a geological examination of the site and its vicinity was made, the report on which will be found in Appendix E.

PLATE L

Monticello Dam Site on Putah Creek

The dam would be of the gravity concrete type and the greater part of its length would be an overflow spillway. It would have a maximum height of 150 feet and a crest length of 385 feet. The plan and profile of the dam are shown on Plate LI, ''Monticello Reservoir on Putah Creek.''

It is estimated that only a small depth of excavation of loose material and weathered sandstone would be required to obtain a firm rock foundation. There would be a cut-off wall at the upstream toe, beneath which any seams in the rock would be sealed by grouting. The foundation would be drained by a row of drainage wells near the upstream toe, connected to a drain pipe in the dam.

Diversion of the stream flow during the construction of the lower portion of the dam would be accomplished by means of coffer dams above and below the foundation area and a flume to carry the stream flow between these dams.

The spillway would be located in the central portion of the dam over the stream channel. It would have a total length of 200 feet and a capacity of 57,000 second-feet. The flow over the spillway would be controlled by four hydraulically operated steel segmental drum gates 42.5 feet long and 20 feet high separated by ten-foot piers in which the operating mechanism would be located.

There would be two outlets through the dam at a distance of 95 feet below the crest and one at a distance of 135 feet, which would serve as sluiceways and for the release of irrigation water. These outlets would be 30 inches in diameter and would be lined with steel. Flow through each outlet would be controlled by a caterpillar type sluicegate, at the upstream face of the dam, and, a short distance from the inlet, by an auxiliary slide gate operated from a chamber inside the dam. One opening would be provided with a 30-inch balanced needle valve at the outlet end for more accurate regulation of the discharge. Each caterpillar gate would be protected by steel trash racks set in a semicircular concrete structure and would operate in a concrete enclosed gate well extending to the top of the dam.

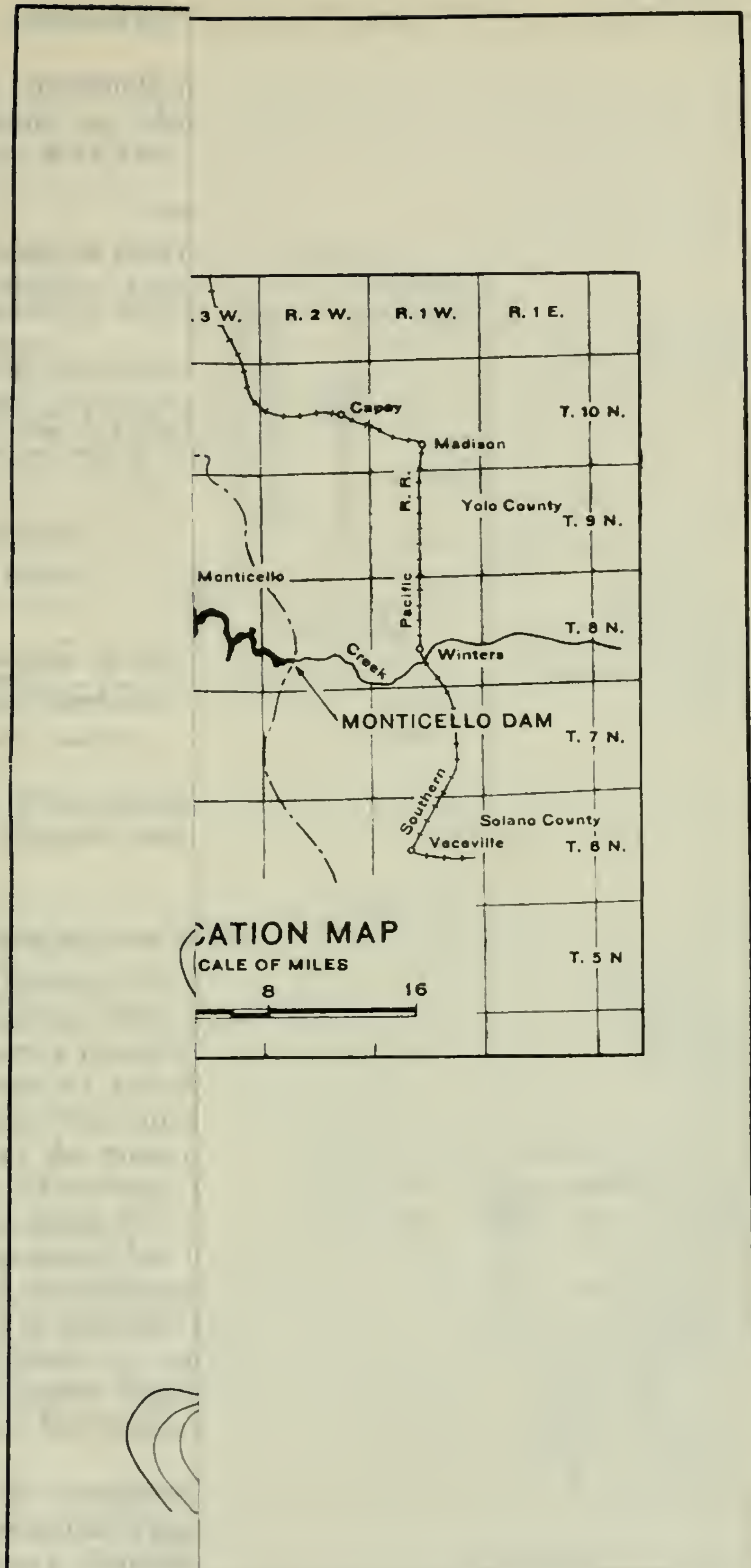
Yield of Reservoir in Water for Irrigation.—A study was made to estimate the amounts of water that would have been made available for irrigation use in each of the years in the 40-year period 1889 to 1929, with the reservoir operating primarily for this purpose, and the amounts of these yields that would have been new water. This study was made by the methods described in the fore part of this chapter. The entire capacity of the reservoir was utilized and the reservoir was operated primarily for supplying irrigation water.

The study indicates that a seasonal irrigation draft of 96,000 acre-feet would have been obtained with a maximum seasonal deficiency of 22.7 per cent and an average for the period of two per cent. All of this yield would have been new water.

Flood Control.—Curves showing the probable frequency of occurrence of flood flows of certain amounts at the gaging station at Winters and the reservoir space required to control floods which are expected to occur at different intervals of time at this point, to certain regulated flows, are shown on Plates VIII and X in Chapter VI.

Since large floods occur as late as the latter part of March, it would be necessary to hold reserve space in the reservoir until the first of April. The run-off from the drainage basin after this date would be too small in most years to fill as much of this reserve space as would have been filled without this reservation for flood control and the irrigation yield of the reservoir would be substantially diminished. Flood control, therefore, was not included as a feature of the proposed reservoir.

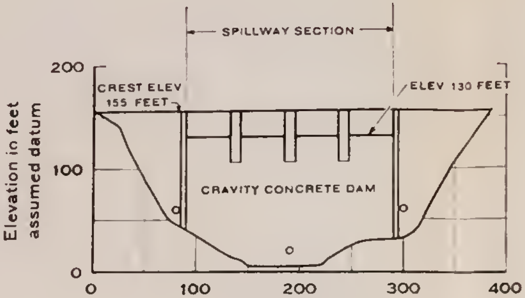
Cost of Reservoir.—The estimate of the cost of the reservoir, set forth in Table 134, was made as generally outlined in the fore part of this chapter and includes all of the items which have been briefly described in the foregoing paragraphs. The items included in the estimate under



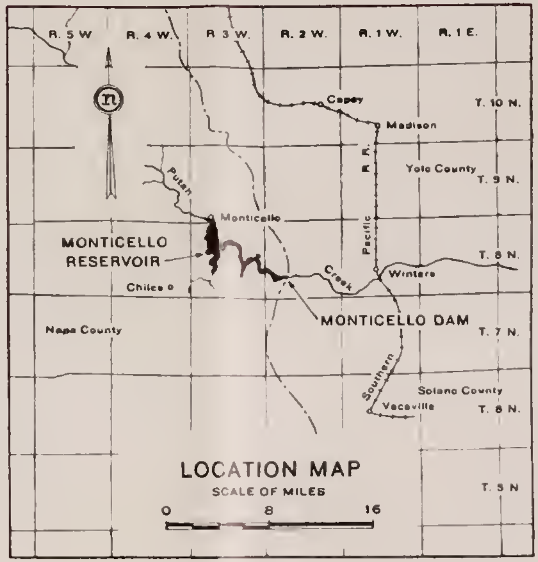
CELLO RESERVOIR

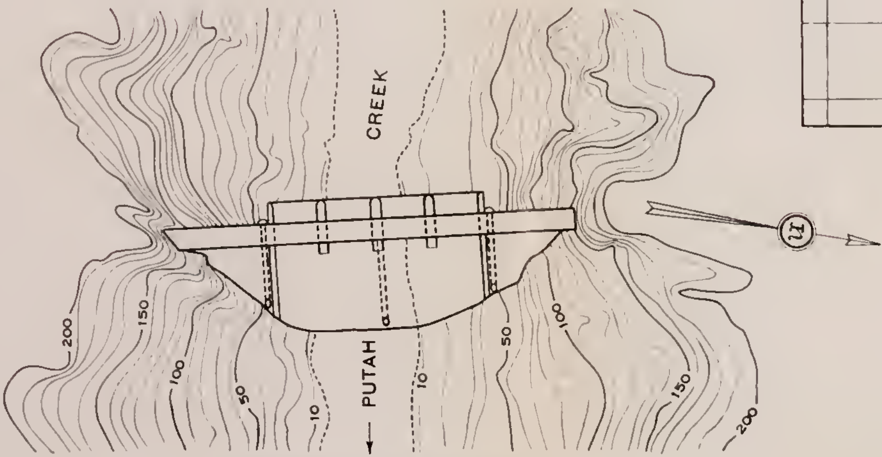
ON

PUTAH CREEK



PROFILE OF DAM
LOOKING UPSTREAM





GENERAL PLAN OF DAM
FEET
0 100 200

MONTICELLO RESERVOIR
ON
PUTAH CREEK

miscellaneous are the construction railroad to the gravel pit, a permanent camp and cleaning up after construction. No power plant is proposed in connection with this reservoir.

TABLE 134

COST OF MONTICELLO RESERVOIR

Height of dam, 150 feet. Capacity of reservoir, 130,000 acre-feet.
Capacity of spillway, 57,000 second-feet.

Exploration and core drilling		$20,000
Diversion of stream during construction		24,000
Clearing reservoir site		83,000
Excavation for dam, 60,000 cu. yds. at $1 to $5	$141,000	
Mass concrete, 116,000 cu. yds. at $6.50	754,000	
Reinforced concrete, 1,600 cu. yds. at $15 to $23	27,000	
Spillway gates	102,000	
Spillway channel	48,000	
Irrigation outlets	39,000	
Drilling and grouting foundation	12,000	
		1,123,000
Lands and improvements flooded		656,000
Miscellaneous		90,000
Subtotal		$1,996,000
Administration and engineering, 10 per cent		200,000
Contingencies, 15 per cent		299,000
Interest during construction based on a rate of 4.5 per cent per annum		105,000
Total cost of dam and reservoir		$2,600,000

The annual cost of the reservoir estimated on the bases given in the fore part of this chapter, and the capital cost given in Table 134, would be $174,000.

Comparison of Major Units of State Water Plan in Sacramento River Basin.

In the foregoing portion of this chapter, a description, estimates of both capital and annual costs, yield in irrigation water, and output in electric energy where a power plant is included, have been given for each of the major units of the State Water Plan in the Sacramento River Basin. For those reservoirs for which comparisons of sizes were made in order to select the most economical height of dam, tables and curves showing costs of storage and irrigation yield also have been given. The estimates made for constructing these tables and curves were for reservoirs operated for irrigation use only and the costs did not include any power development features. In this section, information on the reservoirs is brought together in two tables, one of which shows costs of water when no power features are included and the other, the costs when power features are included and deductions are made from annual costs for revenues from the sale of the electric energy generated.

Table 135 gives the comparative costs, yields and average capital cost per acre-foot of seasonal irrigation yield for different capacities of reservoirs at the Kennett, Oroville, Auburn and Coloma sites; for one capacity of reservoir at the Narrows, Camp Far West, Folsom, Millsite, Capay and Monticello sites; and for the American River unit (Folsom, Auburn and Coloma reservoirs). These capital costs do not include power features, as the reservoirs were assumed to be constructed and operated for irrigation use only. The capital costs per acre-foot of seasonal irrigation yield in new water set forth in the table are shown graphically on Plate LII, "Capital Cost of Seasonal Irrigation Yield in

miscellaneous are the construction railroad to the gravel pit, a permanent camp and cleaning up after construction. No power plant is proposed in connection with this reservoir.

TABLE 134

COST OF MONTICELLO RESERVOIR

Height of dam, 150 feet. Capacity of reservoir, 130,000 acre-feet. Capacity of spillway, 57,000 second-feet.

Exploration and core drilling		$20,000
Diversion of stream during construction		24,000
Clearing reservoir site		83,000
Excavation for dam, 60,000 cu. yds. at $1 to $5	$141,000	
Mass concrete, 116,000 cu. yds. at $6.50	754,000	
Reinforced concrete, 1,600 cu. yds. at $15 to $23	27,000	
Spillway gates	102,000	
Spillway channel	48,000	
Irrigation outlets	39,000	
Drilling and grouting foundation	12,000	
		1,123,000
Lands and improvements flooded		656,000
Miscellaneous		90,000
Subtotal		$1,996,000
Administration and engineering, 10 per cent		200,000
Contingencies, 15 per cent		299,000
Interest during construction based on a rate of 4.5 per cent per annum		105,000
Total cost of dam and reservoir		$2,600,000

The annual cost of the reservoir estimated on the bases given in the fore part of this chapter, and the capital cost given in Table 134, would be $174,000.

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TABLE 135

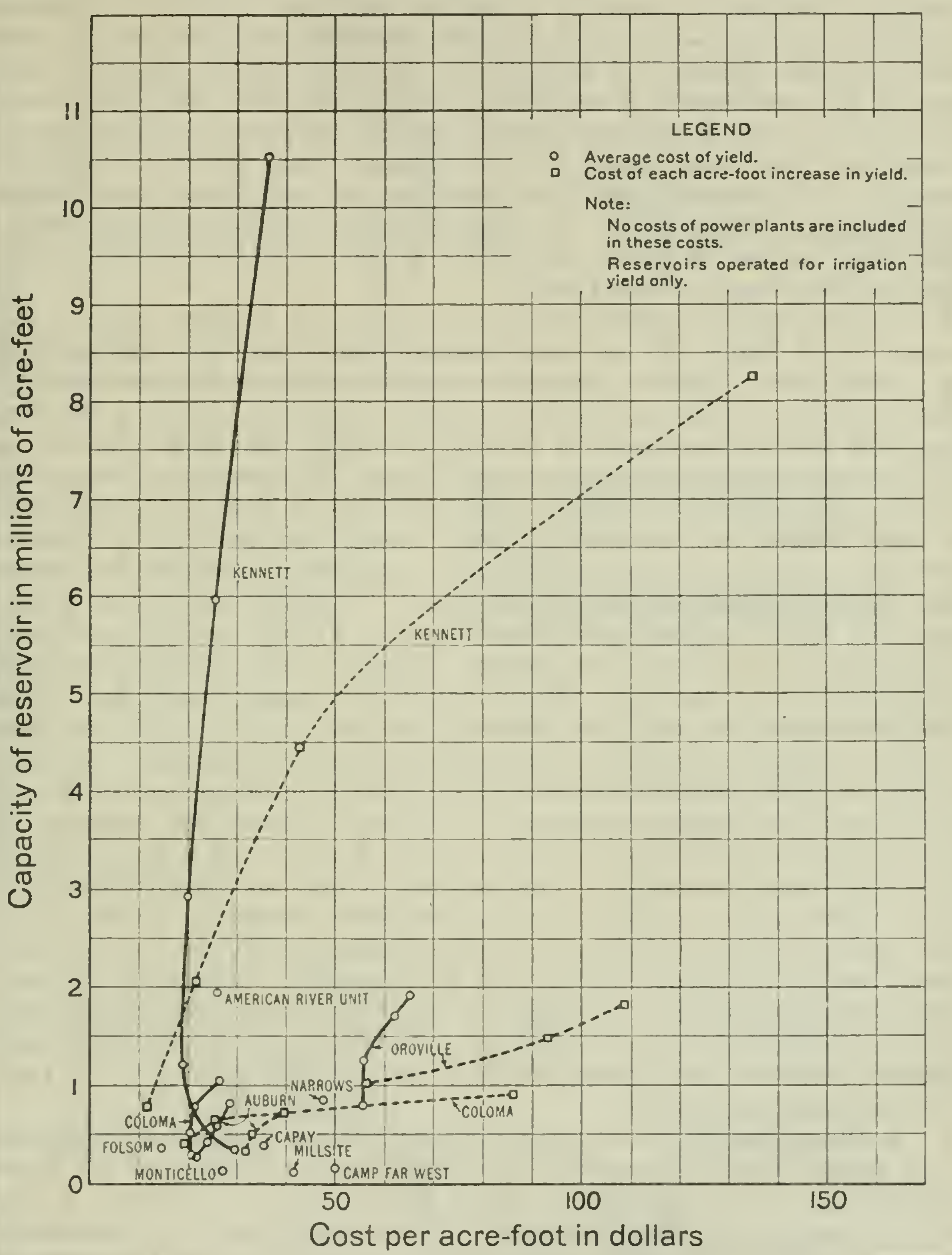
COST OF YIELD IN WATER FOR IRRIGATION FROM MAJOR RESERVOIR UNITS OF STATE WATER PLAN IN SACRAMENTO RIVER BASIN (WITHOUT POWER FEATURES)

Stream	Reservoir	Height of dam, in feet	Capacity of reservoir, in acre-feet	Cost of reservoir		Seasonal irrigation yield[1]		Capital cost, per acre-foot				Annual cost per acre-foot of irrigation yield	
								Irrigation yield		Increase in irrigation yield			
				Capital	Annual	Total yield, in acre-feet	New water, in acre-feet	Total yield	New water	Total yield	New water	Total yield	New water
Sacramento River	Kennett	220	353,000	$22,900,000	$1,396,000	2,260,000	770,000	$10 10	$29 70	$11 30	$11 30	$0 62	$1 81
		320	1,209,000	35,600,000	2,133,000	3,386,000	1,896,000	10 50	18 80	21 70	21 70	0 63	1 12
		420	2,940,000	61,000,000	3,598,000	4,555,000	3,065,000	13 40	19 90	42 70	42 70	0 79	1 17
		520	5,967,000	100,500,000	5,877,000	5,481,000	3,991,000	18 30	25 20	135 10	135 10	1 07	1 47
		620	10,555,000	160,500,000	9,363,000	5,925,000	4,435,000	27 10	36 20			1 58	2 11
Feather River	Oroville	455	807,000	68,000,000	3,990,000	1,791,000	1,221,000	38 00	55 70	56 30	56 30	2 23	3 27
		525	1,258,000	95,300,000	5,574,000	2,276,000	1,706,000	41 90	55 90	93 10	93 10	2 45	3 27
		580	1,705,000	126,400,000	7,380,000	2,610,000	2,040,000	48 40	62 00	108 70	108 70	2 83	3 62
		605	1,933,000	142,700,000	8,322,000	2,760,000	2,190,000	51 70	65 20			3 02	3 80
Yuba River	Narrows	580	853,000	45,600,000	2,761,000	1,064,000	958,000	42 90	47 60	----	----	2 59	2 88
Bear River	Camp Far West	180	151,000	6,500,000	403,000	192,000	130,000	33 90	50 00	----	----	2 10	3 10
American River	Folsom	190	355,000	9,500,000	601,000	800,000	666,000	11 90	14 30	----	----	75	90
American River	Auburn	290	266,000	8,800,000	541,000	420,000	405,000	21 00	21 70	31 60	31 60	1 29	1 31
		340	412,000	12,500,000	757,000	537,000	522,000	23 30	23 90	32 90	32 90	1 41	1 45
		390	598,000	17,400,000	1,044,000	686,000	671,000	25 40	25 90	39 50	39 50	1 52	1 56
		440	831,000	24,000,000	1,429,000	853,000	838,000	28 10	28 60			1 68	1 71
American River	Coloma	255	293,000	7,100,000	432,000	417,600	345,600	17 00	20 50	19 10	19 10	1 03	1 25
		305	534,000	10,500,000	628,000	595,200	523,200	17 60	20 10	25 40	25 40	1 06	1 20
		345	766,000	13,400,000	798,000	709,500	637,500	18 90	21 00	86 00	86 00	1 12	1 25
		385	1,049,000	18,600,000	1,101,000	770,000	698,000	24 20	26 60			1 43	1 58
American River	American River unit[2]	----	1,952,000	46,900,000	2,828,000	1,933,000	1,799,000	24 30	26 10	----	----	1 46	1 57
Stony Creek	Millsite	135	115,000	3,200,000	212,000	92,000	77,000	34 80	41 60	----	----	2 30	2 75
Cache Creek	Capay	170	378,000	5,500,000	338,000	155,000	155,000	35 50	35 50	----	----	2 18	2 18
Putah Creek	Monticello	150	130,000	2,600,000	174,000	96,000	96,000	27 10	27 10	----	----	1 81	1 81

[1] Based on 40-year period 1889-1929. Maximum seasonal deficiency 35 per cent. Mean deficiency for period 2 per cent or less. Yields of Kennett reservoir are those which would have been available at Red Bluff from unregulated stream flow supplemented by releases from reservoir.

[2] Folsom reservoir, Auburn reservoir (440 foot dam), Coloma reservoir (345-foot dam).

PLATE LII



CAPITAL COST

OF

SEASONAL IRRIGATION YIELD IN NEW WATER

FROM

MAJOR RESERVOIR UNITS OF STATE WATER PLAN

IN

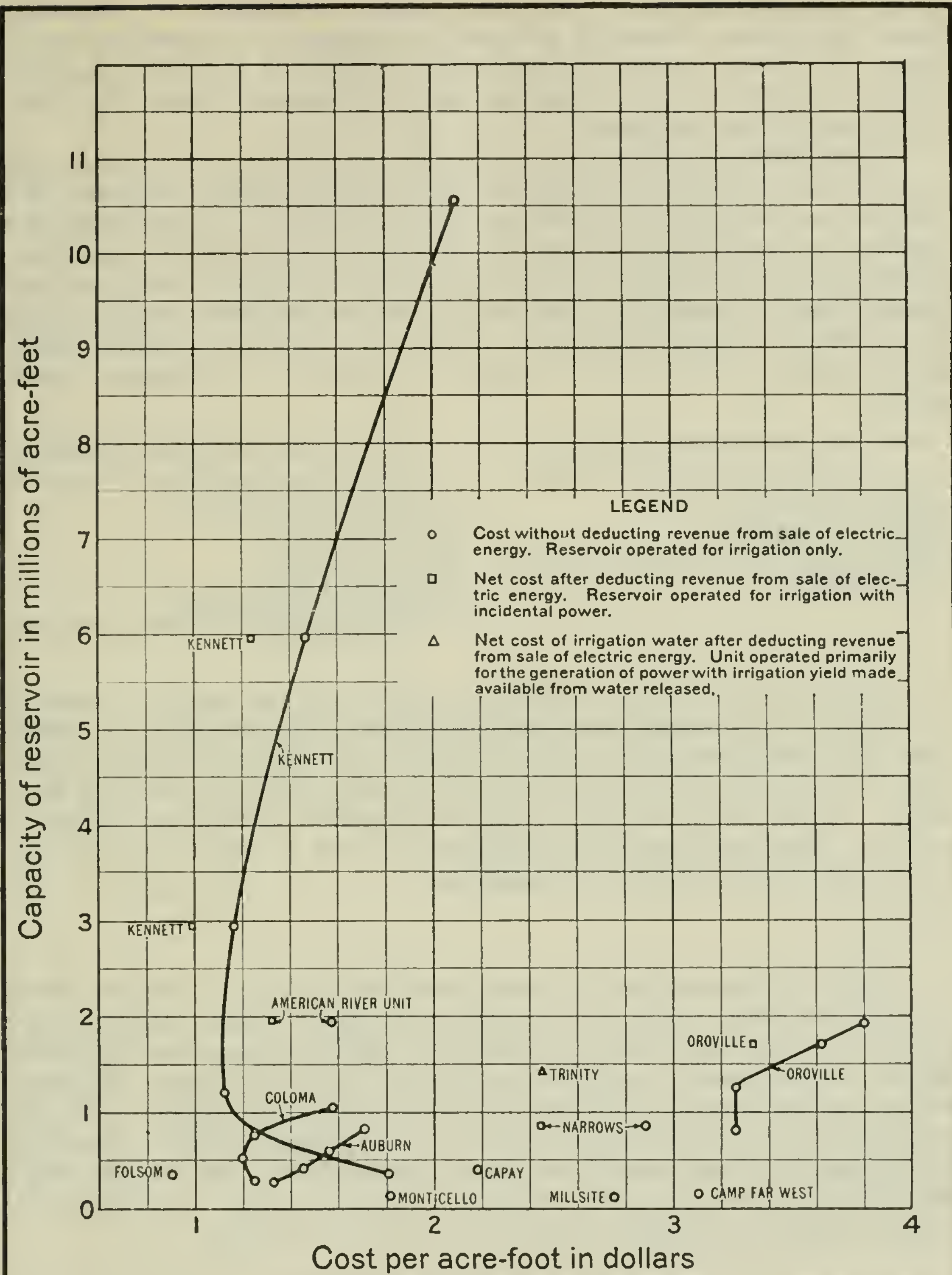
SACRAMENTO RIVER BASIN

New Water From Major Reservoir Units of State Water Plan in Sacramento River Basin.'' Also in Table 135, the comparative annual costs per acre-foot of seasonal irrigation yield are shown for different capacities of reservoir at the Kennett, Oroville, Auburn and Coloma sites; for one capacity of reservoir at the other major reservoir unit sites in the Sacramento River Basin; and for the American River unit. These costs do not include any annual charges for power features and no deductions have been made for the revenue from the sale of electric energy. The annual costs per acre-foot of new water are shown graphically on Plate LIII, ''Average Annual Cost of Seasonal Irrigation Yield in New Water From Major Reservoir Units of State Water Plan in Sacramento River Basin.''

The seasonal irrigation yields shown for the Auburn and Coloma reservoirs in Table 135 are those which would have been available at their dam sites. Studies also were made to estimate the seasonal irrigation yields at Folsom with the Auburn reservoir having a 440-foot dam and the Coloma reservoir having a 345-foot dam each operated as the only major unit on the American River. The maximum irrigation yields, with deficiencies similar to those shown in Table 135, estimated in these studies are those which would have been available at Folsom with the Auburn or Coloma reservoir, respectively, operated to supplement the unregulated flows at that point. With this method of operation, the total seasonal irrigation yields at Folsom would have been 1,135,000 acre-feet with the Auburn reservoir and 908,000 acre-feet with the Coloma reservoir. The yields in new water would have been 1,001,000 acre-feet with the Auburn reservoir and 774,000 acre-feet with the Coloma reservoir. The annual costs per acre-foot of total irrigation yield would have been $1.26 with the Auburn reservoir and $0.88 with the Coloma reservoir. The annual costs per acre-foot of new water would have been $1.43 with the Auburn reservoir and $1.03 with the Coloma reservoir. The amount of new water with either of these reservoirs in operation would have been somewhat greater than that made available at Folsom by the operation of the Folsom reservoir alone, but the unit cost would have been greater. Although the unit cost of new water made available by the Colma reservoir would have been less than that for new water made available by the 420-foot dam Kennett reservoir, the Kennett reservoir would have yielded about four times as much new water.

A comparison of the average net annual costs of seasonal irrigation yield from the selected sizes of the major reservoir units of the State Water Plan in the Sacramento River Basin, without reference to any other advantages or disadvantages, also was made and the results are shown in Table 136. This table gives a comparison of the costs of water for irrigation, first with the reservoirs operated primarily for the generation of power with such yield in water for irrigation as can be obtained from the power drafts and, second, with the reservoirs operated primarily to furnish as large amounts of water for irrigation as possible with electric energy generated with these drafts incidental to the primary use of the water for irrigation. The average net annual cost of water for irrigation from any reservoir is equal to the total annual cost of the reservoir less the average annual revenue that can be obtained from the electric energy generated by water released from it. The net

PLATE LIII



AVERAGE ANNUAL COST

OF

SEASONAL IRRIGATION YIELD

IN NEW WATER

FROM

MAJOR RESERVOIR UNITS OF STATE WATER PLAN

IN

SACRAMENTO RIVER BASIN

annual cost and the total yield and yield in new water are shown in Table 136 for each reservoir, with the two methods of operation stated above. No power plants are proposed for four of the units and for these the annual cost of irrigation water necessarily equals the total annual cost of the reservoir.

In the last two columns of Table 136, the average net annual costs per acre-foot of seasonal irrigation yield, for the total yield and the yield in new water, are given for each reservoir. In comparing the reservoirs on an irrigation basis, the average annual cost per acre-foot of new water is probably the best unit as it includes no value of any natural flow of the stream that may be utilized without regulation by the reservoir. Using this unit as a basis and listing the major units in the order of cost from lowest to highest, the following order results:

Unit operating primarily for power

Kennett reservoir and Keswick afterbay (Kennett reservoir unit)
American River unit
Trinity River diversion
Narrows reservoir
Oroville reservoir and afterbay (Oroville reservoir unit)

Unit operating primarily for irrigation

Kennett reservoir and Keswick afterbay (Kennett reservoir unit)
American River unit
Monticello reservoir
Capay reservoir
Narrows reservoir
Millsite reservoir
Camp Far West reservoir
Oroville reservoir and afterbay (Oroville reservoir unit)

The Kennett reservoir, therefore, would yield the largest volume of new water at the lowest unit cost with either of the methods of operation. The American River unit would be next lowest in unit cost but would be surpassed by the Oroville reservoir in the amount of new water. Yield from the latter reservoir, however, would be higher in unit cost than that from any other major unit in Sacramento River Basin under both methods of operation.

Summary.

Table 137 summarizes the more important data on the major units of the State Water Plan in the Sacramento River Basin, including the heights of dams, capacities of reservoirs, installed capacities of power plants and estimated capital costs without and with power features. The capacities selected for these units are those that appear to be the proper ones from knowledge obtained from present studies. Further information on water supply and water requirements that will be available when the units are constructed may show that some changes in the present selected capacities should be made at that time.

TABLE 136

NET COST OF WATER FOR IRRIGATION FROM MAJOR UNITS OF STATE WATER PLAN IN SACRAMENTO RIVER BASIN

Stream	Unit	Height of dam, in feet	Storage capacity of reservoir, in acre-feet		Power plant			Capital cost			Gross annual cost			Average annual electric energy output, in kilowatt hours	Seasonal yield in irrigation water, in acre-feet		Value of electric energy per kilowatt hour, in mills[2]	Average annual revenue from sale of electric energy	Average net annual cost not covered by revenue from sale of electric energy	Average net annual cost per acre-foot of seasonal irrigation yield	
			Total	Utilized in analyses	Installed capacity, in kilovolt amperes	Power factor	Load factor	Dam and reservoir	Power plant	Total	Dam and reservoir	Power plant	Total		Total	New water				Total yield	New water
	OPERATING PRIMARILY FOR POWER WITH INCIDENTAL IRRIGATION																				
Sacramento River	Kennett reservoir	420	2,940,000	2,599,000	275,000	0.80	0.75	$65,000,000	$13,500,000	$78,500,000	$3,820,000	$1,081,000	$4,901,000		[1]2,085,000	[1]595,000					
	Keswick afterbay	95	14,000	0	50,000	0.80	1.00	2,000,000	3,500,000	5,500,000	122,000	274,000	396,000								
	Kennett reservoir unit		2,954,000	2,599,000	325,000					84,000,000			5,297,000	1,622,800,000	[1]2,085,000	[1]595,000	2.72	$4,414,000	$883,000	$0.42	$1.45
Trinity River	Fairview reservoir and power plant No. 1	365	1,436,000	1,208,000	62,000	0.80	0.60	37,000,000	3,500,000	40,500,000	2,210,000	289,000	2,499,000								
	Lewiston reservoir	98		0				900,000		900,000	58,000		58,000								
	Conduit and power plant No. 2				50,000	0.80	1.00		10,700,000	10,700,000		741,000	741,000								
	Conduit and power plant No. 3				19,000	0.80	1.00		2,400,000	2,400,000		182,000	182,000								
	Conduit and power plant No. 4				53,000	0.80	1.00		7,500,000	7,500,000		538,000	538,000								
	Trinity River diversion		1,436,000	1,208,000	62,000 131,000	0.80 0.80	0.60 1.00			62,000,000			4,018,000	1,063,900,000	[1]2,045,000	[1]555,000	2.50	2,660,000	1,358,000	0.66	2.45
Feather River	Oroville reservoir	580	1,705,000	1,429,000	280,000	0.80	0.75	126,400,000	16,200,000	142,600,000	7,380,000	1,261,000	8,641,000		1,117,000	547,000					
	Oroville afterbay	69	7,700	0	34,000	0.80	1.00	2,000,000	3,100,000	5,100,000	122,000	238,000	360,000								
	Oroville reservoir unit		1,712,700	1,429,000	314,000					147,700,000			9,001,000	1,409,100,000	1,117,000	547,000	3.10	4,369,000	4,632,000	4.15	8.47
Yuba River	Narrows reservoir	580	853,000	680,000	160,000	0.80	0.75	45,600,000	7,400,000	53,000,000	2,761,000	603,000	3,364,000	570,300,000	377,000	271,000	2.98	1,699,000	1,665,000	4.42	6.14
American River	Folsom reservoir	190	355,000	247,000	100,000	0.80	0.75	9,500,000	5,700,000	15,200,000	601,000	452,000	1,053,000								
	Folsom afterbay	89		0	25,000	0.80	1.00	1,500,000	2,800,000	4,300,000	94,000	206,000	300,000								
	Auburn reservoir	440	831,000	681,000	85,000	0.80	0.75	24,000,000	3,900,000	27,900,000	1,429,000	323,000	1,752,000								
	Pilot Creek reservoir	110		0	25,000	0.80	0.75	1,200,000	1,500,000	2,700,000	71,000	126,000	197,000								
	Coloma reservoir	345	766,000	687,000	40,000	0.80	0.75	13,400,000	2,500,000	15,900,000	798,000	201,000	999,000								
	Webber Creek reservoir	85		0	20,000	0.80	0.75	700,000	1,800,000	2,500,000	41,000	142,000	183,000								
	American River unit		1,952,000	1,615,000	295,000					68,500,000			4,484,000	1,052,400,000	658,000	524,000	3.27	3,441,000	1,043,000	1.59	1.99
	OPERATING PRIMARILY FOR IRRIGATION WITH INCIDENTAL POWER																				
Sacramento River	Kennett reservoir	420	2,940,000	2,621,000	275,000	0.80	Variable	65,000,000	13,500,000	78,500,000	3,820,000	1,081,000	4,901,000		[1]4,340,000	[1]2,850,000					
	Keswick afterbay	95	14,000	0	50,000	0.80	1.00	2,000,000	3,500,000	5,500,000	122,000	274,000	396,000								
	Kennett reservoir unit		2,954,000	2,621,000	325,000					84,000,000			5,297,000	1,285,000,000	[1]4,340,000	[1]2,850,000	1.93	2,480,000	2,817,000	0.65	0.99
Sacramento River	Kennett reservoir	520	5,967,000	5,325,000	400,000	0.80	Variable	100,500,000	16,500,000	117,000,000	5,877,000	1,359,000	7,236,000		[1]5,386,000	[1]3,896,000					
	Keswick afterbay	95	14,000	0	50,000	0.80	1.00	2,000,000	3,500,000	5,500,000	122,000	274,000	396,000								
	Kennett reservoir unit		5,981,000	5,325,000	450,000					122,500,000			7,632,000	1,459,000,000	[1]5,386,000	[1]3,896,000	1.93	2,816,000	4,816,000	0.89	1.24
Feather River	Oroville reservoir	580	1,705,000	1,494,000	280,000	0.80	Variable	126,400,000	16,200,000	142,600,000	7,380,000	1,261,000	8,641,000		2,480,000	1,910,000					
	Oroville afterbay	69	7,700	0	34,000	0.80	1.00	2,000,000	3,100,000	5,100,000	122,000	238,000	360,000								
	Oroville reservoir unit		1,712,700	1,494,000	314,000					147,700,000			9,001,000	1,172,200,000	2,480,000	1,910,000	2.25	2,637,000	6,364,000	2.57	3.33
Yuba River	Narrows reservoir	580	853,000	728,000	160,000	0.80	Variable	45,600,000	7,400,000	53,000,000	2,761,000	603,000	3,364,000	528,100,000	975,000	869,000	2.35	1,241,000	2,123,000	2.18	2.44
Bear River	Camp Far West reservoir	180	151,000	151,000	0			6,500,000		6,500,000	403,000		403,000		192,000	130,000			403,000	2.10	3.10
American River	Folsom reservoir	190	355,000	310,000	100,000	0.80	Variable	9,500,000	5,700,000	15,200,000	601,000	452,000	1,053,000								
	Folsom afterbay	89		0	25,000	0.80	1.00	1,500,000	2,800,000	4,300,000	94,000	206,000	300,000								
	Auburn reservoir	440	831,000	702,000	85,000	0.80	Variable	24,000,000	3,900,000	27,900,000	1,429,000	323,000	1,752,000								
	Pilot Creek reservoir	110		0	25,000	0.80	Variable	1,200,000	1,500,000	2,700,000	71,000	126,000	197,000								
	Coloma reservoir	345	766,000	686,000	40,000	0.80	Variable	13,400,000	2,500,000	15,900,000	798,000	201,000	999,000								
	Webber Creek reservoir	85		0	20,000	0.80	Variable	700,000	1,800,000	2,500,000	41,000	142,000	183,000								
	American River unit		1,952,000	1,698,000	295,000					68,500,000			4,484,000	898,800,000	1,790,000	1,656,000	2.56	2,301,000	2,183,000	1.22	1.32
Stony Creek	Millsite reservoir	135	115,000	115,000	0			3,200,000		3,200,000	212,000		212,000		92,000	77,000			212,000	2.30	2.75
Cache Creek	Capay reservoir	170	378,000	378,000	0			5,500,000		5,500,000	338,000		338,000		155,000	155,000			338,000	2.18	2.18
Putah Creek	Monticello reservoir	150	130,000	130,000	0			2,600,000		2,600,000	174,000		174,000		96,000	96,000			174,000	1.81	1.81

[1] Yield at Red Bluff from unregulated flow of Sacramento River supplemented by regulated water from Kennett reservoir or Trinity River diversion.
[2] The estimated values of electric energy at the power plants are based on the cost of producing an equivalent amount of electric energy of the same characteristics with a steam-electric plant located in the area of consumption, taking into account the cost of transmission from point of generation to the load center, and are the lowest values resulting from several methods of evaluation.

TABLE 137

ULTIMATE MAJOR UNITS OF STATE WATER PLAN IN SACRAMENTO RIVER BASIN

Unit	Stream on which unit is located	Height of main dam, in feet	Capacity of reservoir, in acre-feet	Installed capacity of power plants, in kilovolt amperes	Capital cost	
					Excluding power features	Including power features
Kennett reservoir	Sacramento River	520	5,967,000	450,000	$100,500,000	$122,500,000
Oroville reservoir	Feather River	580	1,705,000	314,000	126,400,000	147,700,000
Narrows reservoir	Yuba River	580	853,000	160,000	45,600,000	53,000,000
Camp Far West reservoir	Bear River	180	151,000	No plant	6,500,000	6,500,000
American River	American River	(1)	1,952,000	295,000	46,900,000	68,500,000
Millsite reservoir	Stony Creek	135	115,000	No plant	3,200,000	3,200,000
Capay reservoir	Cache Creek	170	378,000	No plant	5,500,000	5,500,000
Monticello reservoir	Putah Creek	150	130,000	No plant	2,600,000	2,600,000
Trinity River diversion	Trinity River	365	1,436,000	193,000	44,600,000	62,000,000
Totals			12,687,000	1,412,000	381,800,000	471,500,000

[1] Folsom, 190 feet; Auburn, 440 feet; Coloma, 345 feet.

TABLE 137

ULTIMATE MAJOR UNITS OF STATE WATER PLAN IN SACRAMENTO RIVER BASIN

Unit	Stream on which unit is located	Height of main dam, in feet	Capacity of reservoir, in acre-feet	Installed capacity of power plants, in kilovolt amperes	Capital cost	
					Excluding power features	Including power features
Kennett reservoir	Sacramento River	520	5,967,000	450,000	$100,500,000	$122,500,000
Oroville reservoir	Feather River	580	1,705,000	314,000	126,400,000	147,700,000
Narrows reservoir	Yuba River	580	853,000	160,000	45,600,000	53,000,000
Camp Far West reservoir	Bear River	180	151,000	No plant	6,500,000	6,500,000
American River	American River	[1]	1,952,000	295,000	46,900,000	68,500,000
Millsite reservoir	Stony Creek	135	115,000	No plant	3,200,000	3,200,000
Capay reservoir	Cache Creek	170	378,000	No plant	5,500,000	5,500,000
Monticello reservoir	Putah Creek	150	130,000	No plant	2,600,000	2,600,000
Trinity River diversion	Trinity River	365	1,436,000	193,000	44,600,000	62,000,000
Totals			12,687,000	1,412,000	381,800,000	471,500,000

[1] Folsom, 190 feet; Auburn, 440 feet; Coloma, 345 feet.

CHAPTER X

OPERATION AND ACCOMPLISHMENTS OF MAJOR UNITS OF STATE WATER PLAN IN GREAT CENTRAL VALLEY UNDER CONDITIONS OF ULTIMATE DEVELOPMENT.

The accomplishments of each major unit of the State Water Plan in the Sacramento River Basin, separately, have been given in Chapter IX. To obtain the greatest benefit from the plan, however, all of the units in the Great Central Valley must be operated coordinately.

The Great Central Valley of California includes both the Sacramento and San Joaquin river basins and, in this chapter, is considered as one geographic division since plans for the development of the water resources of the two basins and their greatest utilization are closely related. Because of the small water supply in proportion to the ultimate water requirements for full development in the San Joaquin River Basin, there will be a deficiency in supply therein. This is particularly true in the upper valley where a large part of the area is highly developed, where surface water is now utilized to the maximum degree possible without regulation, and where there is, in some localities, a serious overdraft even at present on the ground water supply. In the Sacramento River Basin on the other hand, there is a surplus of water over its ultimate needs. The logical source of an additional supply for the San Joaquin River Basin, therefore, is in the surplus water of the Sacramento River Basin.

Major Units of State Water Plan in Great Central Valley.

To make the surface water supply of both basins available for use in the desired quantities and at the proper time, would require both surface and underground storage to regulate the winter and spring run-offs of the major streams to meet the demands for irrigation and other uses. Conduits would be required to convey the surplus water from the Sacramento River Basin to the areas of deficient supply in the San Joaquin Valley. Other major conduit units would be required to divert surplus water from the Trinity River into the Sacramento River Basin and to export water from the San Joaquin and Kern rivers into areas of the San Joaquin Valley where there are insufficient local supplies for present and future water requirements.

The major units of the State Water Plan in the Sacramento River Basin, including the Trinity River diversion, have been described in Chapter IX, are shown on Plate XXII, and are set forth in Table 138.

The major units of the plan in the San Joaquin River Basin are described in another report,* are shown on Plate XXII, and are set forth in Table 138. These units would consist of surface storage reservoirs and conveyance systems with pumping plants as required. It is proposed to operate the units in such a manner as to most

* Bulletin No. 29, "San Joaquin River Basin," Division of Water Resources, 1931.

effectively utilize all local waters to meet the demands. This would be accomplished in the Upper San Joaquin Valley by utilizing the large natural underground reservoir capacity located therein to the greatest advantage.

TABLE 138

MAJOR UNITS OF STATE WATER PLAN IN GREAT CENTRAL VALLEY

Storage Units

Reservoir	Stream on which reservoir is located	Height of main dam, in feet	Capacity of reservoir, in acre-feet	Installed capacity of power plants, in kilovolt amperes
Sacramento River Basin				
Kennett	Sacramento River	520	5,967,000	450,000
Oroville	Feather River	580	1,705,000	314,000
Narrows	Yuba River	580	853,000	160,000
Camp Far West	Bear River	180	151,000	
Auburn	American River	440	831,000	110,000
Coloma	American River	345	766,000	60,000
Folsom	American River	190	355,000	125,000
Fairview (Trinity River diversion)	Trinity River	365	1,436,000	193,000
Millsite	Stony Creek	135	115,000	
Capay	Cache Creek	170	378,000	
Monticello	Putah Creek	150	130,000	
San Joaquin River Basin				
Nashville	Cosumnes River	270	281,000	
Ione	Dry Creek	120	610,000	
Pardee	Mokelumne River	343	222,000	18,750
Valley Springs	Calaveras River	200	325,000	
Melones	Stanislaus River	460	1,090,000	[1]68,000
Don Pedro	Tuolumne River	455	1,000,000	[2]120,000
Exchequer	Merced River	307	279,000	31,250
Buchanan	Chowchilla River	147	84,000	
Windy Gap	Fresno River	206	62,000	
Friant	San Joaquin River	252	[3]400,000	[4]10,000
Pine Flat	Kings River	274	400,000	40,000
Pleasant Valley	Tule River	125	39,000	
Isabella	Kern River	190	338,000	
Totals			17,817,000	1,700,000

Conveyance Units

Unit	Maximum capacity, in second-feet	Length, in miles
San Joaquin River Basin		
Sacramento-San Joaquin Delta cross channel		24
San Joaquin River pumping system	8,000	167
Madera canal	1,500	18
San Joaquin River-Kern County canal	3,000	165
Kern River canal	1,500	75
Mendota-West Side pumping system	4,500	100
Total		549

[1] Present installed capacity 27,000 kilovolt amperes.
[2] Present installed capacity 33,740 kilovolt amperes.
[3] Effective capacity 270,000 acre-feet.
[4] A 30,000 kilovolt ampere power plant would be constructed on the river and the cost thereof amortized in ten years. A 10,000 kilovolt ampere plant would then be constructed on the Madera canal to utilize the power drop at the dam into that canal after water is no longer available for the larger river plant.

The surface storage reservoir units in the San Joaquin River Basin would be thirteen in number, namely, Nashville on Cosumnes River; Ione on Dry Creek, a tributary of Mokelumne River; Pardee on Mokelumne River; Valley Springs on Calaveras River; Melones on

Stanislaus River; Don Pedro on Tuolumne River; Exchequer on Merced River; Buchanan on Chowchilla River; Windy Gap on Fresno River; Friant on San Joaquin River; Pine Flat on Kings River; Pleasant Valley on Tule River, and Isabella on Kern River.

Power plants are proposed at the Melones, Don Pedro, Friant, and Pine Flat reservoirs. The Exchequer and Pardee reservoirs and power plants as constructed, are included in the plan and are assumed to be operated for the purposes for which they were designed. The Valley Springs reservoir would be enlarged from 76,000 acre-feet to 325,000 acre-feet capacity, reserving 165,000 acre-feet of space in the reservoir for flood control purposes. At the Melones and Don Pedro reservoirs, it is proposed to construct new dams downstream from the existing ones, creating reservoirs of larger capacity, and to reconstruct and enlarge the power plants.

Flood control features would be included in the Nashville, Melones, Don Pedro, Friant, Pine Flat, and Isabella dams.

The conveyance system would consist of six units. Beginning at the northerly end of this system, a new connecting channel, into which water would be diverted by a suitable structure in the Sacramento River, would carry water from the Sacramento River to the San Joaquin Delta for use in that delta and for exportation to the San Joaquin Valley. This channel would extend from a point near Hood to the head of Snodgrass Slough, which slough would be improved and used as a channel to the Mokelumne River at Deadhorse Island. Natural channels would convey the water from this point to the first unit of the pumping system near Mossdale bridge.

The next unit of the conveyance system would be the San Joaquin River pumping system which would utilize the river channel and a canal west of the river, from Mossdale bridge to the Mendota Weir. In this channel there would be five dams and pump lifts in the river and five pump lifts in the canal west of the river. Water would be delivered at Mendota Weir at elevation 159 feet. The total distance from the first pumping plant to the weir would be 135 miles.

The delivery of imported waters to Mendota, to meet the demand of existing rights, would make possible the diversion at the Friant reservoir of the entire flow of the San Joaquin River for use on the eastern slope of the upper San Joaquin Valley. To effect such diversion it is proposed to construct, in addition to the Friant reservoir, two main canals, one on each side of the San Joaquin River. The Madera canal, with a diversion capacity of 1500 second-feet, on the north side of the river would extend for eighteen miles to the channel of the Fresno River. The San Joaquin River-Kern County canal on the south side of the stream would extend southward along the eastern rim of the valley a distance of 165 miles. With a diversion capacity of 3000 second-feet at the Friant reservoir, it would cross in turn the channels of the Kings, Kaweah, Tule, and Kern rivers, terminating at the Kern Island Canal with a capacity of 500 second-feet.

In order to utilize Kern River waters released by the importation of new supplies, it would be necessary to construct the Kern River canal on the south side of the stream and extending from the diversion point near the mouth of the canyon, under the Kern Mesa, and thence around the south end of the valley to Buena Vista Valley. The diversion capacity of this canal would be about 1500 second-feet and the total length 75 miles.

To make water available for the good lands lying on the western slope of the Upper San Joaquin Valley would require a pumping system extending from Mendota Pool to Elk Hills. An essential element of such a system would be a conveyance channel which, for full development, would be 100 miles long and have a capacity varying from 4500 to 500 second-feet. This canal would be located along the lower edge of the irrigable lands and terminate at an elevation of 250 feet. Water for this area would be imported through the San Joaquin River pumping system.

Objects to Be Accomplished.

The units of the State Water Plan should be so operated that they would furnish an adequate irrigation supply for all irrigable lands in the Great Central Valley; would control flood flows in the major streams to certain specified amounts; would improve navigation on the Sacramento and San Joaquin rivers; would maintain a flow past Antioch into Suisun Bay sufficient to control salinity to the lower end of the Sacramento-San Joaquin Delta; and would furnish a supply of water to the San Francisco Bay Basin, which, with water available from local sources and importations from other basins, would provide for the full agricultural and industrial development of that basin.

The irrigation and navigation requirements and the operation of the reservoirs for flood control in the Sacramento River Basin, have been described in the foregoing chapters. The irrigation requirements for the San Joaquin River Basin are given in another report* and amount to 13,326,000 acre-feet gross allowance and 10,952,000 acre-feet net use per season for all irrigable lands, excluding the San Joaquin Delta. The total ultimate requirement for the irrigation of the lands in the Sacramento-San Joaquin Delta and unavoidable losses in the delta are estimated to be 1,200,000 acre-feet per season.

The requirements for the annual use in the San Francisco Bay Basin are estimated to be 1,735,000 acre-feet gross allowance, of which 1,075,000 acre-feet would be imported from the Great Central Valley.

The requirements for salinity control are analyzed in another report.** From the studies made for that report, it was estimated that a fresh water flow of not less than 3300 second-feet past Antioch into Suisun Bay would be required to control the chlorine content of the water at the lower end of the delta to a maximum of 100 parts in 100,000 parts of water. This is equivalent to about 2,390,000 acre-feet of water annually.

Operation and Accomplishments

In estimating the water requirements for the Sacramento River Basin as outlined in Chapter V, the valley floor was divided into "water service areas" each of which would be served by water from one or more of the major streams. A study was made through the eleven-year period

* Bulletin No. 29, "San Joaquin River Basin," Division of Water Resources, 1931.
** Bulletin No. 27, "Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay," Division of Water Resources, 1931.

1918–1929, which is the period of lowest average run-off of any of the same length of which there was definite knowledge prior to 1929, and which contains the extremely dry season of 1923–1924, to determine whether each of these areas could have been given a full supply of irrigation water in all years. This study showed that the Bear River service area would have had a deficiency in supply in some years if dependent entirely upon the yield of the Camp Far West reservoir, but that this deficiency could have been made up from the Narrows reservoir which could have supplied this amount in addition to a full supply for the Yuba River service area. The Sacramento-Feather service area would have received a full supply from the surplus from the Sacramento, Feather, and Yuba river service areas and return water. There also would have been deficiencies in the supplies to the west side foothill service areas which could have been made up from the Sacramento River by pumping. All other service areas would have received a full supply in all years.

In the north end of the San Joaquin Valley, there would have been large deficiencies in the supplies for the Cosumnes, Mokelumne and Calaveras river and the Dry Creek areas, if these areas had been entirely dependent upon the water resources of these streams. The amounts of these deficiencies, however, would have been supplied from the American River unit, from which there would have been a large surplus over the requirements for the American River service area.

The utilization of space for flood control in each of the major unit reservoirs on the more important streams is proposed under the State Water Plan. In Table 139, there is given a list of the streams on which flood control by reservoirs is proposed, the maximum reservoir space required to regulate floods to certain controlled flows, the amount of the controlled flows, and the frequency with which the controlled flows would be exceeded.

TABLE 139

RESERVOIR SPACE REQUIRED FOR CONTROLLING FLOODS TO CERTAIN SPECIFIED FLOWS

Reservoir	Stream	Point of control	Maximum reservoir space employed, in acre-feet	Controlled flow, in second-feet	Number of times controlled flow would be exceeded on the average
Kennett	Sacramento River	Red Bluff	512,000	[2]125,000	Once in 14 years
Oroville	Feather River	Oroville	521,000	100,000	Once in 100 years
Narrows	Yuba River	Smartsville	272,000	70,000	Once in 100 years
Camp Far West	Bear River	Wheatland	50,000	20,000	Once in 100 years
Folsom, Auburn and Coloma	American River	Fairoaks	300,000	[3]80,000	One day in 250 yrs.
Nashville	Cosumnes River	Michigan Bar	56,000	15,000	Once in 100 years
Ione	Dry Creek	Galt	[1]121,000	5,000	Once in 100 years
Pardee	Mokelumne River	Clements	[1]0	10,000	Once in 100 years
Calaveras	Calaveras River	Jenny Lind	165,000	25,000	Once in 100 years
Melones	Stanislaus River	Knights Ferry	204,000	15,000	Once in 100 years
Don Pedro	Tuolumne River	La Grange	214,000	15,000	Once in 100 years
Exchequer	Merced River	Exchequer	59,000	25,000	Once in 100 years
Friant	San Joaquin River	Friant	75,000	15,000	Once in 100 years
Pine Flat	Kings River	Piedra	80,000	15,000	Once in 100 years

[1] Floods which would cause flows in excess of 10,000 second-feet in the Mokelumne River at Clements would be diverted from the Pardee Reservoir to Dry Creek by the Jackson Creek Spillway and the water stored in Ione Reservoir.

[2] Mean daily flow on day of flood crest. Floods would be controlled to 125,000 second-feet maximum flow exceeded once in 100 years, except when this amount is exceeded by uncontrolled run-off between Kennett Reservoir and Red Bluff. Flows greater than 125,000 second-feet would continue for only a short time.

[3] Folsom reservoir alone would control the flow at Fairoaks to a maximum of 100,000 second-feet exceeded one day in 100 years on an average, by employing 175,000 acre-feet of space in the reservoir for flood control.

The operation of all the foregoing reservoirs specifically for flood control, employing the reservoir space assigned to each reservoir for the purpose of controlling floods to the specified flows, would result in a substantial reduction in flood flows and in an increased degree of protection to the areas subject to overflow, particularly those within the Sacramento Flood Control Project, and therefore would decrease the potential annual flood damages in those areas.

Table 140 sets forth, for various points on the main stream channels, the flood flows exceeded once in 100 years on the average, except as noted, without and with reservoir control. The flows in the Sacramento Valley are those that would obtain with the completed Sacramento Flood Control Project, including the protection of Butte Basin. In the San Joaquin Valley, the flows without reservoir control are those that would obtain with levees constructed along the San Joaquin River from Herndon to the delta to form a channel of sufficient width to care for these flows and protect the remaining land now subject to overflow. The flows with reservoir control are those that would obtain with the same channel, but with the flood flows from the larger streams controlled by means of regulation in the major reservoir units of the State Water Plan in this basin to those at the foothill gaging stations shown in Table 139. If protection of the valley lands by means of levees were not effected until after the reservoirs with flood control features were completed, a narrower flood channel along the river could be constructed because of the smaller regulated flows. Under this condition, however, the flows might be slightly larger than those shown in the third column of Table 140, since the reduction of quantities by storage in the narrower channel might be less and the rate of concentration somewhat greater.

TABLE 140

FLOOD FLOWS IN GREAT CENTRAL VALLEY WITHOUT AND WITH RESERVOIR CONTROL

Stream	Maximum mean daily flow, in second feet		Number of times flow would be exceeded, on the average
	Without reservoir control	With reservoir control	
Sacramento River at Red Bluff	303,000	[1]187,000	Once in 100 years
Sacramento River at Red Bluff	218,000	[1]125,000	Once in 14 years
Sacramento River and Sutter-Butte By-pass opposite Colusa	370,000	250,000	Once in 100 years
Sacramento River and Sutter-Butte By-pass opposite Colusa	254,000	170,000	Once in 14 years
Sacramento River at Sacramento and Yolo By-pass at Lisbon	670,000	535,000	Once in 100 years
Feather River below confluence with Yuba River	400,000	201,000	Once in 100 years
Feather River below confluence with Bear River	430,000	226,000	Once in 100 years
American River at Fairoaks	185,000	80,000	Once in 250 years
San Joaquin River below confluence with Merced River	70,000	50,000	Once in 100 years
San Joaquin River below confluence with Tuolumne River	103,000	64,000	Once in 100 years
San Joaquin River below confluence with Stanislaus River	133,000	82,000	Once in 100 years
Sacramento and San Joaquin rivers at confluence	780,000	596,000	Once in 100 years

[1] Floods would be controlled to 125,000 second-feet maximum flow exceeded once in 100 years, except when this amount is exceeded by uncontrolled run-off between Kennett Reservoir and Red Bluff. Flows greater than 125,000 second-feet would continue for only a short time.

Analyses were made of operation of the major units of the State Water Plan in the great Central Valley, including the Trinity River diversion, both storage and conveyance units, and the underground storage basins in the upper San Joaquin Valley, operated coordinately for various purposes through the eleven-year period 1918–1929. These studies were made with three methods of operation which, together with their accomplishments, are as follows:

Method I.

1. The amount of water utilized for storage and regulation in the major reservoir units and underground storage basins was obtained by deducting from the full natural run-off of the streams entering the Great Central Valley, the net use of 2,283,000 acre-feet per season for an adequate and dependable irrigation supply for 1,439,000 acres of land, being the net irrigable mountain valley and foothill lands lying at elevations too high to be irrigated by gravity from the major reservoir units, thus providing for the ultimate needs of these areas; and also deducting 448,000 acre-feet per year from the Tuolumne River for the water supply of the city of San Francisco. An additional amount of 224,000 acre-feet per year also was deducted for the San Francisco Bay Basin from water regulated in Pardee Reservoir on the Mokelumne River.
2. Reserve storage space would have been held in the reservoirs listed in Table 139 for controlling floods. The amount of this space and the regulated flow to which floods on each stream would have been controlled also are shown in the same table.
3. Stored water would have been drawn from the major surface reservoir units, and underground basins in the Upper San Joaquin Valley, in such amounts and at such times as to supplement unregulated flows and return waters, to make water available for:
    a. A supply of 9,033,000 acre-feet per season, gross allowance, without deficiency, available in the principal streams, for the irrigation of all of the net area of 2,640,000 acres of irrigable lands of all classes on the Sacramento Valley floor.
    b. A supply of 1,200,000 acre-feet per season, without deficiency, for the irrigation of all the net area of 392,000 acres of irrigable lands, and for unavoidable losses, in the Sacramento-San Joaquin Delta.
    c. Improvement of navigation on Sacramento River to Red Bluff.
    d. A fresh water flow of not less than 3300 second-feet past Antioch into Suisun Bay, which would have controlled salinity to the lower end of the Sacramento-San Joaquin Delta.
    e. A supply of 5,342,000 acre-feet per season, gross allowance, with a maximum seasonal deficiency of 35 per cent in those areas dependent upon local supplies, for the irrigation of all the net area of 1,810,000 acres of land of all classes in the lower San Joaquin Valley, including 134,000 acres of foothills on the eastern side of the valley below the major reservoirs.
    f. A supply of 4,700,000 acre-feet per season, without deficiency, for the irrigation of a net area of 2,350,000 acres of class 1 and 2 lands on the eastern and southern slopes of the upper

San Joaquin Valley. This would have been accomplished by the utilization of underground storage capacity in conjunction with the major reservoir and conveyance units proposed.

g. A supply of 520,000 acre-feet per season in all years, except 1924 when there would have been a deficiency of 14 per cent, for the irrigation of a net irrigable area of 260,000 acres lying entirely on the western slope of the upper San Joaquin Valley.

h. A water supply and channel depth in the San Joaquin River sufficient to provide a navigable depth of six feet as far upstream as Salt Slough, nine miles above the Merced River.

i. A supply of 403,000 acre-feet per season in the Sacramento-San Joaquin Delta, for use in the San Francisco Bay Basin. There would have been a deficiency of 18.5 per cent in 1924 in the 323,000 acre-foot portion of this supply allotted to use for irrigation. This amount of 403,000 acre-feet per season, together with full practicable development of local resources and annual importations of 224,000 acre-feet from the Mokelumne River and 448,000 acre-feet from the Tuolumne River, and an importation from the Eel River, would have given an adequate and dependable supply for the ultimate development of this basin.

j. The generation of more than five billion kilowatt hours of electric energy, on the average, annually.

Method II.

The method of operation would have been the same as numbers 1, 2, and 3 under Method I, except that more water would have been furnished to supply additional irrigable lands along the west side of the upper San Joaquin Valley. There also would have been a larger deficiency in supply for lands in the San Joaquin Valley, other than those dependent upon local supplies, and for lands in the San Francisco Bay Basin, than under Method I. Under this method of operation, water would have been made available for:

a. Same as a under 3 in Method I.

b. Same as b under 3 in Method I.

c. Same as c under 3 in Method I.

d. Same as d under 3 in Method I.

e. A supply of 5,342,000 acre-feet per season, gross allowance, with a maximum seasonal deficiency of 35 per cent, for the irrigation of all the net area of 1,810,000 acres of irrigable land of all classes in the lower San Joaquin Valley, including 134,000 acres of foothills on the eastern side of the valley below the major reservoirs.

f. Same as f under 3 in Method I.

g. A supply of 1,570,000 acre-feet per season, with a maximum deficiency of 35 per cent, for the irrigation of all the net irrigable area of 785,000 acres of class 1 and 2 lands lying on the western slope of the upper San Joaquin Valley.

h. Same as h under 3 in Method I.
i. Same as i under 3 in Method I, except that the deficiency in the supply for irrigated lands would have been 35 per cent in 1924.
j. Same as j under 3 in Method I.

Method III.

In the accomplishments with the two foregoing methods of operation, the Sacramento Valley would have received an irrigation supply without deficiency. Another study was made of the coordinated operation of all of the major units of the State Water Plan in the Great Central Valley, through the eleven-year period 1918–1929, to show that by the Sacramento Valley lands accepting a reasonable and endurable deficiency in irrigation supply, a substantial supply, additional to that under Method II, would have been made available in the Sacramento-San Joaquin Delta for use in other areas. The method of operation would have been the same as Method II except that the additional supply would have been made available in the delta and there would have been new or increased deficiencies over those in Method II in some of the other supplies. Under this method of operation, water would have been made available for:

a. A supply of 9,033,000 acre-feet per season, gross allowance, with a deficiency of 22 per cent in 1924, available in the principal streams, for the irrigation of all the net irrigable lands—2,640,000 acres—on the Sacramento Valley floor.
b. Same as b under 3 in Method I.
c. Same as c under 3 in Method I.
d. Same as d under 3 in Method I.
e. Same as e under 3 in Method II.
f. Same as f under 3 in Method I.
g. Same as g under 3 in Method II.
h. Same as h under 3 in Method I.
i. Same as i under 3 in Method II.
j. A supply of 1,500,000 acre-feet annually, in the Sacramento-San Joaquin Delta, distributed in accordance with a uniform demand. This supply would have had a maximum seasonal deficiency of 35 per cent in 1924.
k. Same as j under 3 in Method I.

Surplus Water in Great Central Valley.

With all of the major units of the State Water Plan in the Great Central Valley operated as just described, there would have been, under each method, substantial amounts of water, over and above the requirements for the accomplishments given, which would have wasted each year, during the eleven-year period 1918–1929, into San Francisco Bay. Most of this waste would have occurred in years of large run-off and in the winter months of other years. Part of the waste water would have been contributed by unregulated run-off and return water and part by spill from the reservoirs. During the summer months there would have been just sufficient water released from the reservoirs to care for all

TABLE 141

ANNUAL WATER REQUIREMENTS AND SURPLUS IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH MAJOR UNITS OF STATE WATER PLAN IN GREAT CENTRAL VALLEY OPERATED UNDER METHOD I

1918-1929

Year	Net flow into delta, in acre-feet[1]			Requirements from net flow into delta, in acre-feet					Surplus water above all requirements, in acre-feet	Total flow into Suisun Bay, in acre-feet
	From Sacramento Valley, including area east of delta[2]	From San Joaquin Valley, excluding area east of delta[2]	From both valleys	Total gross allowance for delta and adjacent uplands	Salinity control to lower end of delta	Full irrigation supply for "crop lands" in San Joaquin Valley having rights to water to be diverted at Friant[3]	Irrigation supply for additional new lands in San Joaquin Valley	Supplemental supply for San Francisco Bay Basin		
1918	8,949,000	968,000	9,917,000	1,551,000	2,389,000	896,000	520,000	403,000	4,158,000	6,547,000
1919	10,111,000	968,000	11,079,000	1,551,000	2,389,000	896,000	520,000	403,000	5,320,000	7,709,000
1920	7,862,000	957,000	8,819,000	1,551,000	2,395,000	896,000	520,000	403,000	3,054,000	5,449,000
1921	14,743,000	965,000	15,708,000	1,551,000	2,389,000	896,000	520,000	403,000	9,949,000	12,338,000
1922	13,729,000	1,592,000	15,321,000	1,551,000	2,389,000	896,000	520,000	403,000	9,562,000	11,951,000
1923	8,754,000	1,050,000	9,804,000	1,551,000	2,389,000	896,000	520,000	403,000	4,045,000	6,434,000
1924	6,109,000	869,000	6,978,000	1,551,000	2,395,000	896,000	446,300	343,000	1,347,000	3,742,000
1925	8,299,000	942,000	9,241,000	1,551,000	2,389,000	896,000	520,000	403,000	3,482,000	5,871,000
1926	9,361,000	777,000	10,138,000	1,551,000	2,389,000	896,000	520,000	403,000	4,379,000	6,768,000
1927	15,595,000	917,000	16,512,000	1,551,000	2,389,000	896,000	520,000	403,000	10,753,000	13,142,000
1928	12,599,000	968,000	13,567,000	1,551,000	2,395,000	896,000	520,000	403,000	7,802,000	10,197,000
Averages	10,555,000	998,000	11,553,000	1,551,000	2,390 000	896,000	513,000	398,000	5,805,000	8,195,000

[1] Includes regulated and unregulated water from reservoirs and return waters. The amounts shown for the San Joaquin Valley include such portions of the waters intercepted by the San Joaquin River pumping system before reaching the delta as could be used in supplying "crop land" rights or additional new lands in this valley, obviating the pumping of that portion of this supply from the delta.

[2] Area east of delta includes the watersheds of the Cosumnes, Mokelumne and Calaveras rivers.

[3] "Crop lands" ar those areas uitable for growing crops which are now served or probably will be served in the near future by diversions from the San Joaquin River above the mouth of the Merced River under existing r hts.

needs. Part of the waste waters could have been conserved by reservoirs other than the major units of the State Water Plan or by larger major units. Studies showed, however, that these additional regulated waters would not have been necessary during the eleven-year period 1918–1929, for the accomplishments set forth in the foregoing paragraphs.

Although the imported water from the Trinity River would add somewhat to the surplus in years of large run-off in the Sacramento River Basin, more than half of it, as stated in Chapter IX, would be required for the irrigation of lands which could be served by gravity from no other source and a considerable portion of the remainder would be required in the winter months of the drier years for salinity control and navigation. This unit and all of the other selected major units of the State Water Plan would have been required to furnish regulated supplies distributed in accordance with the demand, especially in years of low run-off.

Table 141 shows, for the operation of the plan under Method I, the net flows into the Sacramento-San Joaquin Delta, the amounts required from this water for all uses in the delta and adjacent uplands, the amounts required for supplemental supplies for irrigation in the San Joaquin Valley and for irrigation and other uses in the San Francisco Bay Basin, the amounts of water which would have flowed past Antioch into Suisun Bay for salinity control, the surplus water which would have reached the delta in addition to that for all requirements, and the total amounts of water which would have flowed into Suisun Bay after all requirements had been satisfied. The amounts shown for net flow into the delta from the San Joaquin Valley include such portions of the regulated and unregulated waters from the reservoirs and return waters intercepted by the San Joaquin River pumping system before reaching the delta, as could have been used in supplying

TABLE 142

MONTHLY DISTRIBUTION OF SURPLUS WATER IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH MAJOR UNITS OF STATE WATER PLAN IN GREAT CENTRAL VALLEY OPERATED UNDER METHOD I

1918–1929

Month	Year of maximum run-off, 1927		Year of minimum run-off, 1924		Average for period 1918-1929	
	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet
January	1,157,000	1,360,000	237,000	440,000	795,000	998,000
February	4,546,000	4,729,000	372,000	562,000	1,497,000	1,682,000
March	1,874,000	2,077,000	103,000	306,000	1,602,000	1,805,000
April	877,000	1,073,000	0	196,000	263,000	459,000
May	504,000	707,000	0	203,000	331,000	534,000
June	199,000	396,000	0	196,000	155,000	351,000
July	0	203,000	0	203,000	0	203,000
August	0	203,000	0	203,000	0	203,000
September	7,000	203,000	0	196,000	5,000	201,000
October	133,000	336,000	129,000	332,000	134,000	337,000
November	763,000	959,000	253,000	449,000	480,000	676,000
December	693,000	896,000	253,000	456,000	543,000	746,000
Totals	10,753,000	13,142,000	1,347,000	3,742,000	5,805,000	8,195,000

TABLE 143

ANNUAL WATER REQUIREMENTS AND SURPLUS IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH MAJOR UNITS OF STATE WATER PLAN IN GREAT CENTRAL VALLEY OPERATED UNDER METHOD II

1918-1929

Year	Net flow into delta, in acre-feet[1]			Requirements from net flow into delta, in acre-feet					Surplus water above all requirements, in acre-feet	Total flow into Suisun Bay, in acre-feet
	From Sacramento Valley, including area east of delta[2]	From San Joaquin Valley, excluding area east of delta[2]	From both valleys	Total gross allowance for delta and adjacent uplands	Salinity control to lower end of delta	Full irrigation supply for "crop lands" in San Joaquin Valley having rights to water to be diverted at Friant[3]	Irrigation supply for additional new lands in San Joaquin Valley	Supplemental supply for San Francisco Bay Basin		
1918	9,726,000	968,000	10,694,000	1,551,000	2,389,000	896,000	1,570,000	403,000	3,885,000	6,274,000
1919	9,953,000	968,000	10,921,000	1,551,000	2,389,000	896,000	1,570,000	403,000	4,112,000	6,501,000
1920	8,146,000	957,000	9,103,000	1,551,000	2,395,000	896,000	1,570,000	403,000	2,288,000	4,683,000
1921	13,915,000	965,000	14,880,000	1,551,000	2,389,000	896,000	1,570,000	403,000	8,071,000	10,460,000
1922	13,651,000	1,592,000	15,243,000	1,551,000	2,389,000	896,000	1,570,000	403,000	8,434,000	10,823,000
1923	8,693,000	1,050,000	9,743,000	1,551,000	2,389,000	896,000	1,570,000	403,000	2,934,000	5,323,000
1924	6,081,000	760,000	6,841,000	1,551,000	2,395,000	583,000	1,020,000	290,000	1,002,000	3,397,000
1925	8,727,000	942,000	9,669,000	1,551,000	2,389,000	896,000	1,570,000	403,000	2,860,000	5,249,000
1926	8,957,000	777,000	9,734,000	1,551,000	2,389,000	896,000	1,570,000	403,000	2,925,000	5,314,000
1927	15,361,000	917,000	16,278,000	1,551,000	2,389,000	896,000	1,570,000	403,000	9,469,000	11,858,000
1928	13,339,000	968,000	14,307,000	1,551,000	2,395,000	896,000	1,570,000	403,000	7,498,000	9,893,000
Averages	10,595,000	988,000	11,583,000	1,551,000	2,390,000	868,000	1,520,000	392,000	4,862,000	7,252,000

[1] Includes regulated and unregulated water from reservoirs and return waters. The amounts shown for the San Joaquin Valley include such portions of the waters intercepted by the San Joaquin River pumping system before reaching the delta as could be used in supplying "crop land" rights or additional new lands in this valley, obviating the pumping of that portion of this supply from the delta.

[2] Area east of delta includes the watersheds of the Cosumnes, Mokelumne and Calaveras rivers.

[3] "Crop lands" are those areas suitable for growing crops which are now served or probably will be served in the near future by diversions from the San Joaquin River above the mouth of the Merced River under existing rights.

"crop land" rights or new lands in this valley, obviating the pumping of that portion of this supply from the delta. "Crop lands," are those lands suitable for growing crops which are now or probably will be served in the near future by diversions, under existing rights, from the San Joaquin River above the mouth of the Merced River.

Table 142 shows the amounts of surplus water in the delta and the total flows into Suisun Bay, by months, for the years of maximum and minimum run-off, and the average for the period 1918–1929. It may be noted that under this method of operation there would have been no surplus in July and August of any year.

Table 143 shows the same items for the operation of the plan under Method II as are shown in Table 141 for the operation under Method I. Table 144 gives the monthly distribution of the surpluses and flows into Suisun Bay for Method II similar to that presented in Table 142 for Method I. It may be noted that there would have been less surplus water in the delta, and more months when there would have been no surplus, than with the operation of the plan under Method I.

TABLE 144

MONTHLY DISTRIBUTION OF SURPLUS WATER IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH MAJOR UNITS OF STATE WATER PLAN IN GREAT CENTRAL VALLEY OPERATED UNDER METHOD II

1918–1929

Month	Year of maximum run-off, 1927		Year of minimum run-off, 1924		Average for period 1918-1929	
	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet
January	1,054,000	1,257,000	204,000	407,000	722,000	925,000
February	4,043,000	4,227,000	249,000	439,000	1,320,000	1,505,000
March	1,719,000	1,922,000	0	203,000	1,486,000	1,689,000
April	1,029,000	1,225,000	0	196,000	167,000	363,000
May	357,000	560,000	0	203,000	219,000	422,000
June	0	196,000	0	196,000	113,000	309,000
July	0	203,000	0	203,000	0	203,000
August	0	203,000	0	203,000	0	203,000
September	0	196,000	0	196,000	0	196,000
October	32,000	235,000	55,000	258,000	33,000	236,000
November	588,000	784,000	248,000	444,000	328,000	524,000
December	647,000	850,000	246,000	449,000	474,000	677,000
Totals	9,469,000	11,858,000	1,002,000	3,397,000	4,862,000	7,252,000

Table 145 shows, for the operation of the plan under Method III, the net flows into the delta, the requirements from this water for a number of different uses, the surpluses after furnishing water for all of these uses and the total flows into Suisun Bay, the same as are shown in Table 141 for the operation under Method I. The monthly distribution of the surpluses and the flows into Suisun Bay is given in Table 146 which is similar to Table 142 for Method I. It may be noted that the amounts of surplus water would have been considerably less than with Method II but that there would have been only one more month in the year of maximum run-off, and the same number of months in the year of minimum run-off, in which there would have been no surplus. With this method, there also would have been an average of one more month per season without a surplus.

TABLE 145

ANNUAL WATER REQUIREMENTS AND SURPLUS IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH MAJOR UNITS OF STATE WATER PLAN IN GREAT CENTRAL VALLEY OPERATED UNDER METHOD III

1918-1929

Year	Net flow into delta, in acre-feet[1]			Requirements from net flow into delta, in acre-feet						Surplus water above all requirements, in acre-feet	Total flow into Suisun Bay, in acre-feet
	From Sacramento Valley, including area east of delta[2]	From San Joaquin Valley, excluding area east of delta[2]	From both valleys	Total gross allowance for delta and adjacent uplands	Salinity control to lower end of delta	Full irrigation supply for "crop lands" in San Joaquin Valley having rights to water to be diverted at Friant[3]	Irrigation supply for additional new lands in San Joaquin Valley	Supply for draft with uniform demand	Supplemental supply for San Francisco Bay Basin		
1918	10,559,000	968,000	11,527,000	1,551,000	2,389,000	896,000	1,570,000	1,500,000	403,000	3,218,000	5,607,000
1919	9,942,000	968,000	10,910,000	1,551,000	2,389,000	896,000	1,570,000	1,500,000	403,000	2,601,000	4,990,000
1920	8,480,000	957,000	9,437,000	1,551,000	2,395,000	896,000	1,570,000	1,504,000	403,000	1,118,000	3,513,000
1921	13,830,000	965,000	14,795,000	1,551,000	2,389,000	896,000	1,570,000	1,500,000	403,000	6,486,000	8,875,000
1922	12,920,000	1,592,000	14,512,000	1,551,000	2,389,000	896,000	1,570,000	1,500,000	403,000	6,203,000	8,592,000
1923	9,422,000	1,050,000	10,472,000	1,551,000	2,389,000	896,000	1,570,000	1,500,000	403,000	2,163,000	4,552,000
1924	6,521,000	760,000	7,281,000	1,551,000	2,395,000	583,000	1,020,000	975,000	290,000	467,000	2,862,000
1925	9,502,000	942,000	10,444,000	1,551,000	2,389,000	896,000	1,570,000	1,500,000	403,000	2,135,000	4,524,000
1926	8,911,000	721,000	9,632,000	1,551,000	2,389,000	735,000	1,287,000	1,230,000	345,000	2,095,000	4,484,000
1927	15,029,000	917,000	15,946,000	1,551,000	2,389,000	896,000	1,570,000	1,500,000	403,000	7,637,000	10,026,000
1928	13,516,000	968,000	14,484,000	1,551,000	2,395,000	896,000	1,570,000	1,504,000	403,000	6,165,000	8,560,000
Averages	10,785,000	982,000	11,767,000	1,551,000	2,390,000	853,000	1,494,000	1,429,000	387,000	3,663,000	6,053,000

[1] Includes regulated and unregulated water from reservoirs and return waters. The amounts shown for the San Joaquin Valley include such portions of the waters intercepted by the San Joaquin River pumping system before reaching the delta as could be used in supplying "crop land" rights or additional new lands in this valley, obviating the pumping of that portion of this supply from the delta.
[2] Area east of delta includes the watersheds of the Cosumnes, Mokelumne and Calaveras rivers.
[3] "Crop lands" are those areas suitable for growing crops which are now served or probably will be served in the near future by diversions from the San Joaquin River above the mouth of the Merced River under existing rights.

TABLE 146

MONTHLY DISTRIBUTION OF SURPLUS WATER IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH MAJOR UNITS OF STATE WATER PLAN IN GREAT CENTRAL VALLEY OPERATED UNDER METHOD III

1918-1929

Month	Year of maximum run-off, 1927		Year of minimum run-off, 1924		Average for period 1918-1929	
	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet
January	896,000	1,099,000	72,000	275,000	531,000	734,000
February	3,949,000	4,133,000	140,000	330,000	1,126,000	1,311,000
March	1,550,000	1,753,000	22,000	225,000	1,208,000	1,411,000
April	463,000	659,000	0	196,000	78,000	274,000
May	230,000	433,000	0	203,000	135,000	338,000
June	0	196,000	0	196,000	102,000	298,000
July	0	203,000	0	203,000	0	203,000
August	0	203,000	0	203,000	0	203,000
September	0	196,000	0	196,000	0	196,000
October	0	203,000	0	203,000	0	203,000
November	187,000	383,000	119,000	315 000	204,000	400,000
December	362,000	565,000	114,000	317,000	279,000	482,000
Totals	7,637,000	10,026,000	467,000	2,862,000	3,663,000	6,053,000

Surplus Water in Sacramento River Basin.

The study from which the foregoing results for Method II were obtained also was analyzed to determine the amounts of surplus water from the Sacramento River Basin alone. In making this study, all of the major units of the State Water Plan in this basin, including the Trinity River diversion, were used. This analysis shows that dependable regulated supplies could have been made available without deficiency, in the principal streams, to irrigate all of the 2,640,000 acres of net irrigable lands in the Sacramento Valley, after allowing a gross annual diversion of 3,241,000 acre-feet, with a net use of 1,945,000 acre-feet per year, for the irrigation of a net irrigable area of 1,234,000 acres of foothill and mountain valley lands in the Sacramento River Basin. The analysis also shows that there would have been a large surplus of water in every year, over and above these needs, in the basin above the Sacramento-San Joaquin Delta. A part of this surplus water would have been contributed directly by releases and spill from the reservoirs, a part would have been return water from irrigation on the valley floor, or foothills at elevations higher than the reservoirs but draining directly to the valley floor, and a part would have been unregulated run-off. The portion of this surplus water not used in or diverted from the Sacramento-San Joaquin Delta would have wasted into the ocean. A large part of this surplus, however, could have been put to beneficial use in all years, except in the winter months when a portion would have been wasted. Table 147 gives the amounts of water that would have been contributed by the reservoirs, the surplus available in the delta in the maximum and minimum years and the average annual surplus for the eleven-year period 1918–1929.

The ultimate average annual requirements for the Sacramento-San Joaquin Delta and salinity control would amount to 3,590,000 acre-feet. A portion of this would be contributed by water from the San Joaquin Valley streams, but if the entire amount had been obtained from Sacramento Valley waters during the eleven-year period 1918–1929, there still would have been surpluses in the maximum and minimum years of 11,399,000 and 2,164,000 acre-feet, respectively, and an average annual surplus for the period of 6,702,000 acre-feet.

TABLE 147

SURPLUS WATER IN SACRAMENTO RIVER BASIN

Exclusive of Sacramento-San Joaquin Delta requirements

	Amount of water, in acre-feet		
	Maximum year, 1927	Minimum year, 1924	Average annual for period 1918-1929
Releases and spill from major reservoir units and unregulated run-off	19,837,000	10,608,000	15,141,000
Gross requirements for lands on Sacramento Valley floor	9,033,000	9,033,000	9,033,000
Surplus from releases and spill and unregulated run-off	10,804,000	1,575,000	6,108,000
Return water—from valley floor	3,843,000	3,843,000	3,843,000
Return water—from foothills above reservoirs	341,000	341,000	341,000
Total surplus available in delta from Sacramento River Basin	14,988,000	5,759,000	10,292,000

Additional Regulated Supplies.

In all of the foregoing methods of operation, the accomplishments would have been obtained with the use of only the major units of the State Water Plan. Investigations, however, were made of other reservoir sites in the Sacramento River Basin upstream from the major reservoirs and on streams on which no major reservoir units are proposed, and of other diversions into the basin, to determine the possibilities of obtaining additional regulated supplies.

It was found that the yield in irrigation water from the Feather River could be increased more than 450,000 acre-feet per year and the yield from the Yuba River probably as much as 170,000 acre-feet per year by the use of other known reservoir sites. A relatively small additional yield also could be obtained from the American River and some of the small streams entering the Sacramento Valley from the east and west side foothills.

A preliminary study indicates that it would be physically feasible to divert 500,000 acre-feet annually from Eel River into the Sacramento River Basin without impairment of the present uses on the upper reaches of the Eel. If 200,000 acre-feet annually from this source were furnished the San Francisco Bay Basin to fully supplement other supplies available to that area, 300,000 acre-feet annually still would be available for use in the Great Central Valley. The cost of this supply would not exceed that obtainable from some of the major reservoir units of the State Water Plan in the Great Central Valley.

It also is physically feasible to divert a substantial supply from the upper Klamath River into the upper Sacramento River drainage basin. This could be accomplished by means of a diversion conduit by way of Shasta Valley into the headwaters of the upper Sacramento River, or by means of a canal, or canals and a tunnel, by way of Tule Lake and the Modoc lava beds into Fall River and thence into the Pit River.

Preliminary studies made subsequent to the publication of Bulletin No. 25 of the Division of Water Resources, indicate that this diversion would give a yield, distributed in accordance with the irrigation demand in the Great Central Valley, of between 550,000 and 800,000 acre-feet per year.

It, therefore, would be physically feasible, if the need should ever arise, to obtain annual water supplies of 1,500,000 to 1,900,000 acre-feet for use in the Great Central Valley in addition to those supplies obtainable from the proposed major reservoir units of the State Water Plan for the Sacramento River Basin.

CHAPTER XI

INITIAL UNIT OF STATE WATER PLAN IN SACRAMENTO RIVER BASIN

In Chapter X, a description has been given of the operation and accomplishments of all of the major units of the State Water Plan in the Great Central Valley operated coordinately under the condition of ultimate development. This condition necessarily will not be reached for many years to come. The various units would be constructed progressively but only as the need for them would arise. There are water problems, however, in certain areas in the Great Central Valley which are acute and necessitate immediate rectification. Major units of the State Water Plan are needed to meet the situation.

Immediate Requirements.

The greatest water problem in the Sacramento River Basin at the present time is that of invasion of saline water into the delta region. In months of low flow from the Sacramento and San Joaquin rivers, saline water from the lower bay has, due to tidal action and decreased stream flow into the delta, invaded the upper reaches of Suisun Bay and far up into the many channels of the delta. It is shown in another report* that this condition could be corrected by either of two methods. One method would be the construction of a physical barrier at some strategic point below the affected area, together with sufficient mountain storage to be utilized to replenish the diminishing fresh water supply in a barrier lake. The second method would be to store water in a mountain reservoir during periods of plenteous run-off and later release it at the proper time and in sufficient volume to supplement the unregulated low water flow to prevent the invasion of saline water to a specified degree beyond a certain point. The practicable limit of control with this method is the lower end of the delta. The report shows that the first method is too costly and not economically justified and recommends that the second method be employed for the correction of the salinity menace. With water supplies maintained fresh in the delta channels, diversion conduits could be constructed therefrom to the industrial and agricultural areas on the north and south sides of upper San Francisco Bay.

To control salinity by the method adopted, would require the storage of fresh water in reservoirs and its later release at the proper time and in sufficient volume into channels tributary to the delta. The amount of release would vary with the season and the month during the season and with the point and degree of control. To prevent the invasion of saline water into the delta, would require a flow past Antioch into Suisun Bay of not less than 3300 second-feet. With stream flow

* Bulletin No. 28, "Economic Aspects of a Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers," Division of Water Resources, 1931.

into the delta as it was during the last ten years and present consumptive use of water in the delta, the supplemental flow required for control of salinity and consumptive demands in the delta would have been 1,128,000 acre-feet in 1924, 825,000 acre-feet in 1920, 359,000 acre-feet in 1928 and 150,000 acre-feet in 1927.

The most advantageous location of a reservoir for the control of salinity would be in the San Joaquin River Basin because two-thirds of the water demands are in the San Joaquin River section of the delta, and further because the present low water inflow into the delta from the San Joaquin River is much less than from the Sacramento River, with only two existing channels, Georgiana Slough and Three Mile Slough, of limited capacity interconnecting the two rivers. The reservoirs in the upper San Joaquin Valley would not be available because the water developed by those units would be used within that area. A study of the major reservoirs of the State Water Plan in the lower San Joaquin River Basin reveals that only two, the Don Pedro and Melones reservoirs, have promise. Each has sufficient capacity to meet the salinity control demands, but, due to the fact that a substantial part of the potential yield of each now is attached to present developed areas, the resultant added yield of each as a unit would be too small to meet salinity requirements. Both taken together, however, would produce sufficient new water to meet the requirements, but at two or more times the net cost of obtaining the same quantity of water at the more favorable reservoirs in the Sacramento River Basin. Other combinations of smaller units with one of these reservoirs also could meet the requirement, but again at much higher costs than could be obtained in the Sacramento River Basin.

Although salinity control is the principal immediate problem in the Sacramento River Basin, others are quite important. During the summer and fall months of subnormal years, the flow in the Sacramento River has been so low that navigation has been greatly impaired and distance of navigability has been much reduced. Also, during several of the past dry years, particularly in 1920 and 1924, the irrigators drawing their supplies from the Sacramento River had hardly enough water for their needs. Increased pumping costs also have resulted from the additional lifts caused by low discharge in the stream. All of these problems—salinity control in the delta and upper San Francisco Bay regions, the maintenance of navigation, and the improvement of irrigation supplies along the Sacramento River—are closely allied and must be given consideration in selecting an initial unit of the State Water Plan in the Sacramento River Basin.

Possible Initial Units.

Only three units in the Sacramento River Basin, each by itself, would be able to meet salinity control requirements in a year like 1924, with existing irrigation and storage developments in the Sacramento and San Joaquin river basins. These are Kennett reservoir (420-foot dam) on the Sacramento River, Oroville reservoir on the Feather River and the American River unit. If it is assumed that perfect salinity control would not be required in a year like 1924, then the Narrows reservoir on the Yuba River, and the Trinity River diversion in conjunction with regulatory storage in the Sacramento River Basin, also would be capable of meeting the situation. Combinations of smaller units by themselves or with the Trinity River diversion or Narrows reservoir also could effectively control salinity.

The Kennett reservoir, located on the Sacramento River, also could be operated to improve navigation on the river to Red Bluff, to perfect the water supply of the lands now under irrigation along the river, to reduce the size of floods in the Sacramento Flood Control Project, and to make available in the Sacramento-San Joaquin Delta supplies for the delta and upper San Francisco Bay area and for the San Joaquin Valley.

In Table 136 in Chapter IX, a comparison is given of the estimated amounts and net costs of irrigation supplies which could be developed by the major units in the Sacramento River Basin, including the Trinity River diversion. This table shows the amounts of water which could be made available in accordance with the irrigation demand and the net costs per acre-foot thereof. The amount of new water in each instance, is that obtainable through development of storage, over and above present possible use from the stream under an irrigation demand schedule. The net cost of yield is the cost after allowance was made for revenue from the sale of electric energy from those units where it would be profitable to install a hydroelectric power plant in order to defray part of the cost of the project.

Although the salinity control demand would vary somewhat from that for irrigation and the net cost per acre-foot would be different from that given, the figures are comparable as to relative costs of regulated water from the various units. To obtain these amounts, the units would be operated primarily to yield a maximum irrigation supply, modified slightly, however, to furnish a more dependable and valuable electric energy output.

From a comparison of the costs of new water from various units. and combinations of units, which would furnish the amount of water and accomplish the objects required of an initial development, it was concluded that only two of these units were worthy of more detailed consideration, namely, Kennett reservoir and American River.

Operation and Accomplishments of Kennett Reservoir and American River Units as Initial Developments.

Detailed analyses were made of the Kennett reservoir and American River units, with several methods of operation, as initial developments in the State Water Plan. In making these analyses, the Kennett reservoir unit comprised the Kennett reservoir with the 420 foot height of dam, the Keswick afterbay and the power plants at the main dam and afterbay. For the American River, analyses were made for both a complete and partial development. For the complete development, the three storage reservoirs, two power drops, Folsom afterbay, and six power plants, described in Chapter IX, were included. Of the three storage reservoirs, Folsom and Auburn would be the more productive in water yield. These two reservoirs in themselves could meet the earlier requirements of an initial development, leaving Coloma to be constructed at a later date when additional water would be needed

The Folsom and Auburn reservoirs. Pilot Creek power drop, Folsom afterbay and the power plant at each dam, therefore, are designated as the "partial American River unit."

In the following outlines of operations and accomplishments, the analyses for Methods I and IV for the Kennett reservoir unit and for the same methods for the complete American River unit cover the forty-year period 1889–1929. The analyses for Methods II and III for the Kennett reservoir unit, for Methods II and III for the complete American River unit, and for Methods I and II for the partial American River unit were made only for the ten-year period of low average run-off, 1919–1929, but the average power outputs for these methods were estimated for the forty-year period 1889–1929.

Under Methods I, II, and III for the Kennett reservoir unit, Methods I, II, and III for the complete American River unit, and Methods I and II for the partial American River unit, the run-off from the basin considered available at each unit was that impaired by present upstream development. Under Method IV for both the Kennett reservoir unit and the complete American River unit, the run-off considered available was that impaired by estimated ultimate future upstream development.

Kennett Reservoir Unit.—The four general methods of operation under which the Kennett reservoir unit was analyzed, together with the accomplishments, are as follows:

Method I.

Water would have been released from the reservoir in such manner as to obtain the greatest possible revenue from the production of electric energy, all other uses of the water being incidental. The following would have been accomplished:

1. An annual average of 1,622,800,000 kilowatt hours of hydroelectric energy would have been generated.
2. Five hundred ninety-five thousand acre-feet of new water would have been made available, with a maximum deficiency of 35 per cent in the driest year, for use in accord with the irrigation demand in the Sacramento Valley.
3. There would have been incidental benefits to navigation, flood control, and salinity control.

Method II.

Space would have been reserved in the reservoirs for flood control, and stored water would have been released in such manner as to supplement the flows from unregulated streams in the Sacramento River Basin or those regulated by present developments, from return irrigation waters in the Sacramento Valley, and from inflows to the Sacramento-San Joaquin Delta from the San Joaquin River Basin under conditions with the immediate initial development* of the State Water Plan in that basin in operation, to make sup-

* Friant reservoir, San Joaquin River-Kern County canal, Madera canal, and Magunden-Edison pumping system constructed.

plies available for irrigation, navigation, salinity control and the generation of power. The following would have been accomplished:

1. The space reserved in the reservoir each season for flood control would have prevented flood flows from exceeding 125,000 second-feet at Red Bluff.
2. A navigable depth on the Sacramento River of five to six feet would have been maintained from the city of Sacramento to Chico Landing, with a substantial increase in present depths from Chico Landing to Red Bluff.
3. Irrigation demands on the Sacramento River above Sacramento would have been supplied, without deficiency, up to 6000 second-feet maximum draft in July. A full irrigation supply would have been furnished in all years to all lands along the Sacramento River above the delta. There would have been over 700,000 acre-feet more water available, in accordance with the irrigation schedule, for these lands in 1924.
4. An irrigation supply, without deficiency, would have been furnished the Sacramento-San Joaquin Delta for its present requirements.
5. A fresh water flow of not less than 3300 second-feet would have been maintained past Antioch into Suisun Bay, controlling salinity to the lower end of the Sacramento-San Joaquin Delta.
6. A water supply, without deficiency, would have been made available in the delta for the developed industrial and agricultural areas along the south shore of Suisun Bay in Contra Costa County.
7. An annual average of 1,591,800,000 kilowatt hours of hydroelectric energy would have been generated, incidental to other uses.

Method III.

Space would have been reserved in the reservoirs for flood control, and stored water would have been released in such manner as to supplement the flows from unregulated streams in the Sacramento River Basin or those regulated by present developments, from return irrigation waters in the Sacramento Valley, and from inflows to the Sacramento-San Joaquin Delta from the San Joaquin River Basin under conditions with the complete initial development* of the State Water Plan in that basin in operation, to make supplies available for irrigation, navigation, salinity control and the generation of power. The following would have been accomplished:

Items 1, 2, 3, 4, 5, and 6, same as under Method II.

7. An irrigation supply, without deficiency, would have been made available in the Sacramento-San Joaquin Delta** sufficient in amount to fully supply the "crop lands" now being served from the San Joaquin River above the mouth of the Merced River. This supply would have been conveyed to those lands by the

* Friant reservoir, San Joaquin River-Kern County canal, Madera canal, Magunden-Edison pumping system, San Joaquin River pumping system and Sacramento-San Joaquin Delta cross channel constructed.

** See footnotes to Table 150.

San Joaquin River pumping system and would have made possible the exportation of all the available supply in the San Joaquin River at Friant if the "grass land" rights on the San Joaquin River above the mouth of Merced River had been purchased.

8. An annual average of 1,581,100,000 kilowatt hours of hydroelectric energy would have been generated, incidental to other uses.

Method IV.

Water would have been released from the reservoir in such manner as to supplement the unregulated flow at Red Bluff to make available a maximum possible irrigation supply at that point. Hydroelectric energy would have been generated with the water released from the reservoir under the irrigation demand schedule. The following would have been accomplished:

1. Two million eight hundred fifty thousand acre-feet of new water would have been made available annually, with a maximum deficiency of 35 per cent in the driest year, for use in accordance with the irrigation demand in the Sacramento Valley.
2. An annual average of 1,285,000,000 kilowatt hours of hydroelectric energy would have been generated.
3. There would have been incidental benefits to navigation, flood control and salinity control.

Complete American River Unit.—The four methods of operation under which the American River unit was analyzed, together with the accomplishments, are as follows:

Method I.

Water would have been released from the reservoirs in such manner as to obtain the greatest possible revenue from the production of electric energy, all other uses of the water being incidental. The following would have been accomplished:

1. An annual average of 1,052,400,000 kilowatt hours of hydroelectric energy would have been generated.
2. Five hundred twenty-four thousand acre-feet of new water would have been made available, with a maximum deficiency of 35 per cent in the driest year, for use in accordance with the irrigation demand in the Sacramento Valley.
3. There would have been incidental benefits to flood control, salinity control, and navigation.

Method II.

Space would have been reserved in the reservoirs for flood control, and stored water would have been released in such manner as to supplement the flows from unregulated streams in the Sacramento River Basin or those regulated by present developments, from return irrigation waters in the Sacramento Valley, and from inflows to the Sacramento-San Joaquin Delta from the San Joaquin River Basin under conditions with the immediate initial development* of the State Water Plan in that basin in operation, to make supplies available for irrigation, navigation, salinity control and the generation of power. The following would have been accomplished:

1. The space reserved in the reservoirs each season for flood control would have reduced flood flows to 80,000 second-feet maximum flow at the U. S. Geological Survey gaging station at Fairoaks.
2. A fresh water flow of not less than 3300 second-feet would have been maintained past Antioch into Suisun Bay, controlling salinity to the lower end of the Sacramento-San Joaquin Delta.
3. An irrigation supply, without deficiency, would have been furnished the Sacramento-San Joaquin Delta for its present requirements.
4. A water supply, without deficiency, would have been made available in the delta for the developed industrial and agricultural areas along the south shore of Suisun Bay in Contra Costa County.
5. An annual average of 972,500,000 kilowatt hours of hydroelectric energy would have been generated, incidental to other uses.

Method III.

Space would have been reserved in the reservoirs for flood control, and stored water would have been released in such manner as to supplement the flows from unregulated streams in the Sacramento River Basin or those regulated by present developments, from return irrigation waters in the Sacramento Valley, and from inflows to the Sacramento-San Joaquin Delta from the San Joaquin River Basin under conditions with the complete initial development** of the State Water Plan in that basin in operation, to make supplies available for irrigation, navigation, salinity control and the generation of power. The following would have been accomplished:

Items 1, 2, 3, and 4, same as Method II.

5. An irrigation supply, without deficiency, would have been made available in the Sacramento-San Joaquin Delta*** sufficient in amount to fully supply the "crop lands" now being served from the San Joaquin River above the mouth of the Merced River. This supply would have been conveyed to these lands by the San Joaquin River pumping system and would have made possible the exportation of all the available supply in the San Joaquin River at Friant if the "grass land" rights on the San Joaquin River above the mouth of Merced River had been purchased.
6. An annual average of 951,700,000 kilowatt hours of hydroelectric energy would have been generated, incidental to other uses.

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* Friant reservoir, San Joaquin River-Kern County canal, Madera canal, and Magunden-Edison pumping system constructed.

** Friant reservoir, San Joaquin River-Kern County Canal, Madera Canal, Magunden-Edison pumping system, San Joaquin River pumping system and Sacramento-San Joaquin Delta cross channel constructed.

*** See footnotes to Table 154.

Method IV.

Water would have been released from the reservoirs in such manner as to make available a maximum possible irrigation supply at Folsom. Hydroelectric energy would have been generated with the water released from the reservoirs under the irrigation demand schedule. The following would have been accomplished:

1. One million six hundred fifty-six thousand acre-feet of new water would have been made available annually, with a maximum deficiency of 35 per cent in the driest year, for use in accordance with the irrigation demand in the Sacramento Valley.
2. An annual average of 898,800,000 kilowatt hours of hydroelectric energy would have been generated.
3. There would have been incidental benefits to flood control, salinity control, and navigation.

Partial American River Unit.—The partial American River unit was analyzed under two methods of operation which, together with the accomplishments, are as follows:

Method I.

Space would have been reserved in the reservoirs for flood control, and stored water would have been released in such manner as to supplement the flows from unregulated streams in the Sacramento River Basin or those regulated by present developments, from return irrigation waters in the Sacramento Valley, and from inflows to the Sacramento-San Joaquin Delta from the San Joaquin River Basin under conditions with the immediate initial development* of the State Water Plan in that basin in operation, to make supplies available for irrigation, navigation, salinity control and the generation of power. The following would have been accomplished:

1. The space reserved in the reservoirs each season for flood control would have reduced flood flows to 100,000 second-feet maximum flow at the United States Geological Survey gaging station at Fairoaks.
2. A fresh water flow of not less than 3300 second-feet would have been maintained past Antioch into Suisun Bay, controlling salinity to the lower end of the Sacramento-San Joaquin Delta.
3. An irrigation supply, without deficiency, would have been furnished the Sacramento-San Joaquin Delta for its present requirements.
4. A water supply, without deficiency, would have been made available in the delta for the developed industrial and agricultural areas along the south shore of Suisun Bay in Contra Costa County.
5. An annual average of 762,500,000 kilowatt hours of hydroelectric energy would have been generated, incidental to other uses.

* Friant reservoir, San Joaquin River-Kern County canal, Madera canal, and Magunden-Edison pumping system constructed.

Method II.

Space would have been reserved in the reservoirs for flood control, and stored water would have been released in such manner as to supplement the flows from unregulated streams in the Sacramento River Basin or those regulated by present developments, from return irrigation waters in the Sacramento Valley, and from inflows to the Sacramento-San Joaquin Delta from the San Joaquin River Basin under conditions with the complete initial development * of the State Water Plan in that basin in operation, to make supplies available for irrigation, navigation, salinity control and the generation of power. The following would have been accomplished:

Items 1, 2, 3, and 4, same as under Method I above.

5. An annual irrigation supply of 500,000 acre-feet, with a deficiency of 31 per cent in 1924, would have been made available in the Sacramento-San Joaquin Delta ** for the supply of the "crop lands" now being served from the San Joaquin River above the mouth of the Merced River. This supply would have been conveyed to these lands by the San Joaquin River pumping system and would have made possible the exportation of a like amount of water from the San Joaquin River at Friant.
6. An annual average of 730,000,000 kilowatt hours of hydroelectric energy would have been generated, incidental to the other uses.

Surplus Water.

Studies were made with certain of the methods of operation described in the foregoing section of this chapter to estimate the amounts of water which would have reached the Sacramento-San Joaquin Delta from the entire Sacramento and San Joaquin valleys, the amounts which would have been surplus after all requirements had been satisfied from this water, and the flows into Suisun Bay. These studies were made for the period 1919–1929 with Methods II and III for the Kennett reservoir unit and complete American River unit and for Methods I and II for the partial American River unit. The results of these studies are shown in Tables 148 to 159.

Table 148 shows for each year, with Kennett reservoir operated under Method II, the net annual amount of water reaching the Sacramento-San Joaquin Delta, the amount required from this water for all purposes in the delta, the amount of water which would have flowed past Antioch into Suisun Bay for salinity control, the amount of water available for irrigation and industrial use in the San Francisco Bay Basin, the surplus water which would have reached the delta in addition to that for the above requirements, and the total amount of water which would have flowed into Suisun Bay, including that required for salinity control. Table 149 is given to show the distribution of the surpluses and flows into Suisun Bay, by months, in the years of maximum and

* Friant reservoir, San Joaquin River-Kern County canal, Madera canal, Magunden-Edison pumping system, San Joaquin River pumping system and Sacramento-San Joaquin Delta cross channel constructed.

** See footnotes to Table 158.

TABLE 148

ANNUAL WATER REQUIREMENTS AND SURPLUS IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH KENNETT RESERVOIR OPERATED AS AN INITIAL UNIT UNDER METHOD II

1919-1929

Year	Net flow into delta, in acre-feet[1]			Requirements from net flow into delta, in acre-feet				Surplus water above all requirements, in acre-feet	Total flow into Suisun Bay, in acre-feet
	From Sacramento Valley	From San Joaquin Valley	Total from both valleys	Total gross allowance for delta	Salinity control to lower end of delta	Industrial and irrigation use in developed areas along south side of Suisun Bay	Total		
1919	16,340,000	2,769,000	19,109,000	1,083,000	2,389,000	44,000	3,516,000	15,593,000	17,982,000
1920	12,625,000	2,312,000	14,937,000	1,083,000	2,395,000	44,000	3,522,000	11,415,000	13,810,000
1921	22,041,000	4,440,000	26,481,000	1,083,000	2,389,000	44,000	3,516,000	22,965,000	25,354,000
1922	19,755,000	6,997,000	26,752,000	1,083,000	2,389,000	44,000	3,516,000	23,236,000	25,625,000
1923	12,339,000	4,116,000	16,455,000	1,083,000	2,389,000	44,000	3,516,000	12,939,000	15,328,000
1924	7,302,000	1,108,000	8,410,000	1,083,000	2,395,000	44,000	3,522,000	4,888,000	7,283,000
1925	15,617,000	3,432,000	19,049,000	1,083,000	2,389,000	44,000	3,516,000	15,533,000	17,922,000
1926	14,819,000	2,190,000	17,009,000	1,083,000	2,389,000	44,000	3,516,000	13,493,000	15,882,000
1927	24,714,000	4,688,000	29,402,000	1,083,000	2,389,000	44,000	3,516,000	25,886,000	28,274,000
1928	17,216,000	3,295,000	20,511,000	1,083,000	2,395,000	44,000	3,522,000	16,989,000	19,384,000
Averages	16,277,000	3,535,000	19,812,000	1,083,000	2,391,000	44,000	3,518,000	16,294,000	18,685,000

[1] Includes regulated water from Kennett, Friant and existing reservoirs, unregulated run-off and return waters.

minimum run-off, and the average for the whole period. This table shows no, or only a small surplus in the summer months, but large quantities of fresh water in excess of those required for salinity control in eight or nine months of the year. These excess flows would improve the salinity condition in upper San Francisco Bay, making it practically equivalent to natural conditions existing before expansion of irrigation and reclamation development in the Great Central Valley.

TABLE 149

MONTHLY DISTRIBUTION OF SURPLUS WATER IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH KENNETT RESERVOIR OPERATED AS AN INITIAL UNIT UNDER METHOD II

1919-1929

Month	Year of maximum run-off, 1927		Year of minimum run-off, 1924		Average for period 1919-1929	
	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet
January	2,521,000	2,724,000	613,000	816,000	1,794,000	1,997,000
February	7,514,000	7,697,000	1,038,000	1,228,000	3,142,000	3,328,000
March	3,883,000	4,086,000	533,000	736,000	2,674,000	2,877,000
April	4,066,000	4,262,000	462,000	658,000	2,537,000	2,733,000
May	2,904,000	3,107,000	64,000	267,000	2,174,000	2,377,000
June	1,853,000	2,049,000	10,000	206,000	1,088,000	1,284,000
July	239,000	442,000	0	203,000	201,000	404,000
August	118,000	321,000	0	203,000	87,000	290,000
September	177,000	373,000	63,000	259,000	150,000	346,000
October	348,000	551,000	364,000	567,000	350,000	553,000
November	1,179,000	1,375,000	762,000	958,000	888,000	1,084,000
December	1,084,000	1,287,000	979,000	1,182,000	1,209,000	1,412,000
Totals	25,886,000	28,274,000	4,888,000	7,283,000	16,294,000	18,685,000

Table 150 shows the same items for the operation of Kennett reservoir unit under Method III as are shown in Table 148 for the operation under Method II, except that in this case the amount of water made available for irrigation supply for lands in the San Joaquin Valley also is shown. It may be noted that the amounts of surplus water and total flows into Suisun Bay would have been smaller than under Method II, because of the allowance for the San Joaquin Valley. However, they still would have been substantial quantities. Table 151 contains the same information on monthly distribution for Method III as is presented in Table 149 for Method II.

Table 152 shows the same things for the operation of the complete American River unit under Method II as are shown by Table 148 for the operation of the Kennett reservoir unit under Method II. Table 153 shows the distribution of the surpluses and flows into Suisun Bay, by months, with the complete American River unit operated under Method II, in the years of maximum and minimum run-off, and the average for the period 1919–1929.

Table 154 shows the same things for the operation of the complete American River unit under Method III as are shown by Table 150 for the operation of the Kennett reservoir under Method III. Table 155 shows the distribution of the surpluses and flows into Suisun Bay, by

TABLE 150

ANNUAL WATER REQUIREMENTS AND SURPLUS IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH KENNETT RESERVOIR OPERATED AS AN INITIAL UNIT UNDER METHOD III

1919-1929

Year	Net flow into delta, in acre-feet[1]			Requirements from net flow into delta, in acre-feet					Surplus water above all requirements, in acre-feet	Total flow into Suisun Bay, in acre-feet
	From Sacramento Valley	From San Joaquin Valley	Total from both valleys	Total gross allowance for delta	Salinity control to lower end of delta	Full irrigation supply for "croplands" in San Joaquin Valley having rights to water to be diverted at Friant[2]	Industrial and irrigation use in developed areas along south side of Suisun Bay	Total		
1919	16,337,000	2,769,000	19,106,000	1,083,000	2,389,000	896,000	44,000	4,412,000	14,694,000	17,083,000
1920	12,642,000	2,312,000	14,954,000	1,083,000	2,395,000	896,000	44,000	4,418,000	10,536,000	12,931,000
1921	21,999,000	4,440,000	26,439,000	1,083,000	2,389,000	896,000	44,000	4,412,000	22,027,000	24,416,000
1922	19,728,000	6,997,000	26,725,000	1,083,000	2,389,000	896,000	44,000	4,412,000	22,313,000	24,702,000
1923	12,306,000	4,116,000	16,422,000	1,083,000	2,389,000	896,000	44,000	4,412000	12,010,000	14,399,000
1924	7,031,000	1,108,000	8,139,000	1,083,000	2,395,000	896,000	44,000	4,418,000	3,721,000	6,116,000
1925	15,407,000	3,432,000	18,839,000	1,083,000	2,389,000	896,000	44,000	4,412,000	14,427,000	16,816,000
1926	15,231,000	2,190,000	17,421,000	1,083,000	2,389,000	896,000	44,000	4,412,000	13,009,000	15,398,000
1927	24,904,000	4,688,000	29,592,000	1,083,000	2,389,000	896,000	44,000	4,412,000	25,180,000	27,569,000
1928	17,126,000	3,295,000	20,421,000	1,083,000	2,395,000	896,000	44,000	4,418,000	16,003,000	18,398,000
Averages	16,271,000	3,535,000	19,806,000	1,083,000	2,391,000	896,000	44,000	4,414,000	15,392,000	17,783,000

[1] Includes regulated water from Kennett, Friant and existing reservoirs, unregulated run-off and return waters. The amounts shown for the San Joaquin Valley include such portions of these waters intercepted by the San Joaquin River pumping system before reaching the delta as could be used in supplying "crop land" rights in this valley, obviating the pumping of that portion of this supply from the delta.

[2] "Crop lands" are those areas suitable for growing crops which are now served or probably will be served in the near future by diversion from the San Joaquin River above the mouth of the Merced River under existing rights.

months, with Method III of operation for the complete American River unit, in the years of maximum and minimum run-off, and the average for the period 1919–1929.

Table 156 shows the same things for the operation of the partial American River unit under Method I as are shown by Table 152 for the operation of the complete unit under Method II. Table 157 shows the distribution of the surpluses and flows into Suisun Bay, by months, with Method I of operation for the partial American River unit, in the years of maximum and minimum run-off, and the average for the period 1919–1929.

Table 158 shows the same things for the operation of the partial American River unit under Method II as are shown by Table 154 for the operation of the complete unit under Method III, except that only 500,000 acre-feet per year, with a deficiency in 1924, would have been made available for use on the "crop lands" in the San Joaquin Valley. Table 159 shows the monthly distribution of surpluses and flows into Suisun Bay for the operation of the partial unit under Method II.

TABLE 151

MONTHLY DISTRIBUTION OF SURPLUS WATER IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH KENNETT RESERVOIR OPERATED AS AN INITIAL UNIT UNDER METHOD III

1919-1929

Month	Year of maximum run-off, 1927		Year of minimum run-off, 1924		Average for period 1919-1929	
	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet
January	2,701,000	2,904,000	534,000	737,000	1,752,000	1,955,000
February	7,486,000	7,670,000	871,000	1,061,000	3,125,000	3,311,000
March	3,831,000	4,034,000	442,000	645,000	2,651,000	2,854,000
April	3,951,000	4,147,000	384,000	580,000	2,371,000	2,567,000
May	2,745,000	2,948,000	0	203,000	2,065,000	2,268,000
June	1,690,000	1,886,000	0	196,000	940,000	1,136,000
July	97,000	300,000	0	203,000	94,000	297,000
August	10,000	213,000	0	203,000	4,000	207,000
September	100,000	296,000	50,000	246,000	79,000	275,000
October	320,000	523,000	260,000	463,000	314,000	517,000
November	1,047,000	1,243,000	505,000	701,000	785,000	981,000
December	1,202,000	1,405,000	675,000	878,000	1,212,000	1,415,000
Totals	25,180,000	27,569,000	3,721,000	6,116,000	15,392,000	17,783,000

TABLE 152

ANNUAL WATER REQUIREMENTS AND SURPLUS IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH COMPLETE AMERICAN RIVER UNIT OPERATED AS AN INITIAL UNIT UNDER METHOD II

1919-1929

Year	Net flow into delta, in acre-feet[1]			Requirements from net flow into delta, in acre-feet				Surplus water above all requirements, in acre-feet	Total flow into Suisun Bay, in acre-feet
	From Sacramento Valley	From San Joaquin Valley	Total from both valleys	Total gross allowance for delta	Salinity control to lower end of delta	Industrial and irrigation use in developed areas along south side of Suisun Bay	Total		
1919	16,477,000	2,769,000	19,246,000	1,083,000	2,389,000	44,000	3,516,000	15,730,000	18,119,000
1920	13,082,000	2,312,000	15,394,000	1,083,000	2,395,000	44,000	3,522,000	11,872,000	14,267,000
1921	22,388,000	4,440,000	26,828,000	1,083,000	2,389,000	44,000	3,516,000	23,312,000	25,701,000
1922	19,932,000	6,997,000	26,929,000	1,083,000	2,389,000	44,000	3,516,000	23,413,000	25,802,000
1923	12,149,000	4,116,000	16,265,000	1,083,000	2,389,000	44,000	3,516,000	12,749,000	15,138,000
1924	7,281,000	1,108,000	8,389,000	1,083,000	2,395,000	44,000	3,522,000	4,867,000	7,262,000
1925	16,123,000	3,432,000	19,555,000	1,083,000	2,389,000	44,000	3,516,000	16,039,000	18,428,000
1926	15,860,000	2,190,000	18,050,000	1,083,000	2,389,000	44,000	3,516,000	14,534,000	16,923,000
1927	24,975,000	4,688,000	29,663,000	1,083,000	2,389,000	44,000	3,516,000	26,147,000	28,536,000
1928	17,235,000	3,295,000	20,530,000	1,083,000	2,395,000	44,000	3,522,000	17,008,000	19,403,000
Averages	16,550,000	3,535,000	20,085,000	1,083,000	2,391,000	44,000	3,518,000	16,567,000	18,958,000

[1] Includes regulated water from complete American River unit, Friant and existing reservoirs, unregulated run-off and return waters.

TABLE 153

MONTHLY DISTRIBUTION OF SURPLUS WATER IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH COMPLETE AMERICAN RIVER UNIT OPERATED AS AN INITIAL UNIT UNDER METHOD II

1919-1929

Month	Year of maximum run-off, 1927		Year of minimum run-off, 1924		Average for period 1918-1929	
	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet
January	2,585,000	2,788,000	672,000	875,000	1,828,000	2,031,000
February	7,350,000	7,534,000	1,176,000	1,366,000	3,242,000	3,428,000
March	3,878,000	4,081,000	577,000	780,000	2,698,000	2,901,000
April	4,279,000	4,475,000	432,000	628,000	2,636,000	2,832,000
May	2,965,000	3,168,000	0	203,000	2,193,000	2,396,000
June	1,902,000	2,098,000	0	196,000	1,045,000	1,241,000
July	99,000	302,000	0	203,000	86,000	289,000
August	0	203,000	0	203,000	3,000	206,000
September	108,000	304,000	22,000	218,000	81,000	277,000
October	336,000	539,000	291,000	494,000	343,000	546,000
November	1,449,000	1,645,000	757,000	953,000	1,050,000	1,246,000
December	1,196,000	1,399,000	940,000	1,143,000	1,362,000	1,565,000
Totals	26,147,000	28,536,000	4,867,000	7,262,000	16,567,000	18,958,000

TABLE 154

ANNUAL WATER REQUIREMENTS AND SURPLUS IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH COMPLETE AMERICAN RIVER UNIT OPERATED AS AN INITIAL UNIT UNDER METHOD III

1919-1929

Year	Net flow into delta, in acre-feet[1]			Requirements from net flow into delta, in acre-feet					Surplus water above all requirements, in acre-feet	Total flow into Suisun Bay, in acre-feet
	From Sacramento Valley	From San Joaquin Valley	Total from both valleys	Total gross allowance for delta	Salinity control to lower end of delta	Irrigation supply for "croplands" in San Joaquin Valley having rights to water to be diverted at Friant[2]	Industrial and irrigation use in developed areas along south side of Suisun Bay	Total		
1919	16,430,000	2,769,000	19,199,000	1,083,000	2,389,000	896,000	44,000	4,412,000	14,787,000	17,176,000
1920	13,185,000	2,312,000	15,497,000	1,083,000	2,395,000	896,000	44,000	4,418,000	11,079,000	13,474,000
1921	22,267,000	4,440,000	26,707,000	1,083,000	2,389,000	896,000	44,000	4,412,000	22,295,000	24,684,000
1922	20,033,000	6,997,000	27,030,000	1,083,000	2,389,000	896,000	44,000	4,412,000	22,618,000	25,007,000
1923	12,078,000	4,116,000	16,194,000	1,083,000	2,389,000	896,000	44,000	4,412,000	11,782,000	14,171,000
1924	7,485,000	1,108,000	8,593,000	1,083,000	2,395,000	896,000	44,000	4,418,000	4,175,000	6,570,000
1925	15,945,000	3,432,000	19,377,000	1,083,000	2,389,000	896,000	44,000	4,412,000	14,965,000	17,354,000
1926	16,104,000	2,190,000	18,294,000	1,083,000	2,389,000	896,000	44,000	4,412,000	13,882,000	16,271,000
1927	24,789,000	4,688,000	29,477,000	1,083,000	2,389,000	896,000	44,000	4,412,000	25,065,000	27,454,000
1928	17,312,000	3,295,000	20,607,000	1,083,000	2,395,000	896,000	44,000	4,418,000	16,189,000	18,584,000
Averages	16,563,000	3,535,000	20,098,000	1,083,000	2,391,000	896,000	44,000	4,414,000	15,684,000	18,075,000

[1] Includes regulated water from complete American River unit, Friant and existing reservoirs, unregulated run-off and return waters. The amounts shown for the San Joaquin Valley include such portions of these waters intercepted by the San Joaquin River pumping system before reaching the delta as could be used in supplying "crop land" rights in this valley, obviating the pumping of that portion of this supply from the delta.

[2] "Crop lands" are those areas suitable for growing crops which are now served or probably will be served in the near future by diversion from the San Joaquin River above the mouth of the Merced River under existing rights.

TABLE 155

MONTHLY DISTRIBUTION OF SURPLUS WATER IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH COMPLETE AMERICAN RIVER UNIT OPERATED AS AN INITIAL UNIT UNDER METHOD III

1919-1929

Month	Year of maximum run-off, 1927		Year of minimum run-off, 1924		Average for period 1919-1929	
	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet
January	2,527,000	2,730,000	599,000	802,000	1,780,000	1,983,000
February	7,215,000	7,399,000	1,082,000	1,272,000	3,192,000	3,378,000
March	3,826,000	4,029,000	469,000	672,000	2,636,000	2,839,000
April	4,164,000	4,360,000	247,000	443,000	2,516,000	2,712,000
May	2,806,000	3,009,000	0	203,000	2,086,000	2,289,000
June	1,739,000	1,935,000	0	196,000	906,000	1,102,000
July	0	203,000	0	203,000	27,000	230,000
August	0	203,000	0	203,000	0	203,000
September	0	196,000	0	196,000	1,000	197,000
October	254,000	457,000	204,000	407,000	254,000	457,000
November	1,342,000	1,538,000	699,000	895,000	962,000	1,158,000
December	1,192,000	1,395,000	875,000	1,078,000	1,324,000	1,527,000
Totals	25,065,000	27,454,000	4,175,000	6,570,000	15,684,000	18,075,000

TABLE 156

ANNUAL WATER REQUIREMENTS AND SURPLUS IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH PARTIAL AMERICAN RIVER UNIT OPERATED AS AN INITIAL UNIT UNDER METHOD 1

1919-1929

Year	Net flow into delta, in acre-feet[1]			Requirements from net flow into delta, in acre-feet				Surplus water above all requirements, in acre-feet	Total flow into Suisun Bay, in acre-feet
	From Sacramento Valley	From San Joaquin Valley	Total from both valleys	Total gross allowance for delta	Salinity control to lower end of delta	Industrial and irrigation use in developed areas along south side of Suisun Bay	Total		
1919	16,362,000	2,769,000	19,131,000	1,083,000	2,389,000	44,000	3,516,000	15,615,000	18,004,000
1920	13,279,000	2,312,000	15,591,000	1,083,000	2,395,000	44,000	3,522,000	12,069,000	14,464,000
1921	22,284,000	4,440,000	26,724,000	1,083,000	2,389,000	44,000	3,516,000	23,208,000	25,597,000
1922	20,049,000	6,997,000	27,046,000	1,083,000	2,389,000	44,000	3,516,000	23,530,000	25,919,000
1923	12,076,000	4,116,000	16,192,000	1,083,000	2,389,000	44,000	3,516,000	12,676,000	15,065,000
1924	6,905,000	1,108,000	8,013,000	1,083,000	2,395,000	44,000	3,522,000	4,491,000	6,886,000
1925	16,513,000	3,432,000	19,945,000	1,083,000	2,389,000	44,000	3,516,000	16,429,000	18,818,000
1926	16,001,000	2,190,000	18,191,000	1,083,000	2,389,000	44,000	3,516,000	14,675,000	17,064,000
1927	24,940,000	4,688,000	29,628,000	1,083,000	2,389,000	44,000	3,516,000	26,112,000	28,501,000
1928	17,233,000	3,295,000	20,528,000	1,083,000	2,395,000	44,000	3,522,000	17,006,000	19,401,000
Averages	16,564,000	3,535,000	20,099,000	1,083,000	2,391,000	44,000	3,518,000	16,581,000	18,972,000

[1] Includes regulated water from partial American River unit, Friant and existing reservoirs, unregulated run-off and return waters.

TABLE 157

MONTHLY DISTRIBUTION OF SURPLUS WATER IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH PARTIAL AMERICAN RIVER UNIT OPERATED AS AN INITIAL UNIT UNDER METHOD I

1919-1929

Month	Year of maximum run-off, 1927		Year of minimum run-off, 1924		Average for period 1919-1929	
	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet
January	2,585,000	2,788,000	618,000	821,000	1,799,000	2,002,000
February	7,336,000	7,520,000	1,118,000	1,308,000	3,240,000	3,426,000
March	3,878,000	4,081,000	517,000	720,000	2,704,000	2,907,000
April	4,317,000	4,513,000	370,000	566,000	2,682,000	2,878,000
May	2,968,000	3,171,000	0	203,000	2,253,000	2,456,000
June	1,905,000	2,101,000	0	196,000	1,044,000	1,240,000
July	65,000	268,000	0	203,000	77,000	280,000
August	0	203,000	0	203,000	8,000	211,000
September	54,000	250,000	0	196,000	42,000	238,000
October	281,000	484,000	241,000	444,000	283,000	486,000
November	1,525,000	1,721,000	723,000	919,000	1,107,000	1,303,000
December	1,198,000	1,401,000	904,000	1,107,000	1,342,000	1,545,000
Totals	26,112,000	28,501,000	4,491,000	6,886,000	16,581,000	18,972,000

TABLE 158

ANNUAL WATER REQUIREMENTS AND SURPLUS IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH PARTIAL AMERICAN RIVER UNIT OPERATED AS AN INITIAL UNIT UNDER METHOD II

1919-1929

Year	Net flow into delta, in acre-feet[1]			Requirements from net flow into delta, in acre-feet					Surplus water above all requirements, in acre-feet	Total flow into Suisun Bay, in acre-feet
	From Sacramento Valley	From San Joaquin Valley	Total from both valleys	Total gross allowance for delta	Salinity control to lower end of delta	Irrigation supply for "croplands" in San Joaquin Valley having rights to water to be diverted at Friant[2]	Industrial and irrigation use in developed areas along south side of Suisun Bay	Total		
1919	16,296,000	2,769,000	19,065,000	1,083,000	2,389,000	500,000	44,000	4,016,000	15,049,000	17,438,000
1920	13,327,000	2,312,000	15,639,000	1,083,000	2,395,000	500,000	44,000	4,022,000	11,617,000	14,012,000
1921	22,324,000	4,440,000	26,764,000	1,083,000	2,389,000	500,000	44,000	4,016,000	22,748,000	25,137,000
1922	20,051,000	6,997,000	27,048,000	1,083,000	2,389,000	500,000	44,000	4,016,000	23,032,000	25,421,000
1923	11,934,000	4,116,000	16,050,000	1,083,000	2,389,000	500,000	44,000	4,016,000	12,034,000	14,423,000
1924	6,989,000	1,108,000	8,097,000	1,083,000	2,395,000	343,000	44,000	3,865,000	4,232,000	6,627,000
1925	16,461,000	3,432,000	19,893,000	1,083,000	2,389,000	500,000	44,000	4,016,000	15,877,000	18,266,000
1926	16,162,000	2,190,000	18,352,000	1,083,000	2,389,000	500,000	44,000	4,016,000	14,336,000	16,725,000
1927	24,963,000	4,688,000	29,651,000	1,083,000	2,389,000	500,000	44,000	4,016,000	25,635,000	28,024,000
1928	17,157,000	3,295,000	20,452,000	1,083,000	2,395,000	500,000	44,000	4,022,000	16,430,000	18,825,000
Averages	16,566,000	3,535,000	20,101,000	1,083,000	2,391,000	484,000	44,000	4,002,000	16,099,000	18,490,000

[1] Includes regulated water from partial American River unit, Friant and existing reservoirs, unregulated run-off and return waters. The amounts shown for the San Joaquin Valley include such portions of these waters intercepted by the San Joaquin River pumping system before reaching the delta as could be used in supplying "crop land" rights in this valley, obviating the pumping of that portion of this supply from the delta.

[2] "Crop lands" are those areas suitable for growing crops which are now served or probably will be served in the near future by diversion from the San Joaquin River above the mouth of the Merced River under existing rights.

TABLE 159

MONTHLY DISTRIBUTION OF SURPLUS WATER IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH PARTIAL AMERICAN RIVER UNIT OPERATED AS AN INITIAL UNIT UNDER METHOD II

1919-1929

Month	Year of maximum run-off, 1927		Year of minimum run-off, 1924		Average for period 1919-1929	
	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet	Surplus water above all requirements, in acre-feet	Flow into Suisun Bay, in acre-feet
January	2,512,000	2,715,000	592,000	795,000	1,783,000	1,986,000
February	7,404,000	7,588,000	1,084,000	1,274,000	3,254,000	3,440,000
March	3,849,000	4,052,000	462,000	665,000	2,682,000	2,885,000
April	4,253,000	4,449,000	330,000	526,000	2,623,000	2,819,000
May	2,879,000	3,082,000	0	203,000	2,174,000	2,377,000
June	1,814,000	2,010,000	0	196,000	968,000	1,164,000
July	0	203,000	0	203,000	46,000	249,000
August	0	203,000	0	203,000	0	203,000
September	19,000	215,000	0	196,000	9,000	205,000
October	264,000	467,000	201,000	404,000	255,000	458,000
November	1,446,000	1,642,000	693,000	889,000	975,000	1,171,000
December	1,195,000	1,398,000	870,000	1,073,000	1,330,000	1,533,000
Totals	25,635,000	28,024,000	4,232,000	6,627,000	16,099,000	18,490,000

Comparison of Kennett Reservoir Unit and American River Units as Initial Developments.

Table 160 shows a financial comparison of the Kennett reservoir unit and American River units operated under the various methods described in this chapter. In this comparison, no deductions were made from the capital costs for possible direct contributions from the Federal government in the interests of navigation and flood control, or for similar contributions from the State for highway reconstruction or for other purposes, since the amounts of such contributions have not been determined. In obtaining the average net annual cost for each unit, the average annual revenue from the sale of electric energy output from that unit was deducted. A deduction, however, was not made for revenue from the sale of water.

The advantages of the American River unit over the Kennett reservoir unit are:

1. The capital investment for partial development would be $34,000,000 less and for complete development $15,500,000 less.
2. It could be constructed progressively.
3. The initial block of hydroelectric energy would be 48 per cent of that at Kennett, thus lessening the problem of power absorption.
4. It would be in a position to control floods on the American River to a degree that would greatly benefit the project of the American River Flood Control District and to a lesser extent the Sacramento Flood Control Project. With either the partial or complete unit, floods would be controlled to 100,000 second-feet or less, exceeded not oftener than one day in 250 years, on the average, whereas the crest flow of the March 25, 1928 flood was 184,000 second-feet.

TABLE 160

FINANCIAL COMPARISON OF KENNETT RESERVOIR UNIT AND AMERICAN RIVER UNITS FOR VARIOUS PLANS OF OPERATION

Unit	Stream	Height of dam, in feet	Storage capacity of reservoirs, in acre-feet	Installed capacity of power plants, in kilovolt amperes	Capital cost of reservoirs, dams, power plants and afterbays	Method of operation	Gross annual cost of operation	Average annual electric energy output, in kilowatt hours	Average annual revenue from sale of electric energy[1]	Average net annual cost not covered by revenue from sale of electric energy	Seasonal irrigation yield in new water, in acre-feet	Average net annual cost per acre-foot of new water
Kennett reservoir—including Keswick afterbay	Sacramento River	420	2,940,000	325,000	$84,000,000	I	$5,297,000	1,622,800,000	$4,414,000	$883,000	595,000	$1 48
						II	5,297,000	1,591,800,000	4,218,000	1,079,000	----------	----------
						III	5,297,000	1,581,100,000	3,826,000	1,471,000	----------	----------
						IV	5,297,000	1,285,000,000	2,480,000	2,817,000	2,850,000	99
Complete American River—Folsom, Auburn and Coloma reservoirs, including afterbay and power drops	American River	--------	1,952,000	295,000	68,500,000	I	4,484,000	1,052,400,000	3,441,000	1,043,000	524,000	1 99
						II	4,484,000	972,500,000	3,219,000	1,265,000	----------	----------
						III	4,484,000	951,700,000	2,779,000	1,705,000	----------	----------
						IV	4,484,000	898,800,000	2,301,000	2,183,000	1,656,000	1 32
Partial American River—Folsom and Auburn reservoirs, including afterbay and power drop	American River	--------	1,186,000	235,000	50,100,000	I	3,302,000	762,500,000	2,493,000	809,000	----------	----------
						II	3,302,000	730,000,000	1,828,000	1,474,000	----------	----------

[1] The estimated values of electric energy at the power plants are based on the cost of producing an equivalent amount of electric energy of the same characteristics with a steam-electric plant located in the area of consumption, taking into account the cost of transmission from point of generation to the load center, and are the lowest values resulting from several methods of evaluation.

5. Water would be released below all of the riparian lands in the Sacramento River Basin above the city of Sacramento. The riparian acreage along the American River is small.
6. No major improvements would be flooded and, therefore, there would be less interference with existing interests.
7. The partial development would have furnished a water supply, during the ten-year period 1919–1929, for present irrigation requirements in the Sacramento-San Joaquin Delta, for salinity control, and for immediate agricultural and industrial requirements along the south shore of Suisun Bay in Contra Costa County, at a net annual cost $270,000 less than the Kennett reservoir unit, if revenues from the sale of electric energy alone had been credited against the annual costs, and there had been no contributions toward the costs of the reservoirs by the Federal and State governments or other interests or agencies.

The advantages of the Kennett reservoir unit over the American River unit are:

1. It would be in a position to control floods on the Sacramento River, thus giving an added degree of protection to a large portion of the lands in the Sacramento Flood Control Project. Flows would be reduced to 125,000 second-feet mean daily flow on the day of the flood crest, measured at Red Bluff, exceeded once in fourteen years, on the average. The controlled flow exceeded once in 100 years, on the average, would be 187,000 second-feet due to the uncontrolled run-off between Kennett reservoir and Red Bluff, but flows in excess of 125,000 second-feet would be of short duration. The maximum flood flow of record at Red Bluff was 278,000 second-feet on February 3, 1909.
2. It would improve navigation facilities in the Sacramento River for 190 miles above the city of Sacramento.
3. It would furnish a full water supply to lands along the Sacramento River above Sacramento now under irrigation or having water rights. There would have been over 700,000 acre-feet more water available, distributed in accordance with the irrigation demand, for these lands in 1924. The sale of that portion of this supply which would be new water made available by the operation of the Kennett reservoir would provide a revenue which would decrease the net annual cost of the reservoir. No such revenue, or at least a very much smaller one, would be available to the American River unit from the sale of water along the American River.
4. It would have furnished a water supply, during the ten-year period 1919–1929, for present irrigation requirements in the Sacramento-San Joaquin Delta, for salinity control, and for immediate agricultural and industrial requirements along the south shore of Suisun Bay in Contra Costa County, and would have made available 896,000 acre-feet more water for irrigation in the San Joaquin Valley, at $234,000 less net annual cost than the complete American River unit, if revenues from the sale

of electric energy only had been credited against the gross annual cost and no contributions had been made toward the costs of the reservoirs by the Federal and State governments or other interests or agencies. Revenues from the sale of water for the foregoing uses would have been the same for the Kennett reservoir and complete American River units and therefore do not enter into their comparison.

5. It would have furnished a water supply, during the ten-year period 1919–1929, for delta, salinity control and immediate upper San Francisco Bay requirements and would have made available 896,000 acre-feet of water for irrigation in the San Joaquin Valley, at a net annual cost of $1,471,000, as compared to $1,474,000 for the partial American River unit, if revenues from the sale of electric energy alone had been credited against the gross annual costs. While the Kennett reservoir would have made available 896,000 acre-feet of water, without deficiency, for irrigation in the San Joaquin Valley, the partial American River unit would have made available only 500,000 acre-feet, with a deficiency of 31 per cent in 1924. The amounts of water furnished for the other uses would have been the same. If revenues from the sale of water for the foregoing uses had been deducted from the gross annual costs, the net annual cost would have been even more in favor of the Kennett reservoir unit. If there were no demand for eleven years or more for water from the Sacramento Valley for irrigation in the San Joaquin Valley, the American River unit would be the more economic unit to construct but if the water would be required in less than eleven years, the Kennett reservoir unit would be the better. This period of deferment is based on the average annual costs for a forty-year amortization period and average annual revenues from power estimated for the forty-year period 1889–1929.
6. Both navigation and flood control benefits would be greater than with the American River unit. On account of these greater benefits accruing to the general public, it would be reasonable to expect larger direct contributions toward the cost of the Kennett reservoir unit in the interest of navigation and flood control, than toward the cost of the American River unit.
7. It would develop one and three-fourths times as much new water as the American River unit, at three-fourths the cost per acre-foot, if the reservoirs were operated primarily for irrigation.

Selection of Unit for Initial Development.

After careful consideration of all the foregoing advantages and disadvantages of each unit and in view of the possibility that water, in addition to that necessary for initial uses, would be required for exportation to the San Joaquin Valley during the earlier years of operation of the plan, and of the greater benefits that would accrue to the greater number of interests, particularly irrigation, navigation and flood control from the construction of the Kennett reservoir, it is believed the first development under the State Water Plan in the Sacramento River Basin should be the Kennett reservoir unit with a 420-foot Kennett dam.

Financial Aspects of Kennett Reservoir Unit.

The foregoing financial analyses of the Kennett reservoir unit have been made on the basis of interest at 4½ per cent per annum, amortization of capital investment in 40 years, and revenues from the sale of electric energy only. No allowances were made for possible direct contributions without repayment from the Federal and State governments, or possible revenues from the sale of stored water. It may be noted that on this basis the unit is not economically feasible. For the unit to be financially feasible, the annual cost must be reduced. This can be accomplished by lowering the rate of interest, extending the period of amortization of capital investment, or by obtaining such direct contributions to the cost of the unit, without repayment, as may be justified by National and State benefits, or the annual cost may be reduced by a combination of these methods.

It is possible that in financing the unit, funds could be borrowed at a lower rate of interest, particularly if arrangements were made for a loan from the Federal government. It is possible also that the State could obtain money at an interest rate less than 4½ per cent. For the purpose of illustrating the effect interest rates, both higher and lower than 4½ per cent, would have on the capital and gross and net annual costs of the initial development of the Kennett Reservoir unit, Table 161 has been prepared. The gross annual costs comprise amounts for operation and maintenance, depreciation, and amortization of the capital investment in 40 years on a 4 per cent sinking fund basis, in addition to those for interest. The effect of extending the amortization period from 40 years to 50, 60, and 70 years in reducing the annual costs also is illustrated by the figures presented in the table. The present legal limitation for State bond issues is 75 years.

Direct revenues from the unit would be derived from the sale of hydroelectric energy and water. While it is uncertain as to the amount of stored water which could be sold immediately upon the completion of the project, and the price that could be obtained, it is estimated that a revenue of at least $400,000 annually should be obtained from the sale of this water in the Sacramento Valley and Sacramento-San Joaquin Delta alone. No deductions have been made for this possible revenue, however, in obtaining the net annual costs in Table 161. The estimated average annual revenue from the sale of the electric energy at the switchboard, with the unit operated under the conditions of the immediate initial development of the State Water Plan, would be $4,218,000.

It is also anticipated that there would be direct contributions toward the cost of the unit by the Federal and State governments, of the amounts justified by National and State benefits. Due to the fact that it is not definitely known at this time what these contributions would be, no deductions have been made from the capital costs shown in Table 161 in calculating the annual costs. However, the Chief of Engineers, United States War Department, has recommended * that the Federal government contribute $6,000,000 to the cost of the Kennett reservoir unit in the interest of navigation and it is generally considered that the State would relocate, at an estimated cost of $3,400,000,

* House Document 791, 71st Congress, 3d Session.

TABLE 161

CAPITAL AND ANNUAL COSTS OF KENNETT RESERVOIR UNIT

Immediate Initial Development

Kennett Reservoir—
Height of dam, 420 feet
Capacity of reservoir, 2,940,000 acre-feet
Installed capacity of power plant, 275,000 kilovolt amperes

Keswick Afterbay—
Height of dam, 95 feet
Capacity of reservoir, 14,000 acre-feet
Installed capacity of power plant, 50,000 kilovolt amperes

Item	Interest rate, in per cent					
	6	5	4½	4	3½	3
Capital cost	$87,200,000	$85,100,000	$84,000,000	$82,900,000	$81,900,000	$80,800,000
Gross annual cost (40-year, 4 per cent sinking fund amortization) [1]	$6,807,000	$5,792,000	$5,297,000	$4,813,000	$4,475,000	$4,106,000
Revenue from sale of electric energy	4,218,000	4,218,000	4,218,000	4,218,000	4,218,000	4,218,000
Net annual cost in excess of revenue	$2,589,000	$1,574,000	$1,079,000	$595,000	$257,000	[2]$112,000
Gross annual cost (50-year, 4 per cent sinking fund amortization) [1]	$6,462,000	$5,456,000	$4,965,000	$4,486,000	$4,131,000	$3,752,000
Revenue from sale of electric energy	4,218,000	4,218,000	4,218,000	4,218,000	4,218,000	4,218,000
Net annual cost in excess of revenue	$2,244,000	$1,238,000	$747,000	$268,000	[2]$87,000	[2]$466,000
Gross annual cost (60-year, 4 per cent sinking fund amortization) [1]	$6,257,000	$5,256,000	$4,768,000	$4,291,000	$3,923,000	$3,530,000
Revenue from sale of electric energy	4,218,000	4,218,000	4,218,000	4,218,000	4,218,000	4,218,000
Net annual cost in excess of revenue	$2,039,000	$1,038,000	$550,000	$73,000	[2]$295,000	[2]$688,000
Gross annual cost (70-year, 4 per cent sinking fund amortization) [1]	$6,131,000	$5,133,000	$4,646,000	$4,171,000	$3,789,000	$3,386,000
Revenue from sale of electric energy	4,218,000	4,218,000	4,218,000	4,218,000	4,218,000	4,218,000
Net annual cost in excess of revenue	$1,913,000	$915,000	$428,000	[2]$47,000	[2]$429,000	[2]$832,000

[1] For interest rates of 3½ and 3 per cent on capital investment, the sinking fund interest rate is assumed as 3½ and 3 per cent, respectively.
[2] Net annual revenue in excess of cost.

the State highway through the reservoir site without charge to the project. If these amounts were deducted from the capital costs, the annual costs shown in the table would be reduced by $323,000 to $663,000, depending upon the rate of interest and the amortization period.

In calculating the net annual costs set forth in Table 161, deductions were made only for revenues from the sale of the hydroelectric energy. With this revenue only, the unit could be financed with an interest rate of four per cent and amortization in a 70-year period on a four per cent sinking fund basis. If there were direct contributions by the Federal and State governments and deductions were made for revenues from the sale of water, the project could be financed on a higher rate of interest, a shorter period of amortization, or both.

Distribution of Releases from Kennett Reservoir Operated as an Initial Unit of the State Water Plan.

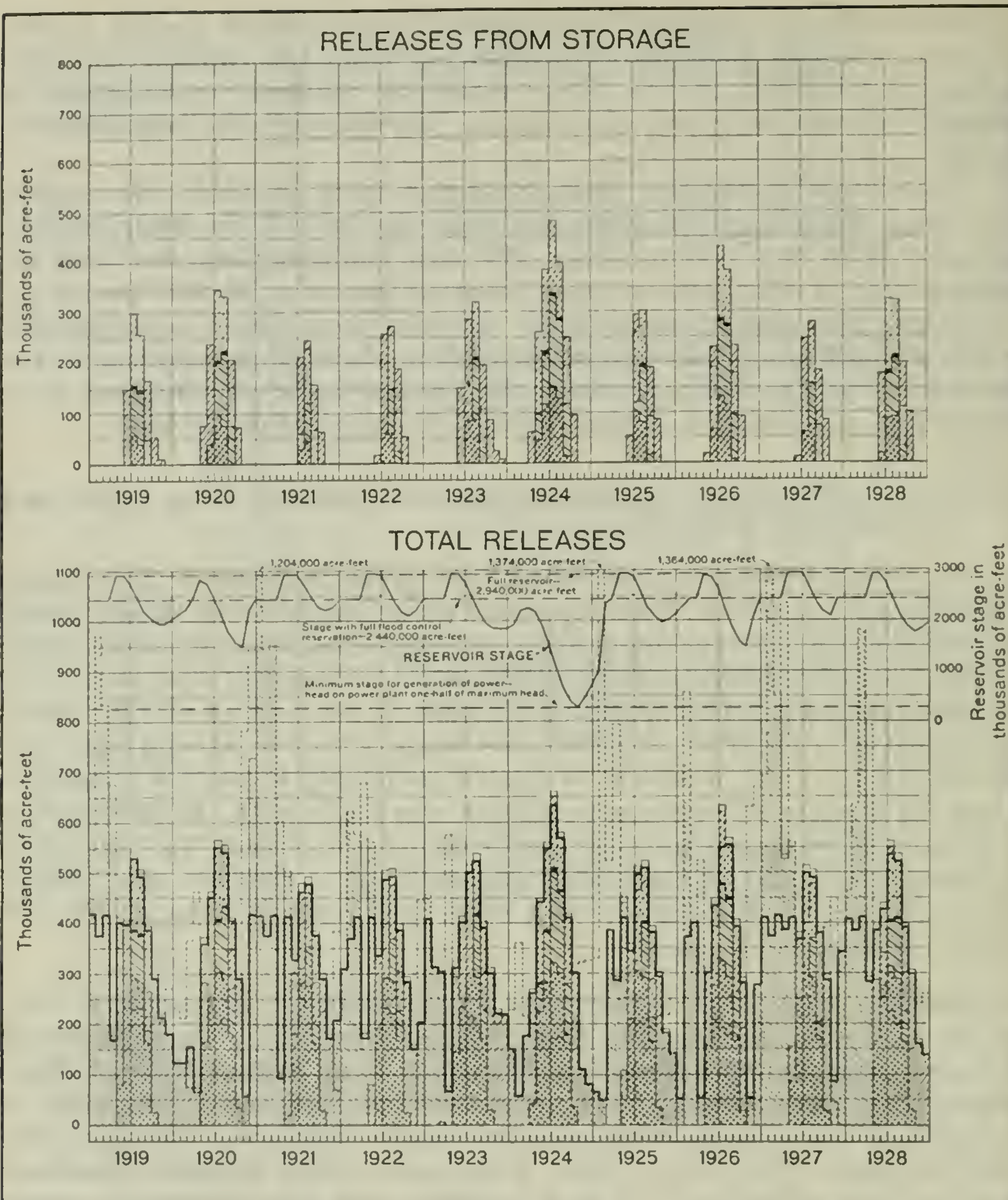
In order to obtain a clear conception of the portions of the releases from Kennett reservoir, when operated as an initial unit, which would be used for each of the immediate requirements, analyses were made for the reservoir operating under Method III, previously described, with two assumptions as to the priority of use of the waters of the Sacramento River. The first analysis was made with the assumption that the flow of the river would be dedicated primarily to use for irrigation along the stream. The second analysis was made with the assumption that navigation would have a prior right to the stream flow and that it, therefore, would be dedicated primarily to navigation use. Many other analyses could be made with other assumptions as to priority of use or as to order of rights.

Distribution of Releases with Stream Flow Dedicated Primarily to Irrigation Along the Sacramento River.—On Plate LIV, "Distribution of Releases from Kennett Reservoir Operated as an Initial Unit of State Water Plan Under Method III—Stream Flow Dedicated Primarily to Irrigation," two graphs of releases are shown. The lower one shows the total releases which would have been made from Kennett reservoir operated under Method III and includes both the releases of water flowing directly through the reservoir, and water from storage when the drafts would have been greater than the stream discharge. The upper graph shows the distribution of the drafts on stored water only.

In obtaining the data for the construction of these graphs, it was assumed that the rights to or uses of the water released from the reservoir would have had the following order:

1. Irrigation along the Sacramento River above Sacramento.
2. Irrigation in the Sacramento-San Joaquin Delta, and salinity control.
3. Irrigation and industrial uses in the developed area along the south shore of Suisun Bay in Contra Costa County.
4. Irrigation in the San Joaquin Valley.
5. Maintenance of navigation on the Sacramento River.
6. Maintenance of electric energy output in months in which no water was released for any of the above purposes.

PLATE LIV



DISTRIBUTION OF RELEASES FROM KENNETT RESERVOIR

OPERATED AS AN INITIAL UNIT OF STATE WATER PLAN UNDER METHOD III

STREAM FLOW DEDICATED PRIMARILY TO IRRIGATION

LEGEND

1. Releases for irrigation along Sacramento River above Sacramento
2. Releases for irrigation in Sacramento-San Joaquin delta and salinity control
3. Releases for irrigation and industrial uses in developed area along south shore of Suisun Bay in Contra Costa County
4. Releases for exportation to San Joaquin Valley for irrigation
5. Releases for maintenance of navigation on Sacramento River.
6. Releases for maintenance of electric energy output when no water was released for other purposes

- Releases to maintain reserve storage space for flood control, and spill
- Losses by evaporation
- Discharge of Sacramento River at Kennett dam site
- Water used for generation of electric energy

NOTE: The assumed priority of the use of water and right to stream flow, are indicated by the numbers opposite the conventions

In addition to the above releases, sufficient water would have been released, when necessary, to maintain the reserve storage space required for flood control. This release might be considered as prior to that for irrigation along the Sacramento River in the foregoing order of uses or rights, since the flood control reserve space would be maintained every year.

The releases shown in the upper graph on Plate LIV were obtained by deducting the discharges of the Sacramento River at the Kennett dam site from the releases shown by the lower graph. In constructing this graph, the stream discharge was deducted from the total releases in the order of priorities given in the foregoing list. The water available in the delta from the San Joaquin Valley was assumed to be used for delta and salinity control requirements rather than for transportation back up the San Joaquin River for the irrigation of the "crop lands."

The amount of water shown for evaporation is an operating loss, and, of course, is not a reservoir release although it is shown with the other releases on the graph.

The amounts of spill and flood control releases are plotted on the graphs to show how much water would have wasted past the dam due to a full reservoir or on account of the reservoir being maintained at flood control stage. Some of this water would have been utilized for the generation of electric energy. The amounts of water used for power, both spill and all releases, are shown on the graphs on Plate LIV by the areas below the heavy black line.

The releases which are shown graphically on Plate LIV also are set up in tabular form in Tables 162 and 163. These tables show the annual releases for each purpose in acre-feet and in per cent of the total water leaving the reservoir excepting spill, flood control release, and evaporation losses, in the same year.

TABLE 162

DISTRIBUTION OF TOTAL RELEASES FROM KENNETT RESERVOIR OPERATED AS AN INITIAL UNIT OF STATE WATER PLAN UNDER METHOD III

Stream flow dedicated primarily to irrigation

Year	Total releases for												Total releases, in acre-feet
	Irrigation along Sacramento River above Sacramento		Irrigation in delta, and salinity control		Irrigation and industrial use along south shore of Suisun Bay		Exportation to San Joaquin Valley for irrigation		Maintenance of navigation on Sacramento River		Maintenance of electric energy output		
	In acre-feet	In per cent of total	In acre-feet	In per cent of total	In acre-feet	In per cent of total	In acre-feet	In per cent of total	In acre-feet	In per cent of total	In acre-feet	In per cent of total	
1919	1,069,000	39.2	225,000	8.3	7,000	0.3	327,000	12.0	1,095,000	40.2	0	0	2,723,000
1920	1,229,000	40.2	340,000	11.1	10,000	0.3	327,000	10.7	1,097,000	35.8	57,000	1.9	3,060,000
1921	953,000	42.3	122,000	5.4	0	0	214,000	9.5	966,000	42.8	0	0	2,255,000
1922	962,000	42.9	146,000	6.5	0	0	185,000	8.2	951,000	42.4	0	0	2,244,000
1923	1,173,000	40.7	179,000	6.2	5,000	0.2	185,000	6.4	1,340,000	46.5	0	0	2,882,000
1924	1,389,000	36.8	596,000	15.8	19,000	0.5	649,000	17.2	1,124,000	29.7	0	0	3,777,000
1925	1,063,000	40.9	173,000	6.7	5,000	0.2	327,000	12.6	910,000	35.0	120,000	4.6	2,598,000
1926	1,253,000	45.3	397,000	14.4	10,000	0.4	449,000	16.2	495,000	17.9	160,000	5.8	2,764,000
1927	1,141,000	50.9	114,000	5.1	0	0	268,000	12.0	717,000	32.0	0	0	2,240,000
1928	1,241,000	44.6	264,000	9.5	10,000	0.4	392,000	14.1	874,000	31.4	0	0	2,781,000
Averages	1,147,000	42.0	256,000	9.4	6,000	0.2	332,000	12.2	957,000	35.0	34,000	1.2	2,732,000

TABLE 163

DISTRIBUTION OF RELEASES OF STORED WATER FROM KENNETT RESERVOIR OPERATED AS AN INITIAL UNIT OF STATE WATER PLAN UNDER METHOD III

Stream flow dedicated primarily to irrigation

Year	Releases from storage for												Total releases from storage, in acre-feet
	Irrigation along Sacramento River above Sacramento		Irrigation in delta, and salinity control		Irrigation and industrial use along south shore of Suisun Bay		Exportation to San Joaquin Valley for irrigation		Maintenance of navigation on Sacramento River		Maintenance of electric energy output		
	In acre-feet	In per cent of total	In acre-feet	In per cent of total	In acre-feet	In per cent of total	In acre-feet	In per cent of total	In acre-feet	In per cent of total	In acre-feet	In per cent of total	
1919	102,000	10.8	198,000	21.0	7,000	0.8	297,000	31.5	338,000	35.9	0	0	942,000
1920	222,000	17.3	318,000	24.8	10,000	0.8	327,000	25.6	403,000	31.5	0	0	1,280,000
1921	74,000	10.9	76,000	11.1	0	0	204,000	29.9	328,000	48.1	0	0	682,000
1922	123,000	15.6	112,000	14.2	0	0	185,000	23.4	370,000	46.8	0	0	790,000
1923	170,000	15.9	151,000	14.1	5,000	0.5	185,000	17.3	559,000	52.2	0	0	1,070,000
1924	452,000	23.5	596,000	30.9	19,000	1.0	649,000	33.7	211,000	10.9	0	0	1,927,000
1925	179,000	19.5	141,000	15.3	5,000	0.5	327,000	35.5	269,000	29.2	0	0	921,000
1926	319,000	23.1	397,000	28.7	10,000	0.7	449,000	32.5	208,000	15.0	0	0	1,383,000
1927	138,000	17.2	80,000	9.9	0	0	268,000	33.3	318,000	39.6	0	0	804,000
1928	204,000	18.2	238,000	21.2	10,000	0.9	392,000	35.0	276,000	24.7	0	0	1,120,000
Averages	198,000	18.2	231,000	21.2	6,000	0.6	328,000	30.0	328,000	30.0	0	0	1,092,000

Distribution of Releases with Stream Flow Dedicated Primarily to Maintenance of Navigation on Sacramento River.—On Plate LV, "Distribution of Releases from Kennett Reservoir Operated as an Initial Unit of State Water Plan Under Method III—Stream Flow Dedicated Primarily to Navigation," there are two graphs similar to those on Plate LIV. These graphs also show releases from Kennett reservoir under Method III of operation as an initial unit, but with a different assumption as to the priority of rights to or uses of the released water.

In obtaining the data for the construction of these graphs, the order of rights to or uses of water released from the reservoir was assumed as follows:

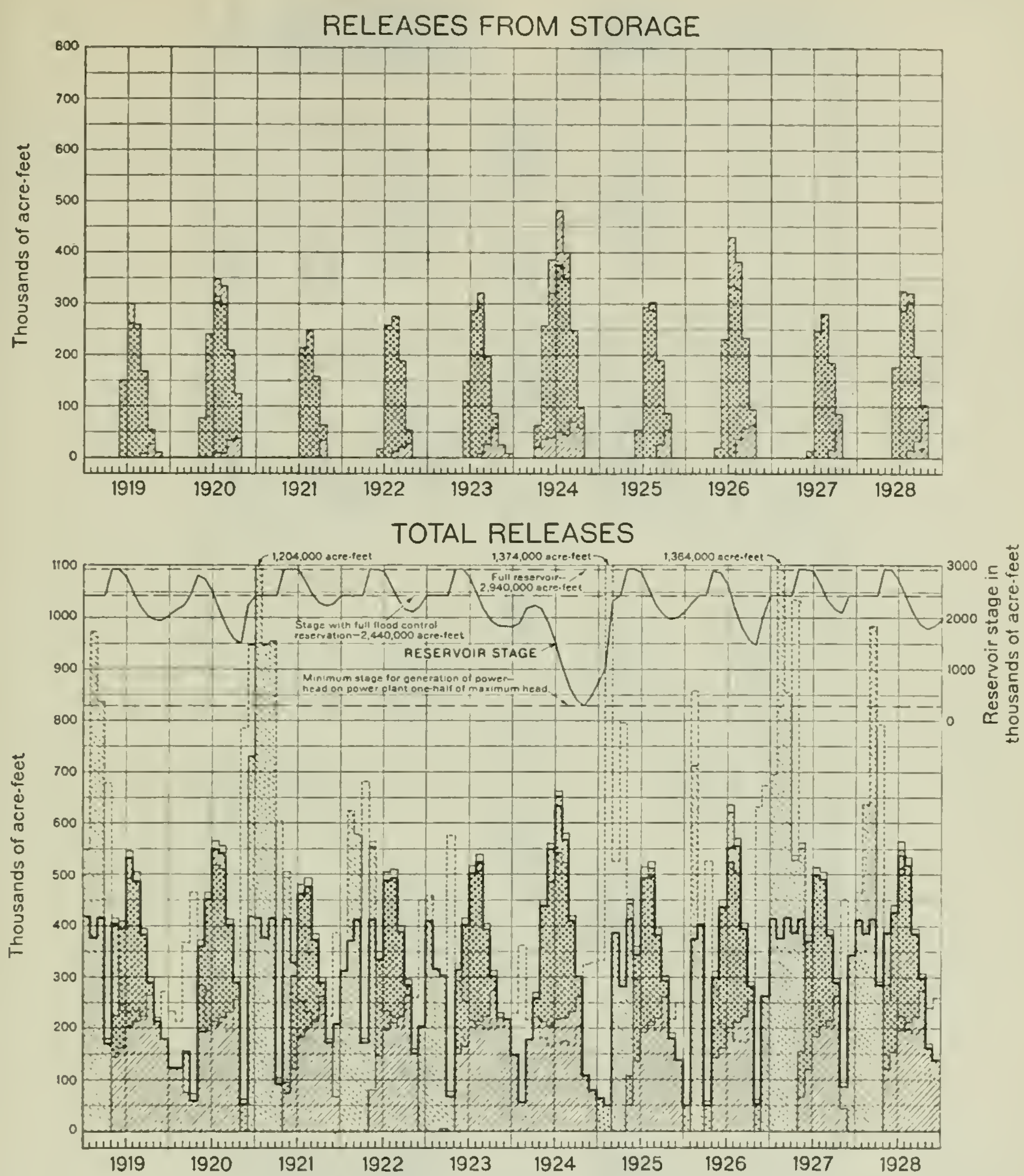
1. Maintenance of navigation on the Sacramento River.
2. Irrigation along the Sacramento River above Sacramento.
3. Irrigation in the Sacramento-San Joaquin Delta, and salinity control.
4. Irrigation and industrial uses in the developed area along the south shore of Suisun Bay in Contra Costa County.
5. Irrigation in the San Joaquin Valley.
6. Maintenance of electric energy output in months in which no water was released for any of the above purposes.

The other statements made in the description of the distribution of releases with the stream flow dedicated primarily to irrigation along the Sacramento River also apply to the graphs and tables with the releases assumed to have the priorities given in the foregoing paragraph.

The releases with the foregoing assumption of priorities of uses are shown in tabular form in Tables 164 and 165. These tables show the annual releases for each purpose in acre-feet and in per cent of the total water leaving the reservoir excepting spill, flood control release, and evaporation losses, in the same year.

Relation of Releases, Spill and Waste.—A comparison of the total amounts of water released for the uses shown in Tables 162 and 164, to the total amounts of spill and flood control release, is shown in Table 166. This table also shows how much of the spill and flood control release is utilized for the generation of electric energy, how much is wasted, and the total amounts of water wasted through spill, flood control releases and evaporation. The amounts shown in this table remain the same no matter what the order of priorities of use of released water may be.

PLATE LV



DISTRIBUTION OF RELEASES FROM
KENNETT RESERVOIR
OPERATED AS AN INITIAL UNIT OF STATE WATER PLAN
UNDER METHOD III

STREAM FLOW DEDICATED PRIMARILY TO NAVIGATION

LEGEND

1 Releases for maintenance of navigation on Sacramento River.

2 Releases for irrigation along Sacramento River above Sacramento.

3 Releases for irrigation in Sacramento-San Joaquin delta and salinity control.

4 Releases for irrigation and industrial uses in developed area along south shore of Suisun Bay in Contra Costa County

Discharge of Sacramento River at Kennett dam site.

5 Releases for exportation to San Joaquin Valley for irrigation.

6 Releases for maintenance of electric energy output when no water was released for other purposes.

Releases to maintain reserve storage space for flood control and spill.

Losses by evaporation.

Water used for generation of electric energy.

NOTE The assumed priority of the use of water and right to stream flow, are indicated by the numbers opposite the conventions.

TABLE 164

DISTRIBUTION OF TOTAL RELEASES FROM KENNETT RESERVOIR OPERATED AS AN INITIAL UNIT OF STATE WATER PLAN UNDER METHOD III

Stream flow dedicated primarily to navigation

Year	Total releases for												Total releases, in acre-feet
	Maintenance of navigation on Sacramento River		Irrigation along Sacramento River above Sacramento		Irrigation in delta, and salinity control		Irrigation and industrial use along south shore of Suisun Bay		Exportation to San Joaquin Valley for irrigation		Maintenance of electric energy output		
	In acre-feet	In per cent of total	In acre-feet	In per cent of total	In acre-feet	In per cent of total	In acre-feet	In per cent of total	In acre-feet	In per cent of total	In acre-feet	In per cent of total	
1919	1,613,000	59.2	1,069,000	39.3	0	0	0	0	41,000	1.5	0	0	2,723,000
1920	1,707,000	55.8	1,229,000	40.2	0	0	0	0	67,000	2.2	57,000	1.8	3,060,000
1921	1,302,000	57.7	953,000	42.3	0	0	0	0	0	0	0	0	2,255,000
1922	1,282,000	57.1	962,000	42.9	0	0	0	0	0	0	0	0	2,244,000
1923	1,689,000	58.6	1,173,000	40.7	0	0	0	0	20,000	0.7	0	0	2,882,000
1924	2,164,000	57.3	1,389,000	36.8	0	0	0	0	224,000	5.9	0	0	3,777,000
1925	1,402,000	54.0	1,063,000	40.9	0	0	0	0	13,000	0.5	120,000	4.6	2,598,000
1926	1,201,000	43.5	1,253,000	45.3	0	0	0	0	150,000	5.4	160,000	5.8	2,764,000
1927	1,099,000	49.1	1,141,000	50.9	0	0	0	0	0	0	0	0	2,240,000
1928	1,485,000	53.4	1,241,000	44.6	0	0	0	0	55,000	2.0	0	0	2,781,000
Averages	1,494,000	54.7	1,147,000	42.0	0	0	0	0	57,000	2.1	34,000	1.2	2,732,000

TABLE 165

DISTRIBUTION OF RELEASES OF STORED WATER FROM KENNETT RESERVOIR OPERATED AS AN INITIAL UNIT OF STATE WATER PLAN UNDER METHOD III

Stream flow dedicated primarily to navigation

Year	Releases from storage for												Total releases from storage, in acre-feet
	Maintenance of navigation on Sacramento River		Irrigation along Sacramento River above Sacramento		Irrigation in delta, and salinity control		Irrigation and industrial use along south shore of Suisun Bay		Exportation to San Joaquin Valley for irrigation		Maintenance of electric energy output		
	In acre-feet	In per cent of total	In acre-feet	In per cent of total	In acre-feet	In per cent of total	In acre-feet	In per cent of total	In acre-feet	In per cent of total	In acre-feet	In per cent of total	
1919	45,000	4.8	856,000	90.9	0	0	0	0	41,000	4.3	0	0	942,000
1920	91,000	7.1	1,122,000	87.7	0	0	0	0	67,000	5.2	0	0	1,280,000
1921	33,000	4.8	649,000	95.2	0	0	0	0	0	0	0	0	682,000
1922	60,000	7.6	730,000	92.4	0	0	0	0	0	0	0	0	790,000
1923	120,000	11.2	930,000	86.9	0	0	0	0	20,000	1.9	0	0	1,070,000
1924	314,000	16.3	1,389,000	72.1	0	0	0	0	224,000	11.6	0	0	1,927,000
1925	76,000	8.3	832,000	90.3	0	0	0	0	13,000	1.4	0	0	921,000
1926	156,000	11.3	1,077,000	77.9	0	0	0	0	150,000	10.8	0	0	1,383,000
1927	69,000	8.6	735,000	91.4	0	0	0	0	0	0	0	0	804,000
1928	118,000	10.5	947,000	84.6	0	0	0	0	55,000	4.9	0	0	1,120,000
Averages	108,000	9.9	927,000	84.9	0	0	0	0	57,000	5.2	0	0	1,092,000

TABLE 166

RELATION OF RELEASES, SPILL AND WASTE FROM KENNETT RESERVOIR OPERATED AS AN INITIAL UNIT OF STATE WATER PLAN UNDER METHOD III

Year	Total release for uses shown in Tables 162 and 164		Spill and flood control release						Total waste from spill and evaporation		Total water leaving reservoir in acre-feet	Total inflow to reservoir in acre-feet
			Total		Utilized for power		Wasted					
	In acre-feet	In per cent of water leaving reservoir	In acre-feet	In per cent of water leaving reservoir	In acre-feet	In per cent of water leaving reservoir	In acre-feet	In per cent of water leaving reservoir	In acre-feet	In per cent of water leaving reservoir		
1919	2,723,000	49.5	2,708,000	49.2	1,559,000	28.3	1,149,000	20.9	1,222,000	22.2	5,504,000	5,097,000
1920	3,060,000	77.7	809,000	20.6	496,000	12.6	313,000	8.0	380,000	9.7	3,936,000	4,343,000
1921	2,255,000	37.0	3,768,000	61.7	1,790,000	29.3	1,978,000	32.4	2,054,000	33.7	6,099,000	6,099,000
1922	2,244,000	47.9	2,368,000	50.5	1,809,000	38.6	559,000	11.9	634,000	13.5	4,687,000	4,687,000
1923	2,882,000	69.9	1,169,000	28.4	1,120,000	27.2	49,000	1.2	122,000	3.0	4,124,000	3,498,000
1924	3,777,000	98.8	0	0	0	0	0	0	45,000	1.2	3,822,000	2,726,000
1925	2,598,000	70.7	1,005,000	27.3	977,000	26.6	28,000	0.7	102,000	2.8	3,677,000	5,064,000
1926	2,764,000	65.6	1,381,000	32.8	1,044,000	24.8	337,000	8.0	406,000	9.6	4,214,000	4,551,000
1927	2,240,000	34.2	4,226,000	64.6	2,242,000	34.3	1,984,000	30.3	2,059,000	31.5	6,541,000	6,541,000
1928	2,781,000	52.2	2,471,000	46.4	1,597,000	30.0	874,000	16.4	947,000	17.8	5,325,000	4,844,000
Averages	2,732,000	57.0	1,991,000	41.6	1,264,000	26.4	727,000	15.2	797,000	16.6	[1] 4,793,000	[1] 4,745,000

[1] Excess of 480,000 acre-feet in draft over inflow is amount of reduction of water in storage at beginning and end of ten-year period.

CHAPTER XII

RELATION OF STATE WATER PLAN TO HYDRAULIC MINING IN SACRAMENTO RIVER BASIN

Debris storage in certain major reservoir units of the State Water Plan in the Sacramento River Basin would afford an opportunity for the resumption of mining of the auriferous gravels in the foothills of the Sierra Nevada by the hydraulic process. The operation of this large and important industry was prohibited by Federal court order in 1884 because it was in conflict with the farming activities in the Great Central Valley and with navigation on the major streams. Large volumes of gravel and debris were discharged into the stream channels and during flood periods were carried into the navigable channels and onto improved farm lands in the valley. Farm property along and navigability of the rivers were destroyed. Later congressional acts permitted the industry to be resumed under certain restrictions. One of those restrictions was that adequate and dependable facilities must be provided for the permanent storage of the debris above the valley floor. It has been estimated that there are remaining in the Feather, Yuba, Bear, and American river watersheds more than 1000 million cubic yards of gold-bearing gravels which could be mined by the hydraulic process if adequate water supplies were available and facilities provided for the storage of the debris.

The major reservoir units proposed on the Feather, Yuba, Bear and American rivers are strategically located both geographically and topographically for utilization in the storing of mining debris, if such procedure should be proven warranted and economically justified.

History of Early Hydraulic Mining.

In the early days of gold mining in California, the attention of the miners centered on rich sand and gravel bars along the beds of streams. After these bars were worked out, efforts were directed toward the extraction of gold from the banks of the streams and the auriferous gravels where they were exposed by erosion in the mountain canyons. These immense gold-bearing gravel beds are the channels of prehistoric rivers whose courses had been changed by upheavals so that now the modern stream channels follow entirely different courses. During the period when thousands of men were engaged working with pick, shovel, pan and rocker in the stream channels, the total amount of material displaced was small and the addition to the debris carried by the streams from natural erosion was negligible and passed unnoticed down the channels. Mining of the older bars and banks and the auriferous gravels in the buried channels of ancient streams involved the movement of increasing volumes of material. Engineering science and resource solved the problem of the miner by introducing the use of water under pressure, the beginning of hydraulic mining, which was defined by

Judge Lorenzo Sawyer in his opinion in the Case of Woodruff vs. North Bloomfield Gravel Mining Company and others, on January 7, 1884, as

> " * * * the process by which a bank of gold-bearing earth and rock is excavated by a jet of water, discharged through the converging nozzle of a pipe, under great pressure, the earth and debris being carried away by the same water, through sluices, and discharged on lower levels into the natural streams and water courses below."

Evolution of the process from the crude apparatus of wooden nozzles and canvas hose first used in 1853 to the hydraulic giant was rapid. Within a decade hydraulic mining had grown to colossal proportions. Millions of cubic yards of earth, sand, and gravel were washed down from the hillsides into the mountain stream channels. Recurrent winter floods laden with this debris caused ever-increasing annoyance and damage to farmers on the low lands along the streams on the valley floor. Then came the great flood of 1862 which brought down from the hills vast quantities of the accumulated debris from several years of mining operations. This debris choked the river channels far down their courses through the valley floor and buried the richest bottom and orchard lands along the Bear and Yuba rivers under deep deposits of sand and gravel.

Opposition to hydraulic mining was carried into the courts. Not until the early 70's, however, did this opposition grow into concerted action. At that time, the farmers of Sutter, Yuba, Sacramento, Yolo, and other valley counties organized the Anti-Debris Association for the purpose of making a united fight in the courts against hydraulic mining. They were opposed by the California Miners Association, and between these groups a bitter legal conflict was carried on for a decade in the State courts. Finally the litigation was carried into the United States courts by the filing of a suit by a man named Woodruff, a farm land owner, against the North Bloomfield Gravel Mining Company and others, the same case referred to in a foregoing paragraph, to enjoin the defendants from discharging their mining debris into streams leading into the Yuba River and thence into the Sacramento Valley. In handing down his decision or opinion Judge Sawyer stated as follows:

> "After an examination of the great questions involved, as careful and thorough as we are capable of giving them, with a painfully anxious appreciation of the responsibilities resting upon us, and of the disastrous consequences to the defendants, we can come to no other conclusion than that complainant is entitled to a perpetual injunction. But as it is possible that some mode may be devised in the future for obviating the injuries, either one of those suggested or some other, and successfully carried out, so as to be both safe and effective, a clause will be inserted in the decree giving leave on any future occasion, when some such plan has been successfully executed, to apply to the court for a modification or suspension of the injunction.
>
> "Let a decree be entered accordingly."

Judge Sawyer's decision, just quoted, closed down the mines of all defendants mentioned in the suit, but it was several years before the valley farmers through the Anti-Debris Association were able to secure injunctions closing down all of the hydraulic mines in the Sacramento and San Joaquin river watersheds which were operating without means of restraining their debris.

Efforts to Control Movement of Debris and Restore Hydraulic Mining.

Paralleling the prolonged litigation carried on between the farming and mining interests, impartial investigations were made by a number of Commissions and officials of the Federal and State governments of the damage by and methods of controlling the movement of hydraulic mining debris. In 1880, William Ham Hall, then State Engineer, made a report on "The Flow of Mining Detritus." In the same year, under congressional authority, an investigation was made by Lieut. Col. George H. Mendell, of the United States Engineer Corps, his final report* being published in 1882. In 1888, a commission of three Army engineers under Lieut. Col. W. H. H. Benyaurd began a more intensive study of the entire subject.

The findings** of the commission headed by Col. Benyaurd, filed in 1891, resulted in the passage by Congress in 1893 of the so-called Caminetti Act, the actual title being, "An act to create the California Debris Commission and regulate hydraulic mining in the State of California." This act created the California Debris Commission, to be composed of three officers of the corps of engineers, United States Army, appointed by the President with the approval of the Senate. It charged the commission with the duties of making surveys of the streams of the Great Central Valley; devising plans for the control of floods, the control of the movement of mining debris, and the restoration of the navigable channels of the Sacramento and San Joaquin valleys to the condition that obtained in the year 1860; and making studies of practical methods whereby hydraulic mining might be resumed. A commission was appointed in accord with the provisions of the act. It has been and now is an active and functioning body. It has jurisdiction over all hydraulic mining on the watersheds tributary to the Great Central Valley and has power to grant licenses to carry on hydraulic mining behind restraining dams, to survey sites for debris dams, and, when funds are available, to erect such dams for impounding mining debris.

Debris Restraining Works.—The activities of the California Debris Commission in controlling the movement of mining debris have been confined to the vast deposits in the lower Yuba River. Plans were made to construct a series of four barriers on that river to prevent the movement of the deposits into the Feather River. The first barrier, located one mile below Parks Bar Bridge was completed in 1905 but was destroyed by the flood of March, 1907. A second barrier was then constructed at Daguerre Point near Hammonton. No others have been built. The volume of the debris in the deposits in the lower Yuba River was given by Grove K. Gilbert*** in 1914 as 330,000,000 cubic yards. Of this quantity, Gilbert estimated that 140,000,000 cubic yards were permanently impounded by the barrier and training walls of the Daguerre Point works and between 110,000,000 and 190,000,000 cubic yards would eventually pass into the Feather River channel. The cost of the debris

* Ex. Doc. 98, House, 47th Congress, 1st Session.
** Ex. Doc. 267, House, 51st Congress, 2d Session.
*** Hydraulic Mining Debris in the Sierra Nevada," United States Geological Survey, Professional Paper 105.

restraining works constructed by the California Debris Commission on the Yuba River has been contributed in practically equal amounts by the Federal government and the State of California and up to December 31, 1930, had amounted to about $920,000. Considerable work also has been done by the gold dredging companies in constructing training walls and rock levies which have been a material aid in restraining the debris.

In addition to the works constructed by the Debris Commission on the Yuba River, considerable money has been expended by the State in an attempt to restrain the debris both on the Yuba and Bear rivers. In the year 1881, dams were built across the Yuba two miles below Daguerre Point, and across the Bear at Johnson's old crossing about three miles upstream from Wheatland. These dams were built of trees, brush and boulders. They impounded several million cubic yards of debris for a few years but were eventually swept away by floods. As nearly as can be ascertained the total cost of these works was around $500,000, thus bringing the total amount expended by governmental agencies for debris control to almost one and one-half million dollars.

Present Status of Hydraulic Mining.

The decline in the hydraulic mining industry on the watersheds tributary to the Great Central Valley of California is best shown by the comparison in Table 167 of the volumes of material handled and gold yields in 1880 and in 1930. The estimate for the year 1880 is that given by Lieutenant Colonel G. H. Mendell in his report to Congress in 1882. The estimate for 1930 was furnished by the California Debris Commission.

TABLE 167

COMPARISON OF HYDRAULIC MINING IN 1880 AND 1930

Year	*Estimated volume of material mined, in cubic yards*	*Estimated value of gold recovered*
1880	46,000,000	$10,000,000
1930	244,300	[1]36,500

[1] Estimated at 15 cents per cubic yard.

On December 31, 1930, there were in force 39 licenses for hydraulic mining operations of which only 17 were active during the year. Of the total yardage mined in 1930, 213,800 cubic yards were in the Yuba River watershed, 80,300 cubic yards being above Bullards Bar on the North Fork. The remaining 30,500 cubic yards were distributed as follows: Mokelumne River, 15,000; Feather River, 10,000; American River, 2000; Calaveras River, 2000; Butte Creek, 1000, and Bear River, 500. The small volume of material mined in 1930 does not vary greatly from the average of 244,435 cubic yards for the decade 1920–1930. It is reported that some of the contributing causes for this small volume of work have been inadequate water supplies, lack of proper or sufficient debris storage space, and fear of legal action by agricultural or recreational interests along the streams below the mines. While some increase may be anticipated should a cycle of wet years provide the necessary water supplies, it is improbable that the industry will be revived to any great extent unless ample and proper debris storage is provided at reasonable costs.

Amounts and Values of Remaining Workable Gravels.

In 1925, a hydraulic mining commission was created by legislative act of the State of California (Chapter 270, Statutes of 1925) to investigate the feasibility of plans whereby hydraulic mining might be resumed in California. This commission consisting of Lloyd L. Root, State Mineralogist, and W. S. Kingsbury, State Surveyor General, employed Arthur Jarman, mining engineer, to perform the technical work. In cooperation with the California Debris Commission, surveys and investigations were made of dam sites on the Yuba, Bear, and American rivers, and cost estimates were prepared for debris storage reservoirs on those streams. Surveys also were made of the auriferous gravels, and the volumes capable of being mined were calculated. The estimated yardages of workable gravels as given in the report* of the Hydraulic Mining Commission are listed in Table 168. The locations of the auriferous gravels are shown on Plate VII.

TABLE 168

AMOUNTS OF WORKABLE GRAVELS IN YUBA, BEAR, AND AMERICAN RIVER BASINS

Compiled from report of Hydraulic Mining Commission, 1927

Watershed	*Amount of workable gravels* In cubic yards	*Amount of workable gravels* In acre-feet
Middle Fork of Yuba River	Over 442,000,000	274,000
South Fork of Yuba River	Over 94,000,000	58,300
Bear River	Over 32,940,000	20,400
North Fork of American River	Over 95,000,000	58,900
Middle Fork of American River	Over 21,000,000	13,000

Jarman, in the report just referred to, also made an estimate of the amounts of gravels on each stream that he estimated could be worked in the first twenty-year period and the money values of the gold yield from those gravels. His estimate of the amounts of gravel that could be worked annually was based on the estimated amount of water available to each mine, as the rate at which gravel can be mined is dependent chiefly upon the volume of water than can be used to carry the gravel through the sluiceboxes. The amounts and values are given in Table 169.

TABLE 169

AMOUNTS OF GRAVELS TO BE WORKED AND YIELDS IN FIRST TWENTY-YEAR PERIOD

Compiled from report of Hydraulic Mining Commission, 1927

Watershed	*Amounts of gravels to be worked, in cubic yards*	*Gold yield* Total	*Gold yield* Per cubic yard
Middle Fork of Yuba River	52,000,000	$5,200,000	$0.1000
South Fork of Yuba River	85,390,000	9,785,000	0.1146
Bear River	26,510,000	4,167,000	0.1572
North Fork of American River	23,000,000	2,640,000	0.1148
Middle Fork of American River	13,280,000	1,347,000	0.1014
Totals	200,180,000	$23,139,000	

If it is assumed that the money yields per cubic yard of gravel shown in Table 169 were applicable to all of the workable gravels on the five streams shown, without limitation of time, the total yield in money from these gravels would be over $73,000,000. If the average yield were at the lowest rate of ten cents per cubic yard, the total yield in money would be about $68,500,000.

* "Report of the Hydraulic Mining Commission Upon the Feasibility of the Resumption of Hydraulic Mining in California—A Report to the Legislature of 1927."

There are also some workable gravels on the North Fork of Yuba River. The amount is relatively small, however, and it is believed that the capacity of the Bullards Bar reservoir, as now constructed, is adequate to store the entire amount of debris which would result from hydraulic mining operations in the watershed of this stream.

In addition to the auriferous gravel deposits on the Yuba, Bear and American rivers, which have been investigated in recent years, there are deposits also in the Sacramento River Basin in the watershed of the Feather River and some of the minor streams. No estimate of the amounts on the minor streams is available but the State Mining Bureau estimates that in the Feather River watershed there are about 500 million cubic yards of unworked auriferous gravels of which 60 per cent are of economic value.* These Feather River gravels occur in deposits of smaller extent than those on the Yuba, Bear and American rivers and are widely scattered.

Storage of Hydraulic Mining Debris.

The resumption of hydraulic mining will be possible only if adequate reservoir space is provided for the storage of debris so that it can not reach the Sacramento Valley floor. It is not likely that storage capacity would be required for the debris from the entire yardage mined because substantial amounts would lodge and remain permanently in the canyons and river channels above the impounding reservoirs. The California Debris Commission in 1928, however, prepared a report** on an investigation it had made of reservoirs with capacities adequate to store the entire yardage which it was estimated could be worked in a 20-year period of operations. These reservoirs, their capacities, costs, and costs per cubic yard of debris stored are set forth in Table 170.

TABLE 170

DEBRIS STORAGE RESERVOIR SITES ON YUBA, BEAR, AND AMERICAN RIVERS

Compiled from Senate Document No. 90, 70th Congress, 1st Session, 1928

Stream and reservoir site	Reservoir capacity, in acre-feet		Dam		Cost	
	Water	Debris	Crest elevation, in feet	Height above streambed, feet	Dam and reservoir	Per cubic yard of debris stored, in cents
Yuba River-Narrows	86,800	72,500	510	240	$3,524,000	3.01
Middle Yuba-Freemans	25,400	30,100	1,571	211	1,265,000	2.60
South Yuba:						
Upper Norton	19,300	20,100	2,383	213	903,300	2.78
Nortons	28,100	28,900	2,299	269	2,976,500	6.37
Jones Bar	24,400	25,500	1,261	261	2,105,700	5.12
Bear River:						
Rollins Site	4,200	16,400	2,041	71	327,600	1.23
Lower Bear Site	5,200	16,400	2,012.5	117.5	326,300	1.23
North Fork American River:						
North Fork Site	12,200	14,100	712	134	430,100	1.89
Middle Fork American River:						
Ruck-a-Chucky	11,100	8,800	846	121	226,700	1.58

* Bulletin No. 92, "Gold Placers of California," California State Mining Bureau, 1923.

** Senate Document No. 90, 70th Congress, 1st Session.

Utilization of Reservoirs of State Water Plan for Debris Storage—The debris storage reservoirs proposed by the California Debris Commission on the American River, North Fork site and Ruck-a-Chucky, would be entirely submerged by the Auburn reservoir. Should these dams be constructed for debris storage, the resulting loss to conservation storage space in the Auburn reservoir would be about 23,000 acre-feet. No other site has been surveyed for debris storage on the Middle Fork. On the North Fork, however, two other sites have been investigated by the Debris Commission, one at the mouth of Owl Creek and the other at Rice Bridge on the Colfax-Iowa Hill road. The stream bed at the Owl Creek site is at elevation 900, fifty feet below the proposed water surface of Auburn reservoir. The utilization of this site for a debris storage dam would result in relatively little loss to the Auburn reservoir. In the case of the Rice Bridge site, the stream bed elevation is about 1170 feet, and this reservoir would not interfere with storage in Auburn reservoir.

The Auburn reservoir as proposed in the State Water Plan would have about 125,000 acre-feet of dead storage with a maximum drawdown of 50 per cent of the total depth of the dam. Only a small part of this space could be utilized for debris storage since only the lighter materials would be carried through the comparatively quiet waters of the reservoir. However, by increasing the height of the Auburn dam 15 feet, additional storage of 80,000 acre-feet could be obtained. This would assure storage for the entire volume of workable gravels on both the North and Middle forks of the American River, estimated at the equivalent of 72,000 acre-feet. The cost of storage would be about $29 per acre-foot or 1.8 cents per cubic yard. Such procedure would not reduce the cost per acre-foot of debris storage, as estimated by the California Debris Commission for the 23,000 acre-feet of storage contemplated in their plans for the North Fork and Ruck-a-Chucky reservoirs, but it would provide storage for all the gravels on the two branches of the river and at the same time add a small per cent to the power yield of the reservoir.

None of the debris storage sites on the Bear River conflict with the major reservoir unit of the State Water Plan at the Camp Far West site. Debris storage at the two sites proposed by the Debris Commission, Rollins and the Lower Bear River site are estimated to cost 1.23 cents per cubic yard of debris stored or about $20 per acre-foot. The Nevada Irrigation District completed an irrigation diversion dam at the Van Giesen or Combie Crossing site in 1928. It is reported that the District is offering storage at three cents per cubic yard of material displaced at the mine. The Debris Commission has recently licensed two mines to operate and store their tailings in the Van Giesen Reservoir.

The Debris Commission's proposed debris storage project with a dam at the site of the United States Geological Survey gaging station in the Narrows on Yuba River conflicts with the Narrows reservoir of the State Water Plan. The water surface elevation of 865 feet in the state's Narrows reservoir, however, is considerably below the lowest of the upstream debris storage projects, that at Jones Bar, where the stream bed elevation at the dam site is 1000 feet. Of the estimated total of over 536,000,000 cubic yards of workable gravels, 122,000,000 could be retained by the proposed upstream reservoirs. To care for the remaining 414,000,000 cubic yards probably would require an additional 256,000 acre-feet of capacity in the Narrows reservoir. The proposed dam is 580 feet high and it is doubtful whether a greater height is practicable. By increasing the height 20 feet, however, storage amounting to about 100,000 acre-feet would be added. This is considerably in excess of the 72,500 acre-feet of debris storage proposed by the Debris Commission for this site. The cost per acre-foot of storage would be $53.50, as compared with $48.50 per acre-foot estimated by the Debris Commission.

The auriferous gravels in the Feather River watershed above Oroville practically all lie at a considerable distance above the Oroville reservoir. The debris from the hydraulic mining of these gravels could practically all be stored in reservoirs which would lie entirely above the highest water surface in the Oroville reservoir and therefore would not in any way interfere with the conservation value of the latter reservoir. Sites exist for such storage on Indian Creek, and the Middle and South forks of Feather River. All of these sites, however, also are feasible ones for reservoirs which could be constructed for conservation purposes.

Summary.

It has been shown in the foregoing paragraphs that several of the major reservoir units of the State Water Plan in the Sacramento River Basin are so located as to be usable for the storage of hydraulic mining debris but that not all of those so located are required for this purpose since other storage reservoirs are available. The other storage sites on the Yuba, Bear and American rivers have been investigated by the California Debris Commission, which also has estimated the costs of storing debris in them.

The major reservoir units of the State Water Plan are important primarily for the reregulation of water once used in the mountainous areas for the generation of power or for hydraulic mining, to make as much of this water and the remainder of the run-off of the streams as is feasible, available for irrigation and other uses in the Great Central Valley. Space used in each major reservoir unit for the storage of debris would impair the conservation value of the reservoir to the extent that storage space for water would be occupied by debris. The space occupied in a reservoir by the debris might not be equal to the volume of the gravels mined since some debris would be stored in the stream channels above the reservoir. A large proportion might eventually be deposited in the reservoir, however, and in estimating costs of storage for gravels which may be worked in the first 20 years, the California Debris Commission has estimated storage space for the entire volume to be mined.

If space in the major reservoir units of the State Water Plan is to be used for the storage of mining debris, the capacities of the units would have to be increased or other sites developed, if the ultimate water requirements of the Great Central Valley are to be supplied.

CHAPTER XIII

RIPARIAN LANDS ON SACRAMENTO AND AMERICAN RIVERS

The developments proposed under the State Water Plan for the Sacramento River Basin, when put in operation, would effect material changes in the regimen of the major streams. Flows would be reduced in magnitude during the winter and spring months and increased during the summer and fall, and a greater and more beneficial utilization of the available water supplies would be obtained. This readjustment of stream flows to meet the demands for water would be accomplished by storage in the major reservoir units.

A plan involving such important alterations of natural flow is widely at variance with well known tenets of the doctrine of riparian water rights and in particular with the declared right of the riparian owner to insist upon maintenance of stream flow undiminished and unaltered except by usage of other riparian owners and under rights which have been established by prescription or prior appropriation. In other words, the developments proposed would conflict with rights asserted in favor of riparian owners. In order to ascertain the magnitude of this conflict, an approximation of the extent of riparian ownerships along the Sacramento and American rivers, on which the first major reservoir units would probably be constructed and operated, and the ultimate water requirements for such riparian ownerships, are herein attempted.

It is emphasized at the outset, in order that there may be no misunderstanding as to the approximations and estimates contained in this chapter, that the purpose is to give a general conception of the magnitude of the problem presented by the riparian doctrine in reference to Sacramento River Basin developments and that the magnitude of the problem depicted herein is predicated upon certain factors concerning some of which much controversy will probably occur and the final determination of which may rest in future judicial decisions. It is realized that if any of such factors are incorrect, or if any important considerations have been omitted, the acreages of riparian lands and the water requirements for these lands also will be incorrect. Time and expense have not permitted a review of titles to lands involved, in minute detail, but the results herein set forth are deemed sufficiently accurate for the purpose for which they are used in this report.

The estimates of the extent of the riparian lands along the Sacramento and American rivers were based upon the following factors:

1. That the riparian right is created by contact with the stream and does not extend outside the watershed which gives the contact.

2. That land is riparian when it borders the stream, is within the watershed, and when it has been continuously in the same holding (not necessarily held by the same owner) since title passed from the United States, since it was transferred to private ownership by Spanish grant, or since it was acquired from the State as a swamp land survey.

3. That a parcel of land loses its riparian right immediately if the contact with the stream is broken (i.e. if it is separated by deed from the stream to which it is riparian), unless the riparian right is reserved thereto.

4. That easements for railroads, canals, levees and roads do not operate to sever riparian rights from lands cut off from access to the stream by such easements.

5. That rights of way deeded in fee do sever the riparian right from the land cut off unless an express reservation of the riparian rights to lands thus severed is contained in the deed of the right of way.

6. That when once lost, a riparian right cannot be restored to a parcel of land even though said parcel be reunited to the original parcel which gave the contact and established the riparian claim.

7. That the lands on tidal waters on navigable channels are riparian, limited, however, by the foregoing factors.

If it be assumed that factor number seven is incorrect, then of course a large acreage in the lower Sacramento Valley and Sacramento Delta must be subtracted from the total riparian area hereinafter estimated.

On the other hand, if it be assumed that riparian rights attach to flood waters which occur in the stream from time to time and spread out over lands adjacent thereto, a considerable acreage of lands in the upper Sacramento Valley must be added to the total riparian area.

TABLE 171

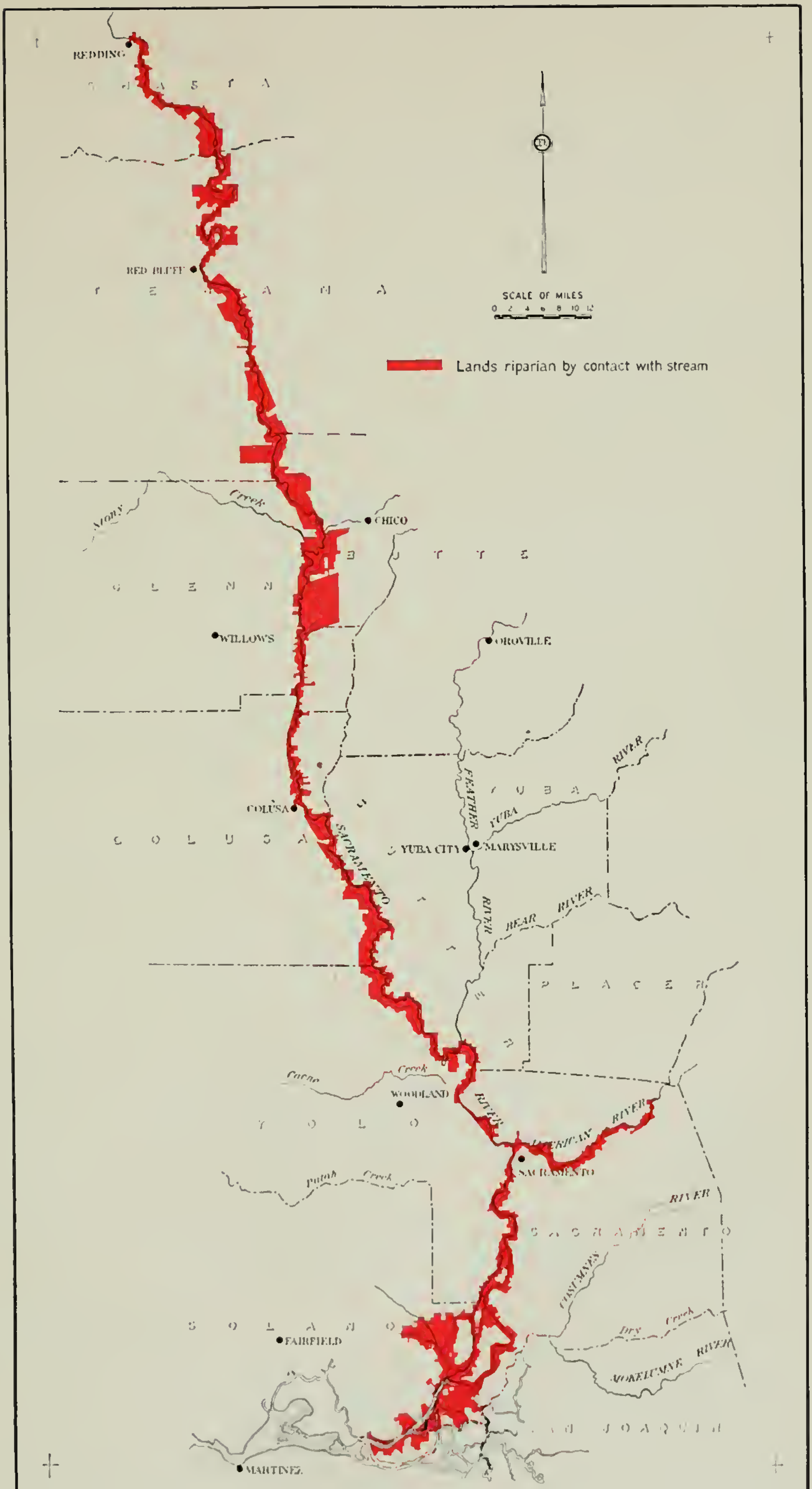
LANDS ALONG THE SACRAMENTO AND AMERICAN RIVERS RIPARIAN BY CONTACT WITH THE STREAMS

County	Area of riparian lands, in acres			
	Along Sacramento River			Along American River, Folsom to mouth
	Collinsville to Sacramento, including connecting channels	Sacramento to Redding	Total, Collinsville to Redding	
Shasta		15,260	15,260	
Tehama		47,980	47,980	
Butte		[1]37,960	[1]37,960	
Glenn		17,190	17,190	
Colusa		28,700	28,700	
Sutter		14,810	14,810	
Yolo	11,970	19,570	31,540	
Sacramento	42,250	3,450	45,700	13,460
Solano	25,380		25,380	
Totals	79,600	184,920	264,520	13,460

[1] Excludes Bidwell State Park.

Extent of Riparian Lands.

Using the foregoing factors, the acreages of lands along the Sacramento and American rivers which are riparian by reason of their contact with the streams were estimated and are set forth by counties,



RIPARIAN LANDS
ON
SACRAMENTO AND AMERICAN RIVERS

in Table 171. In Table 171 the acreage along the Sacramento River is further divided between the area below Sacramento, which is classed as delta land, and that from Sacramento to Redding, most of which does not border on the portion of the stream which is subject to tidal action. The locations and areas of these riparian lands are shown on Plate LVI, "Riparian Lands on Sacramento and American Rivers."

Classification of Lands Riparian by Contact with the Sacramento and American Rivers.

In Chapter III, the division of Sacramento River Basin lands into five classes is described. By superimposing a map of riparian lands over a map showing the land classification, it was possible to estimate the acreage of riparian lands in each of the five classes. The areas of riparian lands which it is estimated would be irrigable were estimated by applying the proper factors as described in Chapter III, to the four classes of agricultural lands. The sum of the areas of Class 5 lands and the nonirrigable lands in the other four classes would be the area of the riparian lands which it is estimated would require no irrigation water. Table 172 sets forth by counties the irrigable and non-irrigable areas of riparian lands along the Sacramento and American rivers. Of the gross area of riparian lands along the Sacramento River, 264,520 acres, it is estimated that 205,750 acres or 78 per cent are irrigable. Of the total area of 13,460 acres of riparian lands along the American river, 8710 acres or 65 per cent are considered irrigable.

TABLE 172

CLASSIFICATION OF LANDS ALONG THE SACRAMENTO AND AMERICAN RIVERS RIPARIAN BY CONTACT WITH THE STREAMS

Area	Net irrigable area of riparian lands, in acres					Non-irrigable riparian lands, in acres
	Class 1	Class 2	Class 3	Class 4	Total	
Sacramento River—						
Sacramento to Redding along main river channel:						
Shasta County	6,950	3,260	1,090	100	11,400	3,860
Tehama County	22,290	7,500	3,100	1,580	34,470	13,510
Butte County	19,580	11,550	890	90	32,100	5,850
Glenn County	6,150	5,760	2,030	----	13,940	3,250
Colusa County	16,300	7,670	350	----	24,320	4,380
Sutter County	9,150	1,950	540	----	11,640	3,170
Yolo County	11,920	2,090	1,100	----	15,110	4,460
Sacramento County	2,590	----	100	----	2,690	760
Subtotals	94,930	39,780	9,200	1,770	145,680	39,240
Sacramento to Collinsville along main river channel and connecting channels:						
Sacramento County	31,350	470	2,040	----	33,860	8,390
Yolo County	9,590	----	----	----	9,590	2,380
Solano County	12,850	1,740	890	1,140	16,620	8,760
Subtotals	53,790	2,210	2,930	1,140	60,070	19,530
Totals Sacramento River, Redding to Collinsville	148,720	41,990	12,130	2,910	205,750	58,770
American River—						
Folsom to mouth along main river channel:						
Sacramento County	6,000	2,430	170	110	8,710	4,750

Use of Water on Lands Riparian by Contact with the Sacramento and American Rivers.

Estimates were made from available data of the present use of water on lands riparian by contact with the Sacramento River from Redding to the city of Sacramento, and with the American River below

TABLE 173

USE OF WATER ON LANDS ALONG SACRAMENTO RIVER, REDDING TO SACRAMENTO, RIPARIAN BY CONTACT WITH THE STREAM

Year and county	Total riparian acreage	Diversions, in acre-feet		Acreage irrigated
		July	April to October, inclusive	
1924—				
Shasta[1]	15,260	3,720	19,700	3,030
Tehama	47,980	600	2,730	860
Butte	37,960	4,960	18,920	2,260
Glenn	17,190	1,210	4,460	1,330
Colusa	28,700	2,350	11,540	3,780
Sutter	14,810	1,120	7,290	1,950
Yolo	19,570	1,270	6,010	2,320
Sacramento	3,450	970	3,980	1,340
Totals	184,920	16,200	74,630	16,870
1925—				
Shasta[1]	15,260	4,640	20,470	3,250
Tehama	47,980	210	770	540
Butte	37,960	4,810	13,500	2,220
Glenn	17,190	320	910	770
Colusa	28,700	4,500	13,960	3,950
Sutter	14,810	910	3,390	1,530
Yolo	19,570	1,020	3,580	1,730
Sacramento	3,450	860	1,760	1,120
Totals	184,920	17,270	58,340	15,110
1926—				
Shasta[1]	15,260	4,440	20,920	3,290
Tehama	47,980	340	940	770
Butte	37,960	4,400	11,910	2,300
Glenn	17,190	220	790	400
Colusa	28,700	5,620	23,030	4,670
Sutter	14,810	2,540	8,530	1,510
Yolo	19,570	3,390	18,420	4,100
Sacramento	3,450	930	4,850	1,340
Totals	184,920	21,880	89,390	18,380
1927—				
Shasta[1]	15,260	4,000	20,070	3,160
Tehama	47,980	290	750	510
Butte	37,960	1,880	10,640	2,110
Glenn	17,190	160	630	400
Colusa	28,700	5,030	15,840	4,490
Sutter	14,810	2,790	11,190	2,800
Yolo	19,570	16,670	80,180	8,850
Sacramento	3,450	500	1,390	660
Totals	184,920	31,320	140,690	22,980
1928—				
Shasta[1]	15,260	4,210	21,800	3,460
Tehama	47,980	330	850	620
Butte	37,960	1,630	4,940	1,480
Glenn	17,190	600	1,660	880
Colusa	28,700	2,730	8,750	4,430
Sutter	14,810	3,450	11,480	3,910
Yolo	19,570	2,910	16,780	4,310
Sacramento	3,450	720	2,510	1,150
Totals	184,920	16,580	68,770	20,240

[1] Considerable riparian acreage is included in the Anderson-Cottonwood Irrigation District and irrigated through the district system.

Folsom. Estimates also were made of the total amounts of water required for the irrigation of lands riparian by contact with the entire Sacramento River from Redding to its mouth, including connecting channels in the delta, and with the American River below Folsom, under conditions of ultimate development.

Present Use of Water.—In the estimate of the present use of water on riparian lands, the records of all diversions and acreages irrigated along the Sacramento River between Redding and Sacramento as given in the records of the Sacramento-San Joaquin Water Supervisor* for the five-year period 1924–1928, inclusive, were used. From those records the diversions and uses for each tract of riparian land were estimated. These uses are summarized by counties in Table 173.

In many instances the acreage irrigated, as shown by the Water Supervisor's report, extended beyond the limits of riparian lands. In these cases, unless specific information was available, the ratio of the diversion for riparian lands to the total diversion was assumed to be the same as that of the riparian acreage to the total acreage. In Shasta County most of the irrigated riparian lands lie within the Anderson-Cottonwood Irrigation District and are served by the district system. The records of acreage irrigated in the district are very meager and the figures included for this area are estimates only.

For the Sacramento Delta riparian lands, Sacramento to Collinsville, no direct measurements of the diversions have been possible and the present use of water was entirely estimated. The Sacramento-San Joaquin Water Supervisor's report gives only an annual census of the acreage irrigated on the delta islands and tracts. In that report, an arbitrary segregation is made between the Sacramento and San Joaquin-Mokelumne deltas, and the total acreage irrigated each year in each delta is shown. The total acreage of the islands and tracts in each delta also is given. An estimate of the irrigated area of riparian lands in the Sacramento Delta, therefore, was made by assuming that, in any year, it would be the same percentage of the total riparian acreage as the irrigated Sacramento Delta acreage was of the total Sacramento Delta acreage. These acreages are shown in Table 174. No attempt was made to estimate the use of water on the present irrigated riparian lands.

TABLE 174

IRRIGATED ACREAGE OF RIPARIAN LANDS IN SACRAMENTO DELTA, SACRAMENTO TO COLLINSVILLE

Year	Irrigated lands in Sacramento Delta: Acres	Irrigated lands in Sacramento Delta: Per cent of total Sacramento Delta acreage	[1] Estimated area of irrigated riparian lands in Sacramento Delta, in acres
1924	122,250	68	54,100
1925	111,830	62	49,300
1926	121,970	67	53,300
1927	126,430	70	55,700
1928	128,500	71	56,500
1929	136,230	70	55,700

[1] Estimated by applying to the total Sacramento Delta riparian acreage (79,600 acres) the percentages in the third column.

* Bulletin No. 23, "Report of Sacramento-San Joaquin Water Supervisor for the Period 1924–1928," Division of Water Resources, 1930.

The use of water on riparian lands along the American River during the years 1925 to 1928, inclusive, is shown in Table 175. The Water Supervisor's records give the diversions from the river from its mouth to Fairoaks only. For the year 1924, only the diversions below "H" Street Bridge, Sacramento, were recorded and this year, therefore, was omitted from the tabulation. Diversions for riparian lands between Fairoaks and Folsom (probably small) were not included. All of the riparian lands along the river below Folsom lie in Sacramento County.

TABLE 175

USE OF WATER ON LANDS ALONG AMERICAN RIVER, FAIROAKS TO MOUTH, RIPARIAN BY CONTACT WITH THE STREAM

Total area of riparian lands, 13,460 acres

Year	*Diversions, in acre-feet* *July*	*April-October, inclusive*	*Acreage irrigated*
1925	840	2,350	1,450
1926	760	1,990	1,180
1927	630	2,000	1,390
1928	390	1,180	880

Ultimate Water Requirements.—An estimate also was made of the ultimate requirements for lands along the Sacramento and American rivers riparian by contact with the stream. These water requirements were ascertained by the same method explained in Chapter V for the water service areas and are based on the Sacramento Valley land classification, crop groups, and unit water allowances. Table 176 sets forth these water requirements for the lands along both rivers, by counties.

TABLE 176

ULTIMATE WATER REQUIREMENTS FOR IRRIGABLE LANDS ALONG SACRAMENTO AND AMERICAN RIVERS RIPARIAN BY CONTACT WITH THE STREAMS

Area	Net irrigable area of riparian lands, in acres	Net allowance of water, in acre-feet per year	Gross allowance of water, in acre-feet per year
Sacramento River—			
Sacramento to Redding along main river channel:			
Shasta County	11,400	24,620	36,900
Tehama County	34,470	65,690	102,910
Butte County	32,110	80,320	120,320
Glenn County	13,940	32,960	49,400
Colusa County	24,320	58,430	87,550
Sutter County	11,640	25,240	37,850
Yolo County	15,110	32,860	49,280
Sacramento County	2,690	5,770	8,650
Subtotals	145,680	325,890	492,860
Sacramento to Collinsville along main river channel and connecting channels:			
Sacramento County	33,860	77,200	77,200
Yolo County	9,590	21,870	21,870
Solano County	16,620	37,890	37,890
Subtotals	60,070	136,960	136,960
Totals, Sacramento River, Red Bluff to Collinsville	205,750	462,850	629,820
American River—			
Folsom to mouth along main river channel:			
Sacramento County	8,710	16,090	24,080

Table 176 shows that the estimated total ultimate net allowance of water for the lands riparian by contact with the Sacramento River between Redding and the city of Sacramento, which latter point is the northern end of the Sacramento-San Joaquin Delta, would be about 326,000 acre-feet per year. This is approximately 5.4 per cent of ultimate annual net allowance for the entire Sacramento Valley, exclusive of the Sacramento-San Joaquin Delta, which is shown in Chapter V to be 6,025,000 acre-feet per year. The ultimate net allowance of 16,090 acre-feet per year for the lands riparian by contact with the American River below Folsom would be less than three-tenths of one per cent of the ultimate net allowance of 6,025,000 acre-feet per year for the Sacramento Valley lands.

For the lands in the Sacramento Delta which are assumed to be riparian by contact with the Sacramento River and connecting channels, the estimated ultimate net allowance of water is shown by Table 176 to be about 137,000 acre-feet per year. This amount is approximately 36 per cent of the total ultimate net allowance for irrigation in the entire Sacramento Delta.

For the riparian lands along the Sacramento River between Redding and the city of Sacramento, a total ultimate gross diversion of about 493,000 acre-feet per year is estimated. With the present distribution of the irrigation requirements in the Sacramento Valley, this would require under conditions of ultimate development, a maximum flow of 1760 second-feet in July.

APPENDIX A

GEOLOGIC REPORT

ON

KENNETT, IRON CANYON AND TABLE MOUNTAIN DAM SITES

ON

SACRAMENTO RIVER

By

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California Institute of Technology

October, 1931

TABLE OF CONTENTS

GEOLOGIC REPORT ON KENNETT, IRON CANYON AND TABLE MOUNTAIN DAM SITES ON SACRAMENTO RIVER

Recent exploratory work in the form of pits and tunnels at the Kennett, Iron Canyon and Table Mountain dam sites on the Sacramento River have made it desirable that a general description and appraisal of these sites be made from the geological point of view, combining the results of earlier studies with those of more recent date. The most recent field examinations made by F. L. Ransome were on October 16, 17 and 18, 1930, and those by G. D. Louderback on September 28 (Kennett) and October 12, 1930 (Iron Canyon), and January 25, 1931 (Table Mountain).

KENNETT DAM SITE

Situation.

The Kennett dam site is situated on the Sacramento River, two miles, in a straight line, south-southwest of Kennett. The topography of the site is shown in Plate A-I, "Location of Diamond Drill Borings and Exploration Tunnels at Kennett Dam Site on Sacramento River."

General Geology.

The rock at the Kennett site is what J. S. Diller, in the Redding folio of the United States Geological Survey, has named the "Copley metaandesite." As the name indicates, the formation consists mainly of metamorphosed lavas and tuffs which originally were of andesitic character. It is generally a hard, greenish gray rock in which the original minerals have been extensively recrystallized as epidote, green amphibole, chlorite, sericite, calcite and quartz, with considerable modification of the primary texture. A rough schistose structure is not uncommon, and in some places this passes into varieties in which the laminated structure is suggestive of slate. As a rule, whatever laminated structure or cleavage the rock possesses is accentuated by weathering and is inconspicuous in the fresh rock. As seen in the tunnels at the dam site, the unweathered rock is apparently massive and such, for all practical purposes, it may be considered.

It is only where the rock has been more or less decomposed or has been scoured by stream action that any schistose structure is evident. The schistosity, moreover, as developed near the dam site, is of a very rough character, the finer-grained, or originally softer materials of the more or less fragmental volcanic rock having been squeezed around the larger, more resistant fragments by the enormous pressures accompanying regional metamorphism. None of the rock seen near the site is easily cleavable in any particular direction and the schistosity is nowhere sufficiently developed or sufficiently regular to constitute an element of weakness in the rock or to permit of percolation by water. Whatever water finds its way through the rock must travel through intersecting joints or factures, exactly as in granite or any other massive rock. From a practical point of view, such imperfect schistosity as is present in the rocks at the Kennett site is wholly negligible as regards either the strength of the rock or water percolation.

The geologic age of the Copley metaandesite is not definitely known. It is considered to be Devonian or older.

Examination of the rock at the surface and in the tunnels has revealed no faulting, shearing or crushing of any importance. Where the tunnels pass through weathered rock, particularly in tunnel No. 2, there are occasional soft zones which, at first glance, have some resemblance to fault gouges. Close examination of these shows, however, that they are essentially zones of decomposition where surface waters have penetrated along cracks or joints. Where such penetration has taken place, the rock may be thoroughly soft and decomposed for a width of a foot or more and may be reduced in part to clay. Such material, however, shows no evidence of crushing or grinding, such as is characteristic of a fault. Along some of these soft seams some slight movement may have occurred, but, if so, it has been local and unimportant.

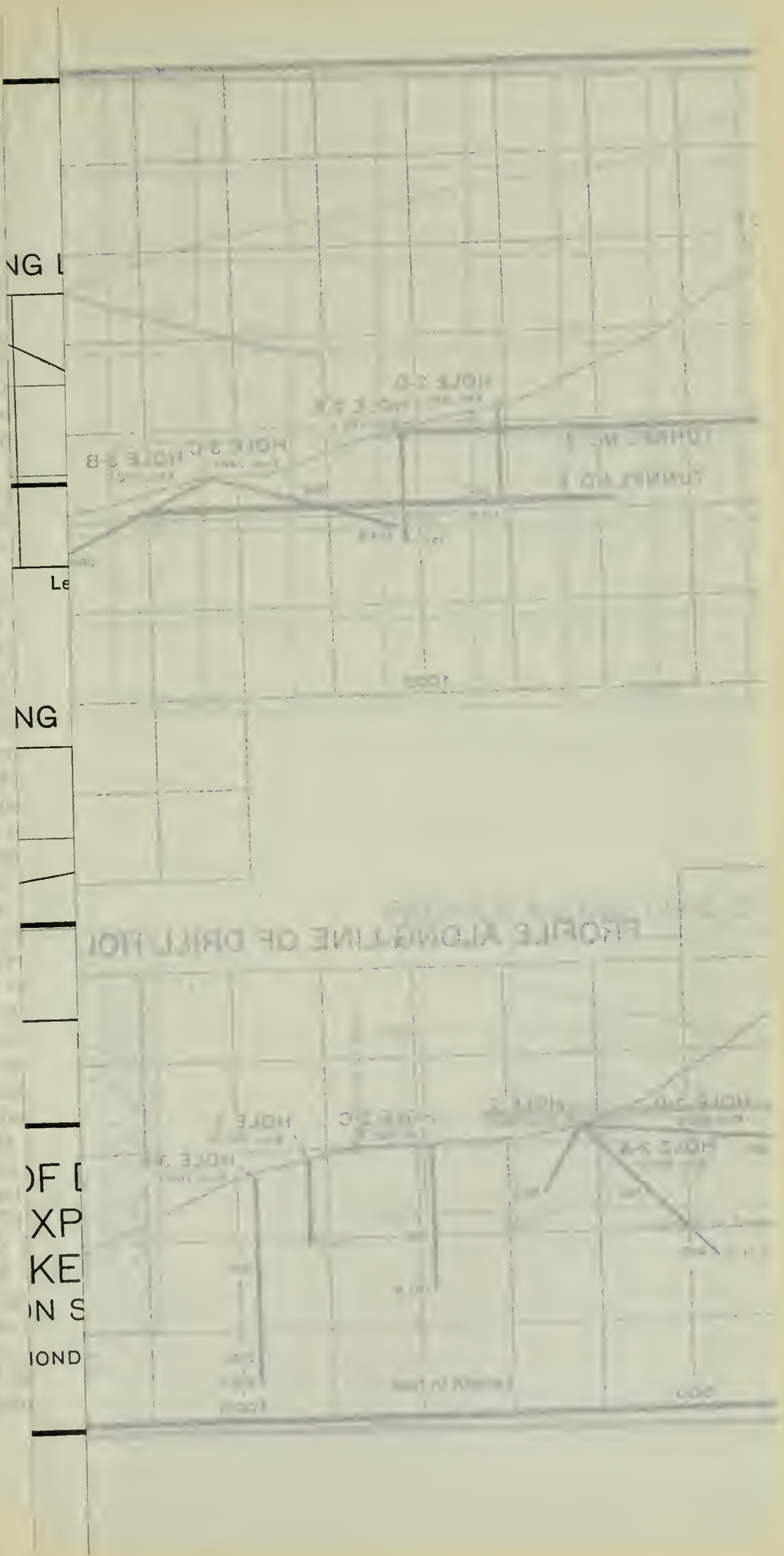
Some fractures in the weathered zone and in relatively hard fresh rock just below that zone are filled with very soft, wet, ferruginous clay, which oozes out into the tunnel. This clay is not fault gouge, but is merely material that has oozed, or been carried by infiltration, into a crevice from the oxidized, decomposed rock above. These crevices are merely local joints which probably have been opened to some extent by volume changes resulting from rock decomposition. Such soft clayey material has not been found, and is not expected to occur, at any considerable depth below the zone of oxidation.

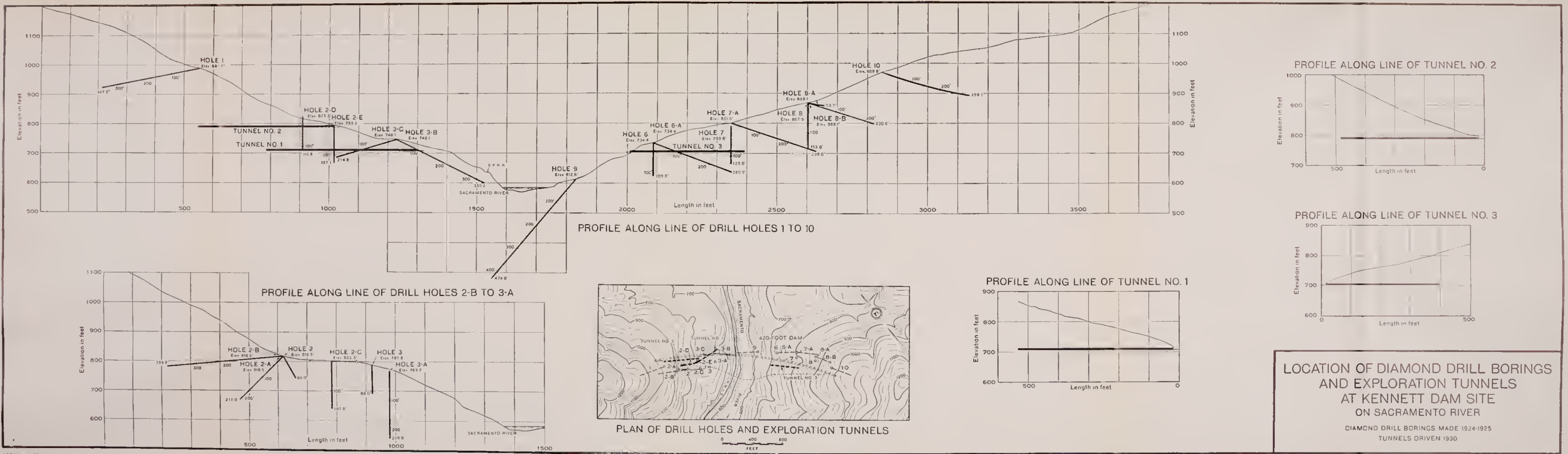
A notable feature at the Kennett dam site is the deep weathering of the rock on slopes above about elevation 700 feet. Below that elevation, along the river banks and under the river, the rock is generally fresh and hard practically at the surface. Here erosion has been relatively so recent that the rock has not been exposed long enough to become deeply weathered. Core from drill-hole No. 9, which is an inclined hole passing under the river bed from the southeast side, shows no oxidation of the rock beyond the first few feet.

G. D. Louderback, in his report of April 2, 1927, calls attention to the indication in this and other cores of certain belts of rock in which schistosity is more pronounced than elsewhere. Careful examination of all the rocks exposed at the site, however, indicates such schistose structure as the greenstone may locally display is not of a character to constitute an element of weakness with reference to the proposed dam or to provide paths of leakage.

Observations on the Tunnels.

On the right bank of the river, tunnel No. 1, at elevation 706 feet, is 514 feet in length. At 370 feet from the portal, as shown on Plate A-I, the tunnel was deflected to the right, or toward the north, so as to bring it more nearly under tunnel No. 2. At the portal, and for a distance of 25 feet in, the rock is partly oxidized, hard greenstone or metaandesite. Generally, for this distance, the upper part of the tunnel is in rock which is considerably oxidized, while the lower part exposes rock in which the oxidation is confined to the vicinity of joints, the rock between the oxidized streaks being sound and hard. From the 25 foot mark to the bend in the tunnel at 370 feet, the rock is sound, moderately-jointed, unweathered greenstone. The joints are tight and the rock is of excellent character for the foundation of a concrete dam.





LOCATION OF DIAMOND DRILL BORINGS AND EXPLORATION TUNNELS AT KENNETT DAM SITE ON SACRAMENTO RIVER

DIAMOND DRILL BORINGS MADE 1924-1925
TUNNELS DRIVEN 1930

From the bend to the face, the greenstone is generally of satisfactory character. In a few places there has been some local shearing under heavy pressure, with the development of numerous closely spaced fractures or joints. This implies some movement, but the movement has not been sufficient to crush the rock or produce any soft gouge or clay. Where the shearing has taken place, the rock is so fractured that it can be loosened with a pick and, as a whole, is relatively soft. Such a zone of shearing appears on the north side of the tunnel, where it extends back for about fifteen feet from the face. Another zone, which forms an acute angle with the one just mentioned, is exposed in the face of the tunnel, where it is associated with a fairly definite seam or wall which strikes about north 70 degrees east and dips north at 65 degrees. Alongside of this seam the greenstone is rather minutely fractured for a width of about four feet.

As a whole, the rock exposed in tunnel No. 1, beyond the first 25 feet, is regarded as of entirely satisfactory character as foundation material for a high dam. The shear zones described in the preceding paragraph are local and are so deep within the mountain as to be negligible with respect to any possible weakness or leakage. If any one of them should appear at the surface after stripping, it can easily be gouged out to any desired depth and any remaining fractured rock made tight by grouting.

Tunnel No. 2, on the right or northwest bank, at elevation 787 feet, is 445 feet in length. For the first 171 feet, the tunnel is in soft, weathered greenstone. At that distance from the portal, sound, unweathered rock appears in the bottom of the tunnel. Beyond 193 feet, the rock is generally hard and unweathered, although it shows some oxidation along joints. This condition, with some variations, continues to a point about 325 feet from the portal and probably all of the rock to this point would have to be stipped off. From 325 feet to the face, the rock is generally hard and unweathered although there is a little decomposition along joints and some of the joints contain infiltrated ferruginous clay of very slushy consistency. At 368 feet from the portal, the rock is of excellent character and continues so to the face. Within this distance, four narrow seams are observed carrying one-fourth to three-fourths inch of soft, wet ochreous clay. They occur at points 375, 422, 425 and 429 feet from the portal. The rock enclosing them is fresh, hard and firm.

Tunnel No. 2, from the portal to a point 325 feet in, is apparently not far above the bottom of the weathered zone. If this weathered material is removed it is expected the remaining rock will be found to be of the same general excellence as in tunnel No. 1.

Tunnel No. 3, on the left bank of the river, at elevation about 701 feet, is 373 feet in length and reveals soft and weathered rock for about 150 feet from the portal, corresponding to a maximum overburden of about 55 feet. At the 150-foot point, there is a well-marked seam of decomposition, with some clay, which strikes squarely across the tunnel and dips toward the portal at about 44 degrees. This seam is about a foot in width. There may have been slight movement along it, but the seam is chiefly the result of decomposition along a joint or crack. Beyond the seam, the tunnel goes into hard,

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Detailed Examination of the Drill Cores.

The notes on drill cores shown on Plate A-II, "Log of Diamond Drill Borings at Kennett Dam Site," are taken from a report submitted by G. D. Louderback on December 28, 1926. The locations of the holes are shown on Plate A-I.

Depth of Stripping Required.

From the study of the drill cores the following tabular summary has been prepared as an aid to the engineers in making preliminary estimates of the amount of stripping which would be required. In general, the maximum depth given in the table probably would be the nearer to the excavation that actually would be necessary and these figures, in connection with observations in the tunnels, have been used in setting the following probable stripping limits. The depths given are distances measured along the hole.

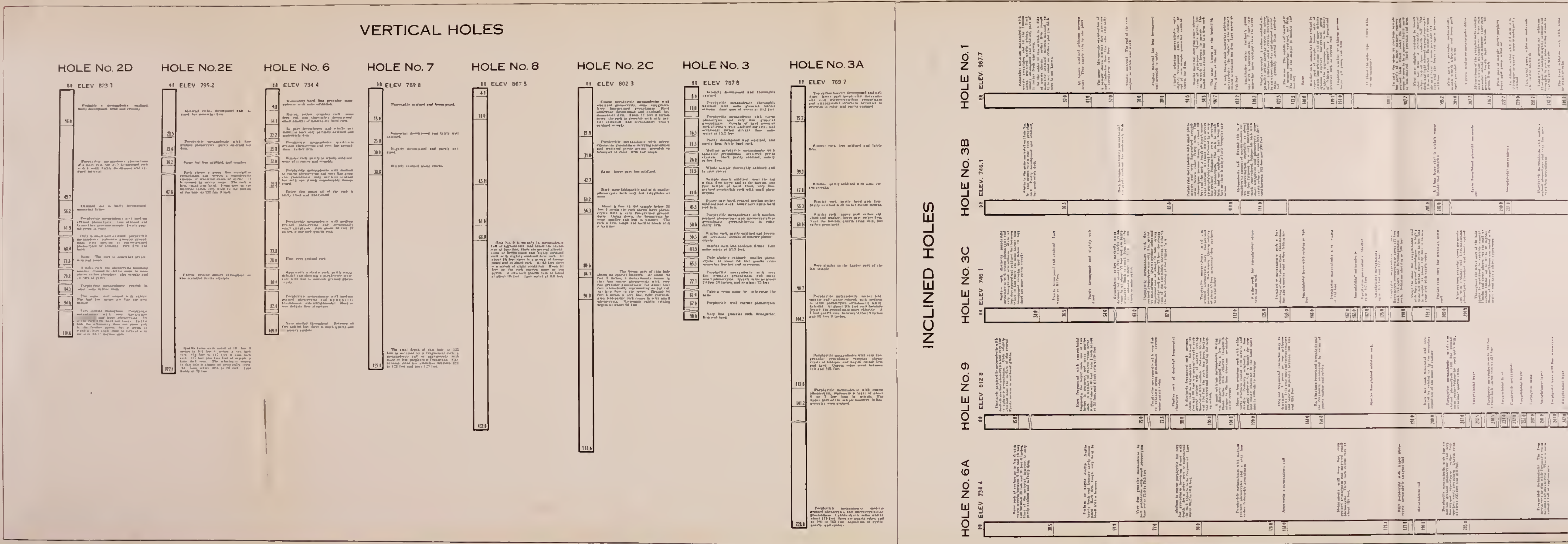
TABLE A-1

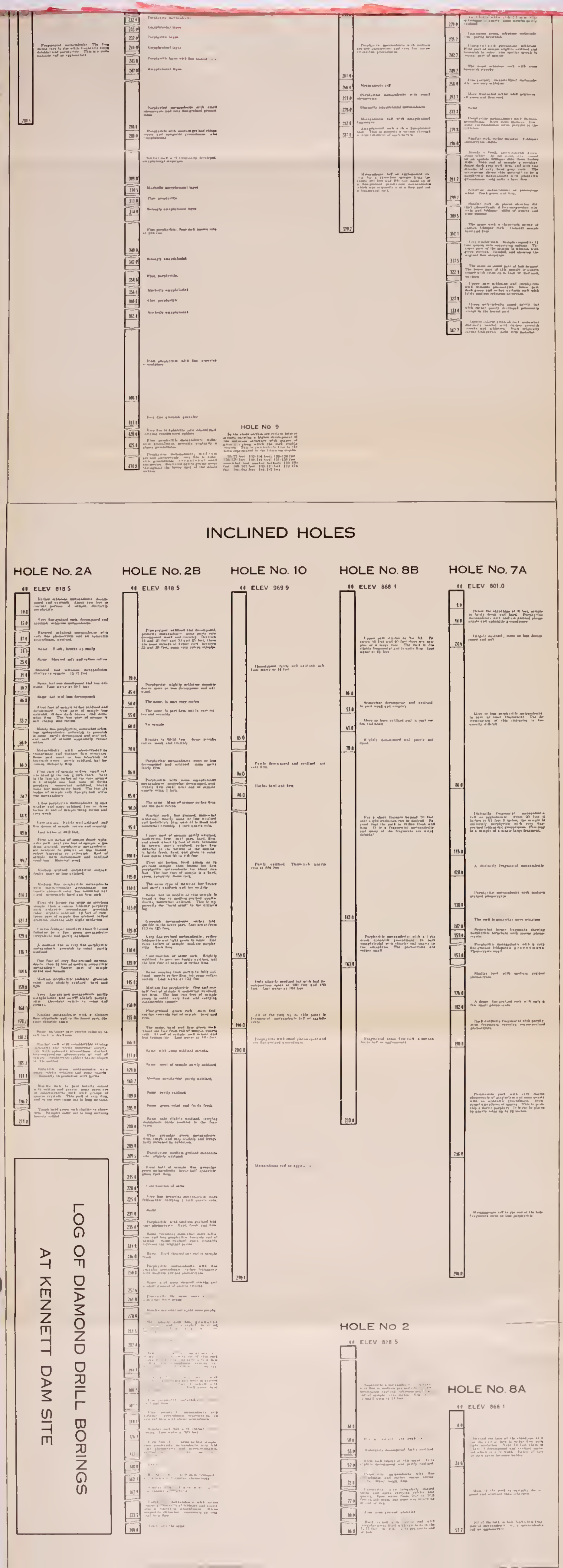
DEPTHS OF STRIPPING REQUIRED AT KENNETT DAM SITE

Test hole (Vertical holes marked V)	*Suggested minimum depth—above which the rock is generally decomposed*	*Suggested maximum depth—below which the rock is generally undecomposed*
1	80 feet	150 feet
2B	about 100 feet	130 to 150 feet
2A	70 feet	106 feet
2	55 feet	55 feet
V 2D	50 feet	65 feet
V 2E	20–25 feet	30 feet
V 2C	20 feet	25–30 feet
V 3	40–45 feet	50–55 feet
V 3A	about 55 feet	about 55 feet
3C	45–50 feet	about 55 feet
3B	40 feet followed by weak streaks	
9	Fresh rock practically from the surface	
V 6	30 feet	about 35 feet
6A	23 feet	30 feet
V 7	25 feet	30 feet
7A	25 feet	25–30 feet
V 8	15 feet	15–20 feet
8B	30 feet but soft streaks between 45–61 feet	60–70 feet
10		85 feet, soft streaks between 180–185 feet

Conclusions.

The rock at the Kennett site, where not decomposed by weathering, is excellent material upon which to found a concrete dam up to at least 500 feet in height. There are no faults or other structural features which would interfere with the construction of such a dam and there is no reason to fear that a dam, when built, would be subject to serious earthquakes. The only objectionable feature of the rock formation is the heavy stripping which probably would be necessary to remove the overburden of weathered, decomposed rock, particularly on the right bank.


VERTICAL HOLES
HOLE No. 2D
ELEV 823.3
HOLE No. 2E
ELEV 795.2
HOLE No. 6
ELEV 734.4
HOLE No. 7
ELEV 789.8
HOLE No. 8
ELEV 867.5
HOLE No. 2C
ELEV 802.3
HOLE No. 3
ELEV 787.8
HOLE No. 3A
ELEV 769.7
INCLINED HOLES
HOLE No. 1
ELEV 987.7
HOLE No. 3B
ELEV 746.1
HOLE No. 3C
ELEV 746.1
HOLE No. 9
ELEV 612.8
HOLE No. 6A
ELEV 734.4



LOG OF DIAMOND DRILL BORINGS AT KENNETT DAM SITE

PLATE A-

IRON CANYON DAM SITE

Situation.

The Iron Canyon dam site is situated on the Sacramento River, about four miles northeast of Red Bluff. The canyon proper at the site, as shown in Plate A-III, "Location of Diamond Drill Borings, Test Pits and Exploration Tunnel at Iron Canyon Dam Site on Sacramento River," is delimited on the right bank by the 350-foot contour and on the left bank by the 325-foot contour, the width of the canyon between these contours being about 1300 feet. A dam at this site, with crest elevation at 410 feet, as may be seen from Plate A-III, would require long wing embankments and a subsidiary embankment across a wide saddle to the west of the main dam.

General Geology.

The general geology at the Iron Canyon site has been described by Homer Hamlin, in a report * dated December 12, 1919, and by A. C. Lawson, in a report ** dated August 31, 1919. A contribution was made by G. D. Louderback in a letter to the State Engineer under date of February 18, 1930. The only site examined by us was the one about half a mile below the United States Geological Survey gaging station.

The rocks at the Iron Canyon site are all nearly horizontal tuffs and agglomerates of Pliocene age, belonging to the formation named "Tuscan tuff" by J. S. Diller. These rocks are prevailingly soft and contain more or less uncemented, pervious and unconsolidated material. The local distribution of certain units of the Tuscan tuff at the dam site is shown in Plate A-IV, "General Topographic and Geologic Features in the Vicinity of Iron Canyon Dam Site on Sacramento River," which is based on geological mapping by Homer Hamlin. It will be noted that at the dam site the lower part of the proposed dam would rest on what has been called "agglomerate No. 1" in preceding reports *** and that the upper part of the structure would abut against and overlap the "upper tuff." This is shown in Plate A-V, "Geologic Sections at Iron Canyon Dam Site on Sacramento River." At the site, the agglomerate is about 140 feet thick, of which thickness, it has been estimated by the Board of Engineers in their report † of May 7, 1920, about 110 feet is below the bed of the river.

The general structure at the dam site, as shown on Plate A-V, is that of a low anticline, transverse to the river, with the dam site on the southern limb.

There are no faults or structural complications and the feasibility of the site depends upon the lithological character of the foundation material.

Homer Hamlin reported ‡ that:

> "agglomerate No. 1 is a dense and impervious formation suitable for a dam foundation and abutments."

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* Page, 45, "Report on Iron Canyon Project, California," by Homer J. Gault and W. F. McClure, Department of the Interior and State of California, 1920.

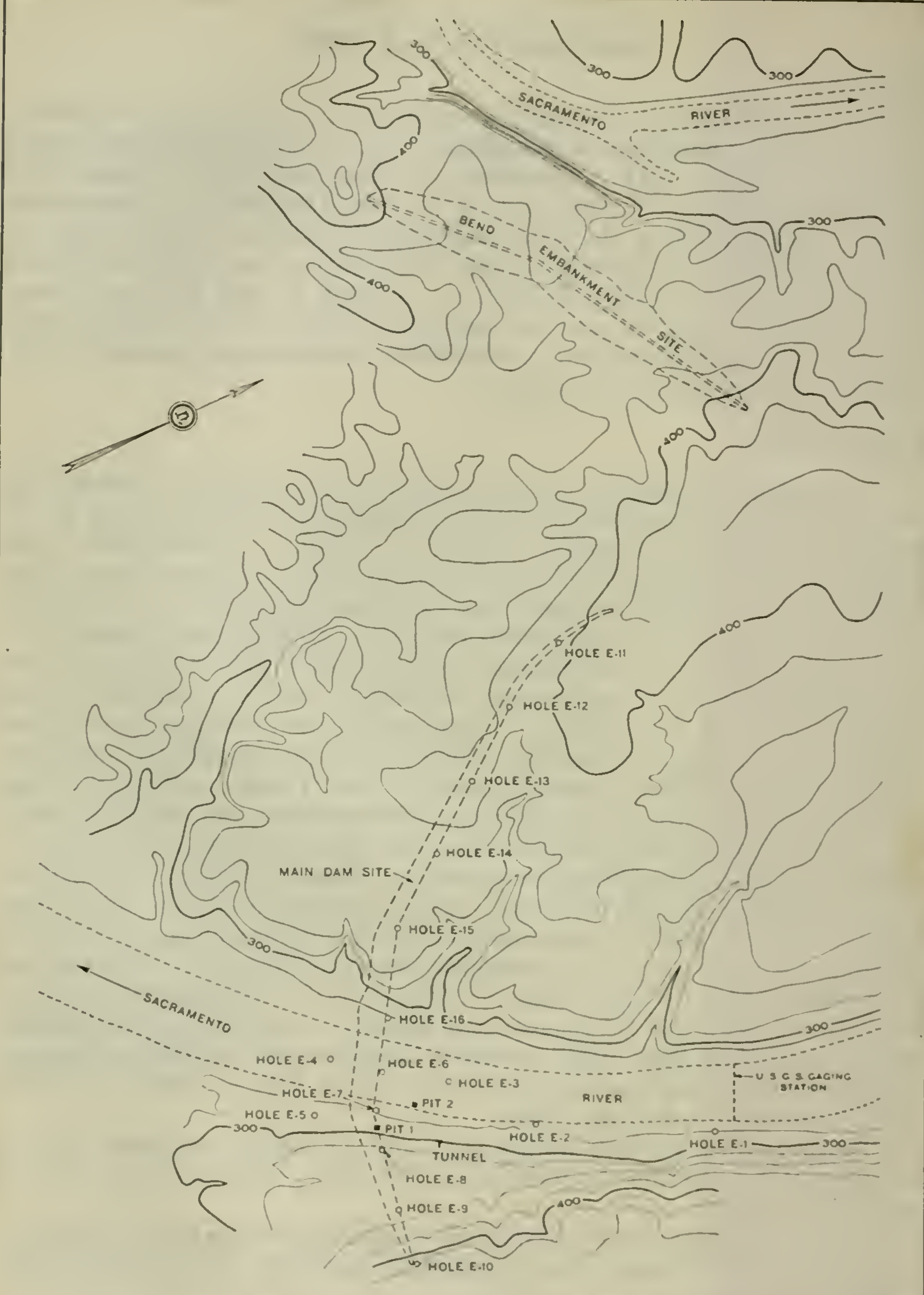
** Page 73, "Report on Iron Canyon Project, California."

*** "Report on Iron Canyon Project, California," by Homer J. Gault and W. F. McClure, Department of the Interior and State of California, 1920.

† Page 64, "Report on Iron Canyon Project, California," by Homer J. Gault and W. F. McClure.

‡ Page 48, "Report on Iron Canyon Project, California," by Homer J. Gault and W. F. McClure.

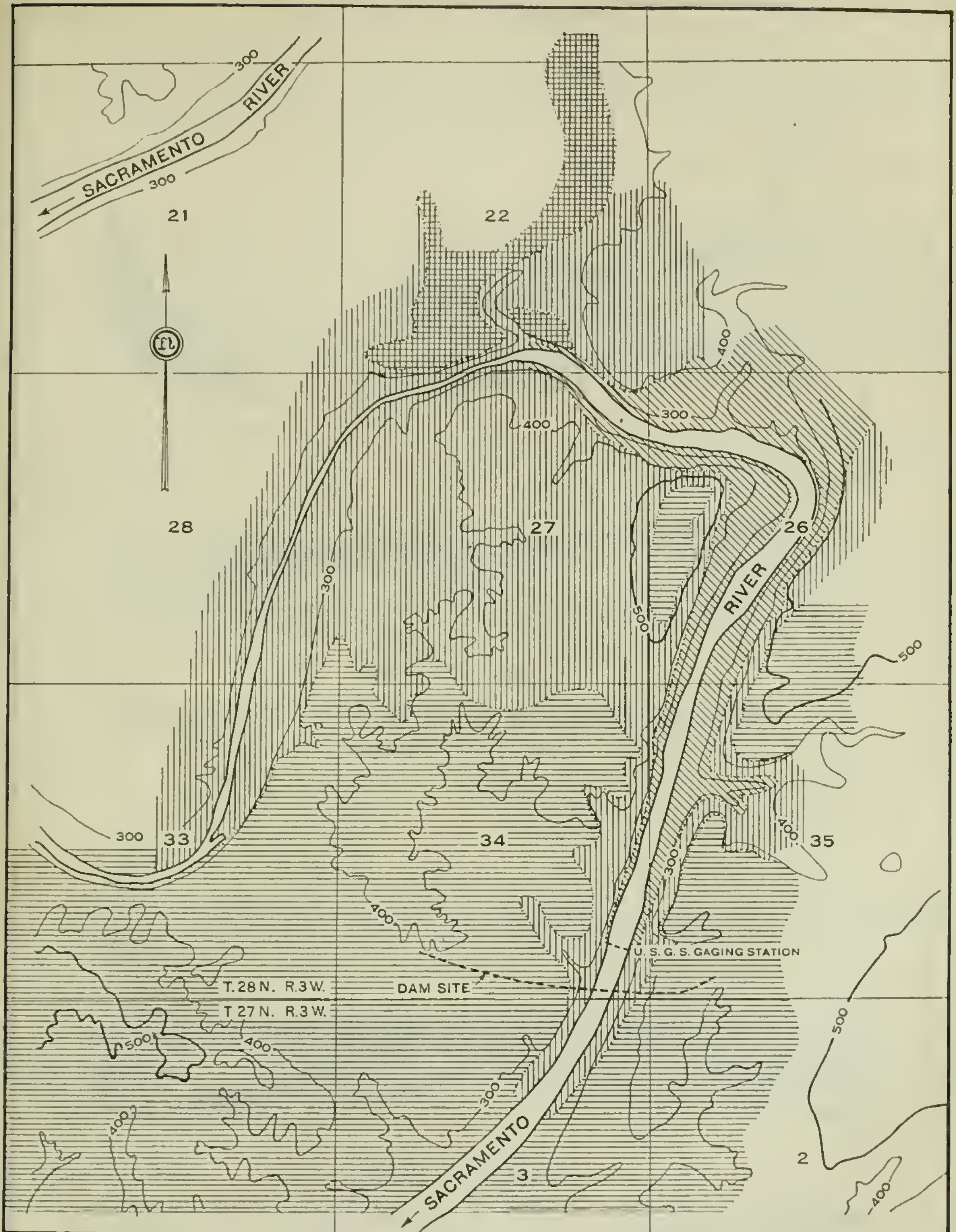
PLATE A-III



LOCATION OF DIAMOND DRILL BORINGS
TEST PITS AND EXPLORATION TUNNEL
AT IRON CANYON DAM SITE
ON SACRAMENTO RIVER

FEET
0 500 1000 1500

PLATE A–IV



GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES
IN THE VICINITY OF
IRON CANYON DAM SITE
ON
SACRAMENTO RIVER

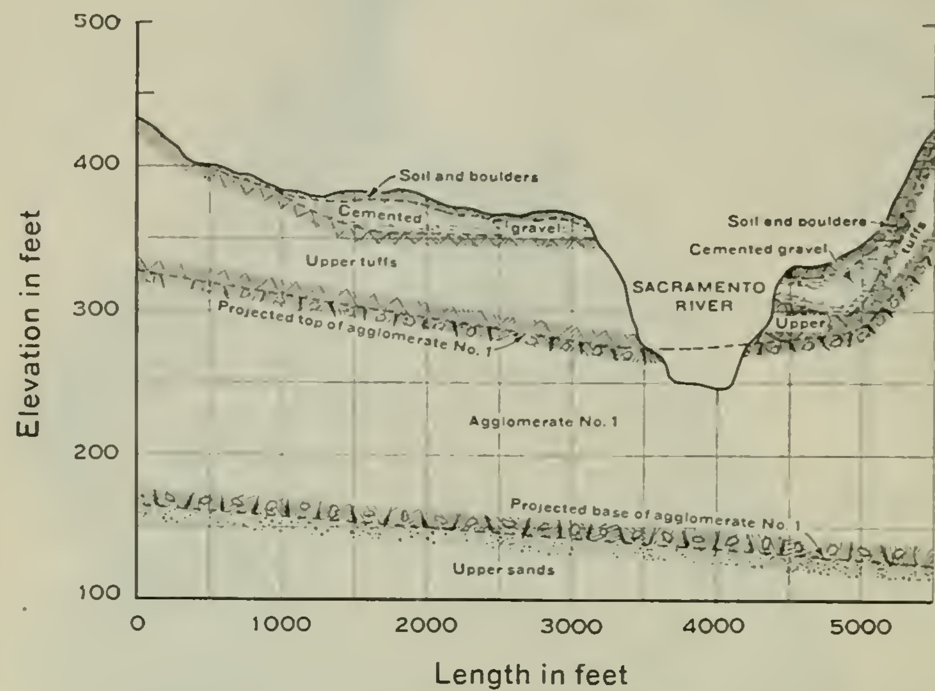
FEET

0 2000 4000 6000

LEGEND

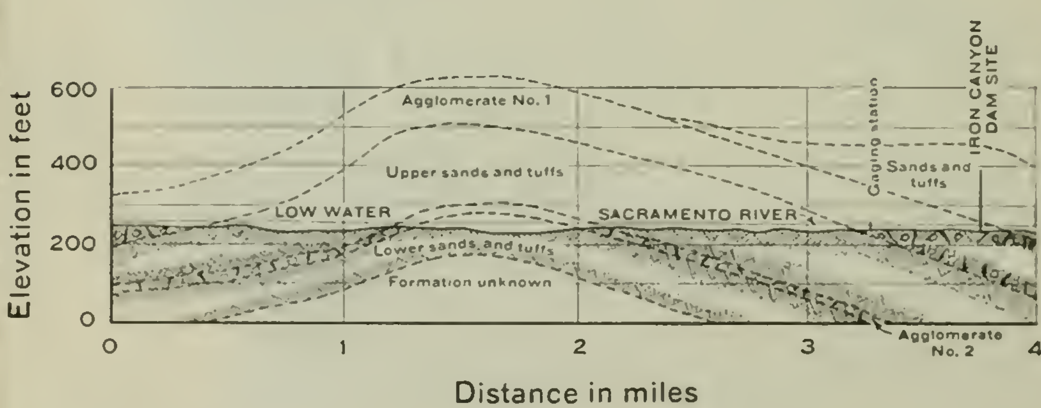
Basalt — Agglomerate No. 1
Upper tuffs — Lower tuffs

PLATE A-V



GEOLOGIC SECTION AT IRON CANYON DAM SITE

LOOKING UPSTREAM



GEOLOGIC SECTION ALONG SACRAMENTO RIVER CANYON

IN VICINITY OF

IRON CANYON DAMSITE

GEOLOGIC SECTIONS

AT

IRON CANYON DAM SITE

ON

SACRAMENTO RIVER

Professor A. C. Lawson says in his report:*

> "The agglomerate is a satisfactory rock for a dam foundation. It has sufficient strength, and, although not homogeneous, is of low permeability. The rate of transmission of water through it would be so slow that there would be practically no leakage. It is not traversed by cracks or joints of importance, nor are there any cavernous openings in it."

The Board of Engineers, in their report of May 7, 1920, state ** that,

> "The principal reason for the selection of Location III was explained in previous paragraphs to be the existence of a mass of agglomerate 110 feet in thickness below the river channel at the dam site. This material where exposed at the surface is a natural concrete which is probably water-tight and has considerable hardness and great bearing power, in every way satisfactory as a foundation for a high concrete dam. The records of borings, however, are not nearly so favorable. The fine binding material in the interior of the mass is rather soft, so that but a small percentage of core was produced. In a drift in the east abutment of the dam also the material becomes rather soft away from air exposure."

However, as a result of a bearing test they concluded ** that the agglomerate would furnish a safe foundation provided the maximum pressures did not exceed ten tons per square foot.

Serious question of the satisfactory character of the agglomerate was raised in a report to the State Engineer under date of February 18, 1930, in which G. D. Louderback called attention to the lack of homogeneity in the agglomerate and to the fact that much of the material is loose and pervious. Subsequent investigation has justified this warning.

The agglomerate, which is composed of blocks and smaller fragments of hard basalt or andesite, possesses a rather remarkable property. Much of the material is loose and permeable, with little or no cementation of the constituent fragments. When exposed to the weather, however, the material becomes superficially cemented, with the formation of a hard, stony crust an inch or two in thickness. Consequently, most natural exposures of the agglomerate give a most deceptive appearance of general hardness, solidity and imperviousness. This peculiarity is well shown in the tunnel, a short distance above the dam site.

The tunnel enters the face of a bluff composed apparently of hard agglomerate. The really hard material, however, is a definite skin or shell, about two inches in maximum thickness. Behind this skin, for a distance of from eight to ten feet, the agglomerate shows some cementation and is fairly firm, although very much softer than the superficial skin. The remaining thirty-five feet of the tunnel is in loose, permeable, crumbling material, which can easily be loosed with a geological pick or can even be pulled down with the fingers. The contrast between the hard face of the bluff and the incoherent material in the tunnel is amazing.

Other exploratory openings at the Iron Canyon site and at the Table Mountain site, some 11.5 miles farther up the river, show that the agglomerate is not everywhere so loose and permeable as in the Iron Canyon test tunnel.

At test pit No. 1, on the east side of the river at the Iron Canyon dam site, which is shown in Plate A-III, the agglomerate is covered with soil and surface material and the hard shell is apparently lacking.

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* Page 74, "Report on Iron Canyon Project, California," by Homer J. Gault and W. F. McClure, Department of the Interior and State of California, 1920.

** Page 66, "Report on Iron Canyon Project, California, by Homer J. Gault and W. F. McClure.

For a depth of 27 feet, the agglomerate, composed of angular blocks of basalt, with finer, interstitial basaltic detritus, is only feebly cemented and can easily be picked down. Near the bottom of the shaft, the material is firmer, but is far from being hard rock. As shown by the inflow of water into the shaft, the agglomerate is obviously permeable, although the rate of inflow has not been measured.

The drill records at the Iron Canyon dam site, which are given in a previous report,* confirm the conclusions drawn from the inspection of the tunnel and shaft. It is obvious from the records and from a brief examination of the cores, that the agglomerate, as penetrated in drilling, is by no means the hard, impervious rock surface exposures might indicate. It is prevailingly soft and loose. Caving is frequently recorded and practically the only core obtained came from embedded blocks or fragments of lava.

Instead of constituting a saving feature of the Iron Canyon dam site, the agglomerate, in our opinion, is less uniform and less trustworthy material than the generally fine-grained tuffs and tuffaceous sandstones which overlie and underlie it.

The tuffs, which make up the greater part of the formation overlying the agglomerate, are only slightly permeable, and the conglomerate contains much interstitial tuffaceous material which prevents free water percolation. Some of the volcanic sand layers are coarsely porous and poorly cemented. They are capable of transmitting water and under its influence may break down into sand and be subject to erosion. In general, they are lenticular and probably would not be effective water carriers where long distances are involved as in the foundation for the Bend embankment. They would present a very serious problem of cutting off leakage around or under the dam at the main site.

The important fact as regards the agglomerate is not that it is everywhere wholly unsatisfactory material for a dam foundation, but that it varies so widely from place to place in degrees of cementation, general hardness and permeability, that very thorough testing would be required at any particular site in order to ascertain whether it could be relied upon as safe foundation material.

In view of the facts already stated, it appears unnecessary to present detailed descriptions of the exploratory work done at the Iron Canyon site and we shall proceed directly to a statement of our conclusions.

Conclusions.

The greatest difficulty at Iron Canyon is at the site of the main dam. Recognition of the true character of the agglomerate at this locality leaves no hard and impermeable rock upon which a dam could be founded. Stability could be obtained only by adapting the design of the dam to a soft and permeable foundation and by cut-offs so extensive as to minimize leakage by making possible paths of percolation exceptionally long. Nowhere at the site is there any hard, strong and impermeable rock upon which concrete could be bonded with the assurance that there would be no leakage around it.

* "Report on Iron Canyon Project, California," by Homer J. Gault and W. F. McClure, Department of the Interior and State of California.

So far as geologists may appropriately express an opinion in the border zone between geology and engineering, we should say the Iron Canyon site does not appear practicable for a concrete dam. It is doubtful whether a rock-fill dam could be constructed here without excessive costs for cut-off precautions.

TABLE MOUNTAIN DAM SITE

Situation.

The Table Mountain dam site on the Sacramento River is situated about ten miles northeast of Red Bluff, in Township 28 North, Range 3 West, M. D. B. and M. The general geology in the vicinity of the site as mapped by Chester Marliave is shown on Plate A-VI, "General Topographic and Geologic Features in the Vicinity of Table Mountain Dam Site on Sacramento River."

Two sites have been suggested at the Table Mountain locality. These are shown on Plate A-VI by lines A-A and B-B. Of these, the lower site, B-B, is the only one at which any exploratory work has been done. Topographically and geologically, site B-B appears preferable to site A-A and is the one to which particular attention will be given in this report. A dam at either site, with crest at elevation higher than 400 feet, would require a subsidiary embankment across a saddle about two miles west of the main dam.

General Geology.

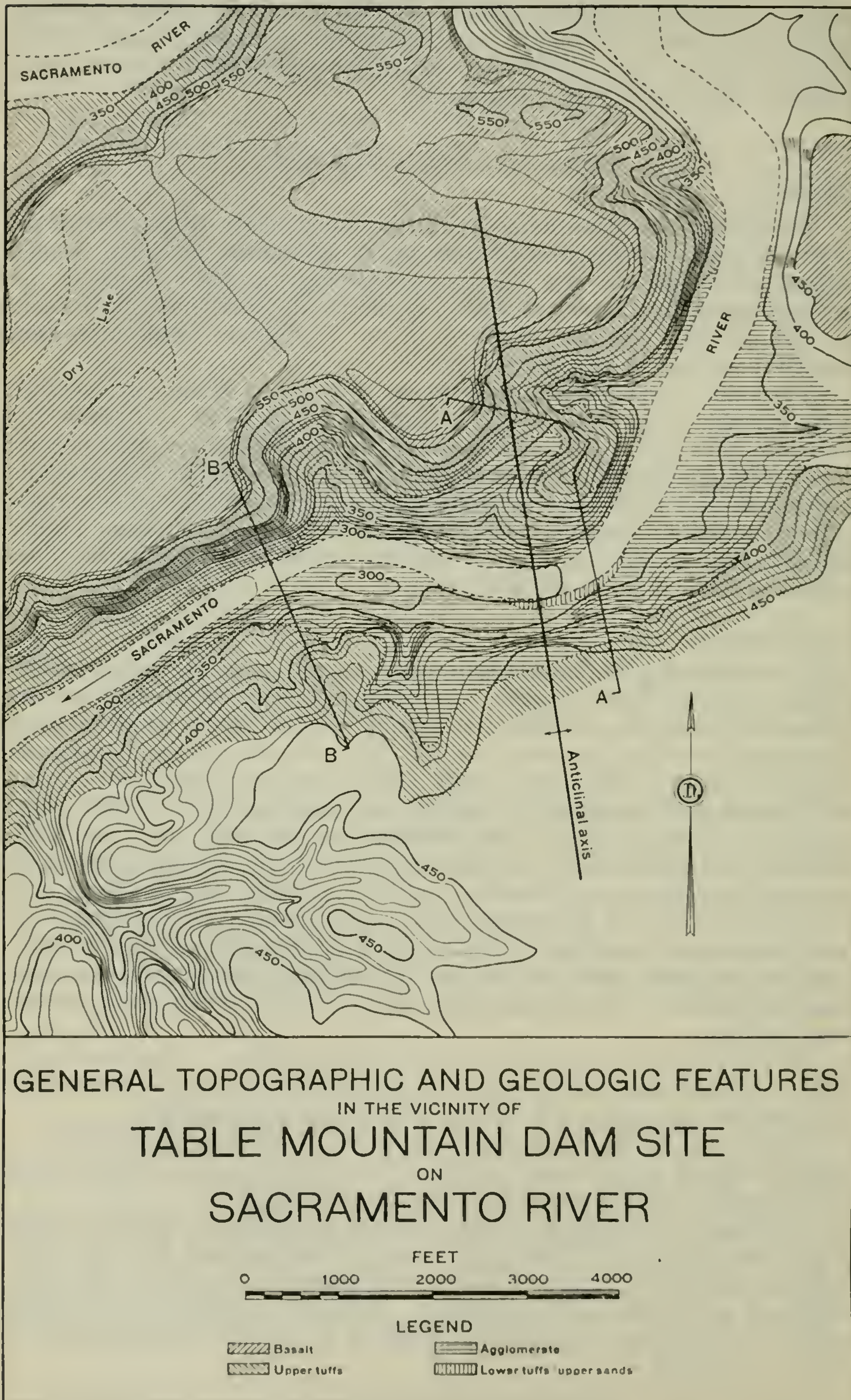
The rocks at the Table Mountain site comprise the same formations as occur in Iron Canyon. In addition, a flow of basalt from six to ten feet in average thickness, resting on the upper tuff, through which the river has cut north of the dam site, forms the flat top of Table Mountain. The lower tuff, the agglomerate, and the upper tuff form a low anticline, of which the axis, pitching a little west of north, is crossed by the river between the two sites A-A and B-B, as shown in Plate A-VI. In the axial part of the anticline, the river has cut through the agglomerate and has exposed about fifteen feet of the upper part of the lower tuff in the vicinity of the line A-A. Test hole records together with surface exposures would seem to indicate a thickness of about 80 feet for the agglomerate close to the river along section B-B. It extends below the low point of the river channel about 28 feet.

Site B-B is on the southern limb of the anticline. The lower part of the proposed dam would rest on agglomerate; the upper part would abut against the upper tuff, which overlies the agglomerate.

There can be no reasonable doubt but that the agglomerate at Table Mountain is the same as that at the Iron Canyon site and that the formation is continuous between the two places.

The upper tuff, which is well exposed in bluffs on the right bank of the river at site B-B and has been further exposed by trenching, varies in character from bed to bed, but generally has about the same coherence as a very soft sandstone. Most of it could be excavated only by blasting, but, on the other hand, it is too soft to be quarried in blocks of any size.

PLATE A-VI



GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES IN THE VICINITY OF TABLE MOUNTAIN DAM SITE ON SACRAMENTO RIVER

The following is a detailed section of the upper tuff, as exposed in the bluffs and by trenching in the west abutment of the proposed dam. The starting point of the measurements was the bottom of the cliff 35 feet above river level. Between this point and the agglomerate exposed at the river is a short interval, covered by soil and rock fragments, where the underlying tuff and agglomerate have not yet been laid bare.

TABLE A-2

SECTION OF UPPER TUFF IN WEST ABUTMENT, TABLE MOUNTAIN DAM SITE B-B

Height above river, in feet	*Description of material*	
143.0–145.0	Tough, light-gray, clay tuff.	
142.0–143.0	Fine, light-gray, sandy tuff. Firm and coherent, no loose sand.	
141.0–142.0	Light-gray, clay tuff. Firm and coherent, no loose sand.	
139.0–141.0	Fine, light-gray, sandy tuff.	
138.0–139.0	Light-gray, clay tuff.	
137.5–138.0	Coarse, tuffaceous sand; porous.	
136.0–137.5	Fine, soft, white, ashy material; light weight. No shaly laminations.	
131.0–136.0	Moderately tough, brownish, clay tuff.	
130.0–131.0	Coarse, tough, pinkish, sandy tuff.	
128.5–130.0	Tough, light-pinkish, clay tuff.	
	From 128.5 up, all practically one material; soft, but coherent, firm tuff.	
126.0–128.5	Coarse, soft tuffaceous sand; coherent; not permeable in a practical sense.	
125.0–126.0	Coarse, light-gray tuffaceous sand; cemented; a soft sandstone.	
124.0–125.0	Medium tough, brownish, clay tuff.	
122.0–124.0	Medium tough, brownish, pebbly tuff.	
121.0–122.0	Tough, brownish, sandy tuff; soft but good firm rock.	
120.0–121.0	Tough, conglomerate tuff; fairly hard and well cemented.	
118.0–120.0	Fine, medium tough, brownish, clay tuff; fairly hard and well cemented.	
117.0–118.0	Fine, medium tough, brownish, sandy tuff; fairly hard and well cemented.	
113.5–117.0	Coarse, medium tough, light-brown tuffaceous sand, fairly hard and well cemented.	
113.0–113.5	Fine, tough, pinkish, tuff; good firm material.	
106.0–113.0	Coarse, hard, light-gray tuff; firm and well cemented.	
104.0–106.0	Coarse, medium-hard, tuffaceous sand; soft sandstone; no loose sand.	
97.0–104.0	Hard, light-gray tuff, with some pebbles.	
91.2– 97.0	Coarse, tough, light-gray tuff.	
91.0– 91.2	Coarse, hard, gray, sandy tuff.	All well cemented, firm soft rock; forms a natural cliff.
69.0– 91.0	Medium tough, gray, sandy tuff.	
86.0– 89.0	Medium tough, light-brown sandy tuff.	
85.0– 86.0	Medium tough, gray, sandy tuff.	
80.0– 85.0	Medium tough, brownish-gray, sandy tuff.	
77.0– 80.0	Medium tough, brownish-gray, sandy tuff.	
76.5– 77.0	Fine, tough, gray tuffaceous sand, no loose sand.	
71.0– 76.5	Tough, brownish tuff.	
68.5– 71.0	Fine, medium-tough gray, tuffaceous sand; soft, tuffaceous sandstone.	
68.0– 68.5	Fine, light-gray, ashy tuff; firm and coherent.	
64.0– 68.0	Medium tough, brown, tuff; firm and coherent.	
60.0– 64.0	Medium tough conglomerate; fairly well cemented.	
59.0– 60.0	Medium tough, gray, pebbly, sandy tuff; fairly well cemented.	
57.0– 59.0	Medium tough, brown, sandy tuff; fairly well cemented.	
55.0– 57.0	Medium tough, pinkish gray sandy tuff; fairly well cemented.	
54.7– 55.0	Brittle, tough, pink tuff; firm material.	
54.5– 54.7	Tough, yellow to white tuff; firm material.	
53.5– 54.5	Brittle, tough, pinkish-gray, shaly tuff; firm material.	
52.5– 53.5	Fine, medium tough pinkish-gray tuff; firm material.	
52.0– 52.5	Soft, light-gray, ashy tuff; firm material.	
47.0– 52.0	Fine, medium tough, gray tuffaceous sand; soft tuffaceous sandstone.	
45.5– 47.0	Coarse, tough, gray, sandy tuff, soft, tuffaceous sandstone.	
44.7– 45.5	Coarse, tough, blue to gray, tuffaceous sand; soft tuffaceous sandstone.	
44.0– 44.7	Fine, tough, light-gray, sandy tuff; soft, tuffaceous sandstone.	
41.4– 44.0	Alternating gravel and sand; fairly well cemented and firm.	
40.0– 41.4	Hard, tough, light-gray sandy tuff; fairly well cemented and firm.	
38.0– 40.0	Medium tough, brown to red clay tuff; argillaceous; probably soft when wet.	
35.0– 38.0	Tough, brown, conglomerate tuff; well cemented.	

Test Borings.

A series of test holes have been drilled along the center line of the dam site, Section B-B, and along a line approximately at right angles to it on the left bank of the river. On both lines the end holes are about 2000 feet apart. The locations are indicated on the map, Plate A-VII, "Location of Diamond Drill Borings, Test Pits and Exploration Tunnels at Table Mountain Dam Site on Sacramento River." The following statements of test hole data and comments were prepared by G. D. Louderback on the basis of the driller's logs and on examination of the samples.

TABLE A-3

LOGS OF TEST BORINGS AT TABLE MOUNTAIN DAM SITE

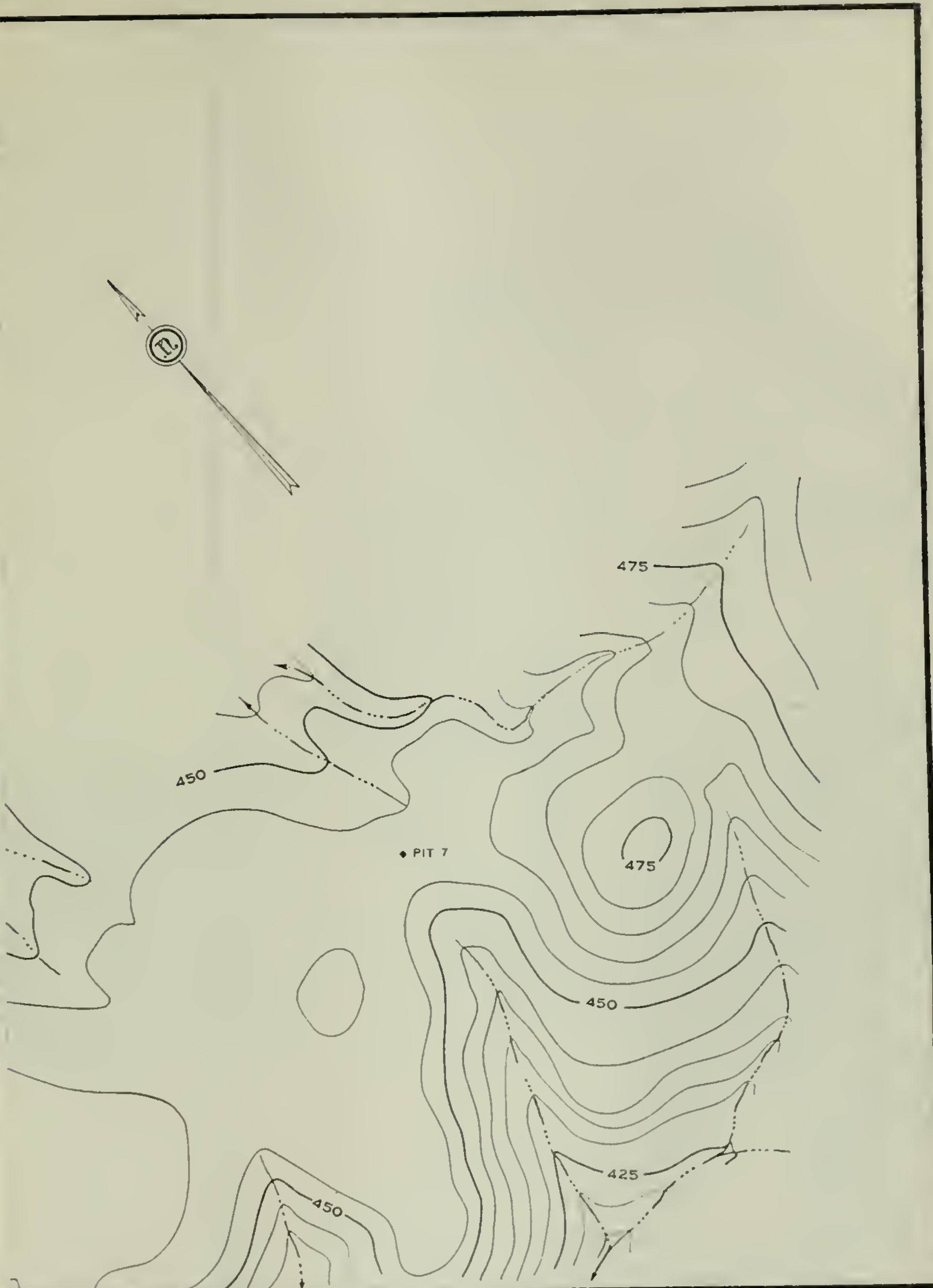
TEST HOLE NO. 1

On Right Bank of River, on Center Line—Elevation 297.7 Feet

Depths, in feet	*Length of core, in feet*	*Per cent of recovery of core*	*Description of formations and cores*	
0.0– 3.0	0.0	0.0	River sand.	
3.0– 8.0	1.8	36.0	Core sections represent lava fragments ("plums").	Volcanic agglomerate
8.0– 10.0	0.5	25.0	Some firm slightly reddish matrix recovered.	
10.0– 20.0	1.0	10.0	Core of lava fragments only.	
20.0– 21.5	0.7	46.6	Core of lava fragments with a little attached matrix.	
21.5– 28.7	2.9	40.2	Core of lava fragments only.	
28.7– 37.0	0.0	0.0	Four small fragments of core.	
37.0– 38.0	0.4	40.0	Small fragments of core only.	
38.0– 41.0	3.0	100.0	Core from one lava block.	
41.0– 42.0	0.6	60.0	Core from lava block—same as 38-41 feet.	
42.0– 44.0	0.4	20.0	Core from lava fragments only.	
44.0– 47.0	1.9	63.4	Core from lava block.	
47.0– 50.5	1.2	34.3	Core from lava block.	
50.5– 56.0	1.7	30.9	Agglomerate matrix with lapilli.	
56.0– 61.0	1.8	36.0	Core (in pieces) from one lava block.	
61.0–108.0	12.4	26.3	Volcanic tuff with black scoriaceous and light pumiceous fragments (various runs yield from 3.1 to 73.4 per cent core).	
108.0–113.0	0.0	0.0	Some coarse black sand recovered.	
113.0–139.0	0.0	0.0	Fine sand in return water.	
139.0–140.0	0.6	60.0	Fine tuffaceous sand and silt, firm.	
140.0–150.3	0.0	0.0	Fine sand in return water.	

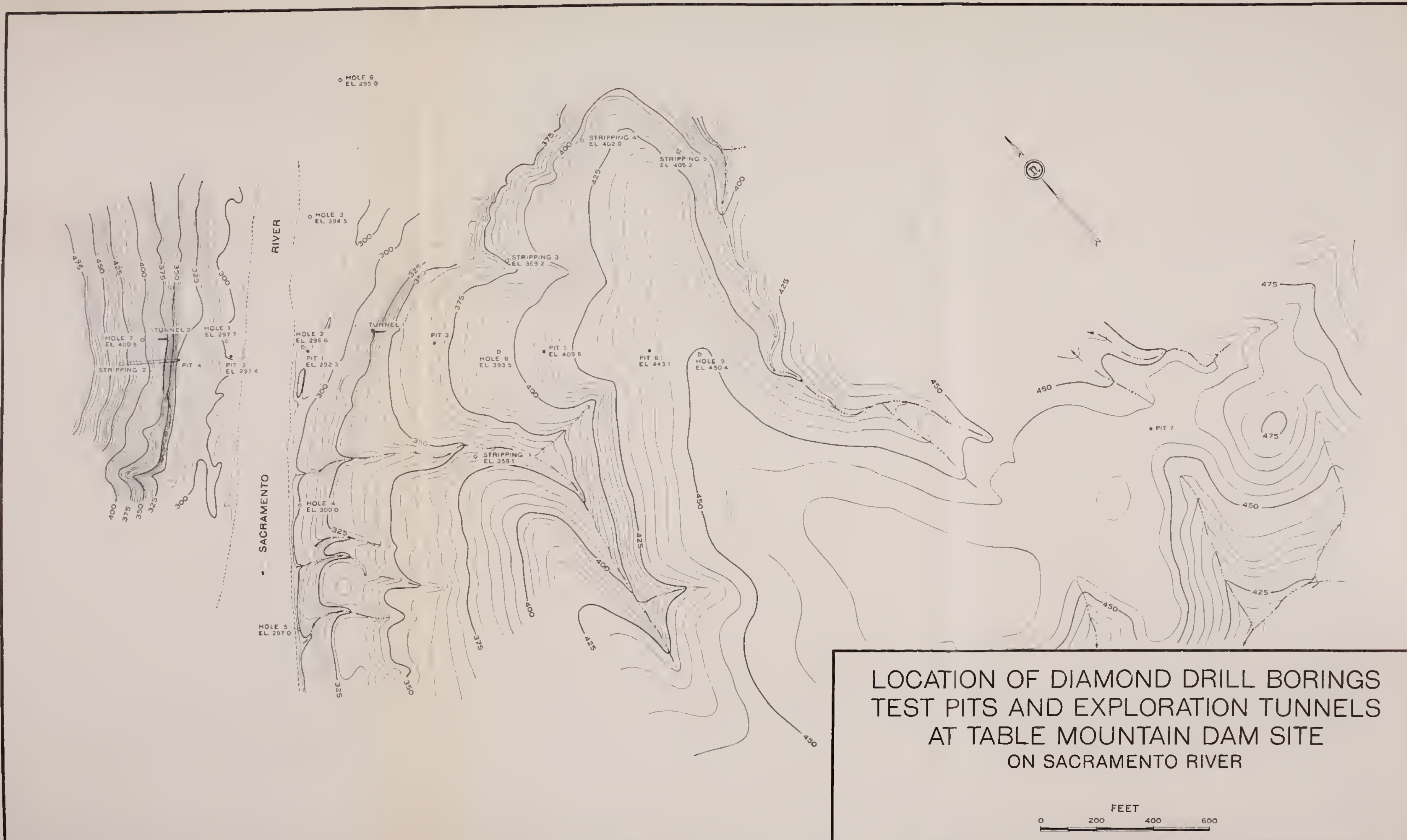
Volcanic agglomerate from 3 to 61 feet or 58 feet of hole; total core 17.9 feet or 30.8 per cent, practically all from the hard lava blocks that occur in the agglomerate. Less than one-half of one per cent was of agglomerate matrix. Pumiceous tuff from 61–108 feet, or 47 feet of hole; total core 12.4 feet or 26.3 per cent. The lowest 42.3 feet of hole appears to be chiefly in uncemented sands which yielded no core, except for one foot of silty material which yielded 60 per cent core.

While not noted in the log, this hole, when visited January 25, 1931, although it was capped, was flowing quite a stream of warm, sulphuretted water.



'ION OF DIAMOND DRILL BORINGS
PITS AND EXPLORATION TUNNELS
T TABLE MOUNTAIN DAM SITE
ON SACRAMENTO RIVER

FEET
0 200 400 600



LOCATION OF DIAMOND DRILL BORINGS
TEST PITS AND EXPLORATION TUNNELS
AT TABLE MOUNTAIN DAM SITE
ON SACRAMENTO RIVER

FEET
0 200 400 600

TEST HOLE NO. 2

On Left Bank of River, on Center Line—Elevation 296.6 Feet

Depths, in feet	*Length of core, in feet*	*Per cent of recovery of core*	*Description of formations and cores*	
0.0– 5.0	0.0	0.0	River sand.	
5.0– 11.0	1.5	25.0	About 1.2 foot of core represents lava blocks, 0.3 foot firm matrix.	
11.0– 16.0	1.4	28.0	About 0.7 foot of core represents lava block; about 0.7 foot firm matrix.	
16.0– 22.0	0.4	6.8	Core of lava fragments only.	
22.0– 28.0	0.6	10.0	Core of lava fragments only.	
28.0– 32.0	1.0	25.0	Core of lava fragments only, except for 0.1 foot matrix.	
32.0– 37.0	0.2	4.0	Core of lava fragments only.	Volcanic agglomerate
37.0– 41.0	1.4	35.0	Core is 0.9 foot matrix; 0.5 foot lava block.	
41.0– 44.0	0.4	13.3	Core is 0.2 foot matrix; 0.2 foot lava fragment.	
44.0– 47.0	0.7	23.3	Core is 0.4 foot matrix; 0.3 foot lava fragment.	
47.0– 49.0	0.6	30.0	Core is lava fragment only.	
49.0– 56.0	1.0	14.3	Tuff with black vesicular fragments and pumice.	
56.0– 67.0	0.0	0.0	Only some grayish sand recovered from return water.	
67.0– 79.0	3.1	25.8	Tuff with scoriaceous and pumiceous fragments.	
79.0– 93.0	1.4	10.0	Same as 67–79 feet.	
93.0– 94.0	0.8	80.0	Core from one piece of vesicular lava.	
94.0– 96.0	1.3	65.0	Pumiceous tuff as before.	
96.0– 97.0	0.0	0.0	Black sand in return water.	
97.0–140.0	0.0	0.0	Fine silty sand recovered from water.	
140.0–150.1	1.6	16.0	Very fine clayey sand.	

Hole cemented at 79–80 feet.

In general, drill penetrated by its own weight.

When drill and casing were removed, warm water with hydrogen sulphide odor flowed out at 29 gallons per minute. Well capped, but on January 25, 1931, water was flowing out through a leak.

Volcanic agglomerate, 5–49 feet or 44 feet of hole; total core 8.2 feet or 18.6 per cent of which 2.6 feet (5.8 per cent) was of matrix, the rest of lava fragments. Pumiceous tuff 49–96 feet or 47 feet of hole, the same thickness as in hole No. 1; total core 7.6 feet or 16.1 per cent. As in hole No. 1, the lower part is made up of uncemented sands, the fine clayey sands yielding a small amount of core, the coarser ones, loose and porous, carry water.

At 97 feet, struck artesian flow of 5 gallons per minute. Tried to cement but failed twice as cement washed out before it could harden. Sank 2¼-inch casing and changed to 1⅜-inch hole.

TEST HOLE NO. 2

On Left Bank of River, on Center Line—Elevation 296.6 Feet

Depths, in feet	*Length of core, in feet*	*Per cent of recovery of core*	*Description of formations and cores*	
0.0– 5.0	0.0	0.0	River sand.	
5.0– 11.0	1.5	25.0	About 1.2 foot of core represents lava blocks, 0.3 foot firm matrix.	Volcanic agglomerate (5.0–49.0)
11.0– 16.0	1.4	28.0	About 0.7 foot of core represents lava block; about 0.7 foot firm matrix.	
16.0– 22.0	0.4	6.8	Core of lava fragments only.	
22.0– 28.0	0.6	10.0	Core of lava fragments only.	
28.0– 32.0	1.0	25.0	Core of lava fragments only, except for 0.1 foot matrix.	
32.0– 37.0	0.2	4.0	Core of lava fragments only.	
37.0– 41.0	1.4	35.0	Core is 0.9 foot matrix; 0.5 foot lava block.	
41.0– 44.0	0.4	13.3	Core is 0.2 foot matrix; 0.2 foot lava fragment.	
44.0– 47.0	0.7	23.3	Core is 0.4 foot matrix; 0.3 foot lava fragment.	
47.0– 49.0	0.6	30.0	Core is lava fragment only.	
49.0– 56.0	1.0	14.3	Tuff with black vesicular fragments and pumice.	
56.0– 67.0	0.0	0.0	Only some grayish sand recovered from return water.	
67.0– 79.0	3.1	25.8	Tuff with scoriaceous and pumiceous fragments.	
79.0– 93.0	1.4	10.0	Same as 67–79 feet.	
93.0– 94.0	0.8	80.0	Core from one piece of vesicular lava.	
94.0– 96.0	1.3	65.0	Pumiceous tuff as before.	
96.0– 97.0	0.0	0.0	Black sand in return water.	
97.0–140.0	0.0	0.0	Fine silty sand recovered from water.	
140.0–150.1	1.6	16.0	Very fine clayey sand.	

Hole cemented at 79–80 feet.

In general, drill penetrated by its own weight.

When drill and casing were removed, warm water with hydrogen sulphide odor flowed out at 29 gallons per minute. Well capped, but on January 25, 1931, water was flowing out through a leak.

Volcanic agglomerate, 5–49 feet or 44 feet of hole; total core 8.2 feet or 18.6 per cent of which 2.6 feet (5.8 per cent) was of matrix, the rest of lava fragments. Pumiceous tuff 49–96 feet or 47 feet of hole, the same thickness as in hole No. 1; total core 7.6 feet or 16.1 per cent. As in hole No. 1, the lower part is made up of uncemented sands, the fine clayey sands yielding a small amount of core, the coarser ones, loose and porous, carry water.

At 97 feet, struck artesian flow of 5 gallons per minute. Tried to cement but failed twice as cement washed out before it could harden. Sank $2\frac{1}{4}$-inch casing and changed to $1\frac{3}{8}$-inch hole.

TEST HOLE NO. 3

On Left Edge of River, 500 Feet Above Center Line—Elevation 294.5 Feet

Depths, in feet	*Length of core, in feet*	*Per cent of recovery of core*	*Description of formations and cores*	
0.0– 10.0	1.4	14.0	Core is 0.3 foot of matrix; 1.1 feet from lava blocks.	Volcanic agglomerate
10.0– 13.0	0.2	6.7	Core is 2 small pieces of lava fragment; slight amount of adhering matrix.	
13.0– 23.0	0.0	0.0	Blackish volcanic sand in return water.	
23.0– 24.0	0.4	40.0	Core is small lava fragments.	
24.0– 32.0	2.4	30.0	Core is chiefly from lava block; some adhering matrix.	
32.0– 39.5	0.8	9.4	Core is about 0.4 foot lava fragment; 0.4 foot matrix.	
39.5– 42.0	2.0	80.0	Lava blocks and firm matrix.	
42.0– 44.0	1.0	50.0	Core from lava fragments.	
44.0– 53.0	6.3	70.0	Core all from one large lava block.	
53.0– 55.0	0.7	20.0	Core from vesicular lava block.	
55.0– 58.0	0.4	13.3	Mixed run; probably a layer of sand with some pebbles or small lava fragments, passing into tuff. All water lost.	
58.0– 78.0	1.2	6.0	Volcanic tuff with scoriaceous and pumiceous fragments.	
78.0– 90.0	0.0	0.0	Some blackish volcanic sand recovered.	
90.0–100.0	0.0	0.0	Only a few small pebbles in sample.	

Full sack of cement used at 55 feet, no cement recovered (ineffective).
190 pounds pressure delivered 10 gallons per minute with no return to surface.
Volcanic agglomerate for 55 feet of hole; 15.2 feet of core or 27.6 per cent.

TEST HOLE NO. 4

On Left Bank of River, 500 Feet South of Center Line—Elevation 300.0 Feet

Depths, in feet	*Length of core, in feet*	*Per cent of recovery of core*	*Description of formations and cores*	
0.0– 1.0	0.0	0.0	River sand.	
1.0– 5.0	1.5	30.0	Core from lava blocks only.	
5.0– 9.0	3.7	92.5	Core from close spaced lava fragments; only a small amount of matrix.	
9.0– 11.0	2.0	100.0	Core from lava fragment.	
11.0– 15.0	1.8	45.0	Core from lava fragments only.	
15.0– 22.0	6.5	92.8	Core from closely packed lava fragments.	
22.0– 25.0	1.4	46.6	Core from red based firm agglomerate.	
25.0– 29.0	4.0	100.0	Core, 1 foot firm matrix; 2 feet lava block; 1 foot firm matrix.	
29.0– 30.0	0.9	90.0	Core from a lava block.	Volcanic agglomerate
30.0– 34.0	2.3	57.5	Core from firm agglomerate.	
34.0– 36.0	1.4	70.0	Core from firm agglomerate with lava block.	
36.0– 37.0	0.5	50.0	Core from lava block.	
37.0– 49.0	5.0	41.6	Core from lava blocks and firm agglomerate matrix.	
49.0– 51.0	0.4	20.0	Core from lava fragments only.	
51.0– 53.0	0.8	40.0	Core from lava fragments only.	
53.0– 55.5	2.1	84.0	Core about half from lava fragments half from matrix.	
55.5– 60.0	1.5	33.3	Core from firm matrix agglomerate.	
60.0– 63.0	0.7	23.3	Core from lava fragments only.	
63.0– 73.0	2.4	24.0	Core from lava fragments with some matrix.	
73.0– 74.0	0.7	70.0	Core from lava block only.	
74.0– 83.0	3.3	36.6	Core from brownish tuff with black vesicular, light pumiceous and pink volcanic fragments.	
83.0–102.0	0.0	0.0	Only dark colored sand with quartz grains recovered from return water.	

The volcanic agglomerate in this hole is characterized in part by a crowding together of volcanic blocks, and in part by an unusual amount of firm matrix. This results in a higher than normal core recovery. It was found from 1 to 74 feet in depth, or 73 feet of hole. Total core 39.6 feet or 54.2 per cent.

While not noted at time of drilling, when visited January 25, 1931, this hole was flowing artesian water through a leak in casing and undermining a concrete slab that had been placed at the collar.

TEST HOLE NO. 5

On Left Bank of River, About 1000 Feet Below Center Line—Elevation 297.0 Feet

Depths, in feet	*Length of core, in feet*	*Per cent of recovery of core*	*Description of formations and cores*	
0.0– 4.5	0.0	0.0	River sand.	
4.5– 5.0	0.8	80.0	Core from volcanic blocks only.	
5.0– 14.0	3.2	35.5	Core from blocks and firm matrix.	
14.0– 27.0	3.0	23.0	Core from lava fragments only.	
27.0– 37.0	1.2	12.0	Core from one red vesicular lava block only.	
37.0– 48.0	0.3	2.7	Two small fragments of core, dark red, no sand in return water.	Volcanic agglomerate
48.0– 51.0	1.4	46.6	Core from one lava block.	
51.0– 59.0	2.0	25.0	Core from one lava block.	
59.0– 61.0	0.2	10.2	Core from lava block.	
61.0– 88.0	1.0	3.7	Core from blocks and fragments only.	
88.0–101.0	0.0	0.0	Sand recovered in dry barrel; heaviest delivery of water got no return.	

Agglomerate rather definitely from 4 to 61 feet or 57 feet of hole; core recovered 12.1 feet or 21.2 per cent. If agglomerate goes to 88 feet, it represents 84 feet of hole, with 13.1 feet of core or 15.6 per cent.

Cemented three times down to 48 feet in attempt to prevent caving of pebbles and rocks.

Cemented at 62 feet but could not get water back.

29—80994

TEST HOLE NO. 6

On Left Bank of River, About 1000 Feet Above Center Line—Elevation About 295 Feet

Depths, in feet	*Length of core, in feet*	*Per cent of recovery of core*	*Description of formations and cores*	
0.0– 6.0	2.0	33.3	Gray agglomerate; hard and firm.	
6.0– 12.0	1.5	25.0	Gray agglomerate; matrix less firm.	
12.0– 14.0	1.2	60.0	Reddish agglomerate varying firmness.	
14.0– 20.0	1.5	25.0	Reddish agglomerate varying firmness.	
20.0– 22.0	1.8	90.0	Core from lava block.	
22.0– 26.0	0.6	15.0	Core is small pieces from lava fragments.	Volcanic agglomerate
26.0– 31.0	1.0	20.0	Core is mostly from lava fragments; only little matrix.	
31.0– 56.0	0.1	0.4	Core is one piece of blackish tuff or agglomerate; blackish sand in return water.	
56.0– 67.0	4.0	36.4	Core is grayish volcanic tuff with lapilli of obsidian, pumice and dacite(?).	
67.0– 72.0	0.0	0.0	Sand; dry barrel sample.	
72.0–101.0	0.5	1.7	Core is a few small pieces of blackish sandstone.	

Agglomerate from surface to 56 feet; 9.7 feet of core or 17.3 per cent.
At 52 feet lost all water; not recovered to bottom of hole.

TEST HOLE NO. 7

On Right Abutment, About 350 Feet From River, on Center Line—Elevation 400.5 Feet

Depths, in feet	*Length of core, in feet*	*Per cent of recovery of core*	*Description of formations and cores*
0.0– 2.0	2.0	100.0	Sandy tuff with small lapilli and some pumice; pale brown; soft cutting; somewhat porous.
2.0– 16.0	0.0	0.0	Light earthy material in return water.
16.0– 26.0	3.4	34.8	Light brownish earthy tuff with small lapilli and pumice; some streaks sandy; last foot of core fine clayey tuff.
26.0– 32.0	0.0	0.0	Brownish rounded to angular, chiefly volcanic, sand in return water.
32.0– 37.0	0.8	16.0	Tuffaceous sandstone, with small pebbles; cuts easily.
37.0– 44.0	0.0	0.0	Sand (as between 26.0 and 32.0) in return water.
44.0– 48.0	0.4	10.0	Pale brown very fine sandy tuff with small lapilli.
48.0– 57.0	0.3	3.3	48–51 feet, apparently gravel; at 51 feet caves occurred in hole; loose.
57.0– 61.0	0.7	17.5	Only pebbles recovered.
61.0– 64.0	0.0	0.0	Light brownish very fine sand in return water.
64.0– 85.0	0.3	1.4	Only a few pebbles recovered.
85.0–102.0	0.0	0.0	Fine sand recovered in return water.

Hole in "upper tuffs" only.

TEST HOLE NO. 8

On Left Abutment, About 800 Feet From River, on Center Line—Elevation 393.5 Feet

Depths, in feet	*Length of core, in feet*	*Per cent of recovery of core*	*Description of formations and cores*
0.0– 10.0	0.4	4.0	Yellowish brown sand and small pebbles. River terrace material.
10.0– 26.0	0.5	3.0	Sand mixed pebbles. River terrace material.
26.0– 30.0	0.0	0.0	Fine sand in return water. From tuffaceous sand (?).
30.0– 35.0	0.0	0.0	Coarse sand in return water; 2 volcanic pebbles.
35.0– 40.0	0.3	6.0	Fine sand in return water; core is fragments, 4 tuff and 1 basalt fragment.
40.0– 45.0	0.1	2.0	Dark brown fine volcanic sand, and 2 small volcanic fragments.
45.0– 50.0	0.5	10.0	Volcanic sand in return water; core, small fragments of tuff and lapilli.
50.0– 72.0	0.0	0.0	Fine volcanic sand, angular to roundish, in return water.
72.0– 85.0	0.0	0.0	Medium volcanic sand in return water; some fragments up to ½ inch.
85.0– 87.0	0.0	0.0	Fine sand in return water.
87.0– 94.0	0.0	0.0	Coarse sand in return water, some fragments up to ¼ inch.
94.0–100.3	0.0	0.0	Fine sand in return water.

Sand and gravel caved into hole each time pipe was withdrawn.

Not clear whether agglomerate was penetrated or not—probably was not.

From the general dip of the layer and determination of the outcrops, one would expect the agglomerate to be struck at about 28 feet in this hole and extend to the bottom of the hole. The very small amount of core, 0.9 foot for 74.3 feet of hole (below the river terrace alluvium), 1.2 per cent, is unusual for the agglomerate, the lava blocks of which may be expected to yield cores. The six holes along the river show recoveries varying from 15.6 to 54.2 per cent of core. The very poor recovery in this hole makes it uncertain as to the type of material penetrated. If it is agglomerate, it is remarkably weak as judged from the lack of core and the persistent caving.

TEST HOLE NO. 9

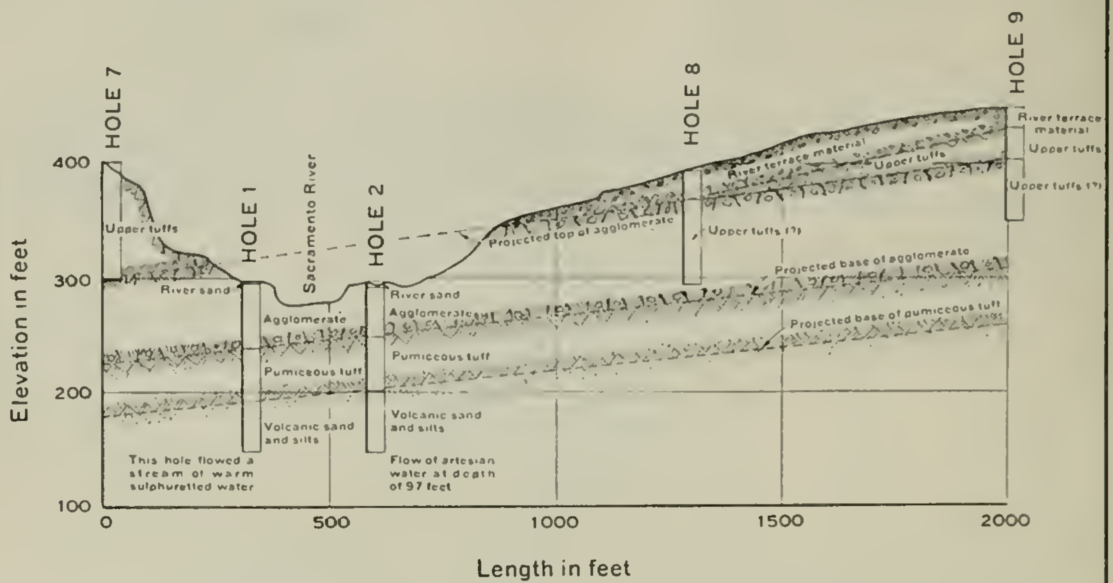
On Left Abutment, About 1600 Feet From River, on Center Line—Elevation 450.4 Feet

Depths, in feet	*Length of core, in feet*	*Per cent of recovery of core*	*Description of formations and cores*
0.0– 10.0	0.3	3.0	Sandy with reddish clayey matrix with a few pebbles. Red Bluff formation (?). River terrace material.
10.0– 15.0	0.0	0.0	Fine sand with reddish brown clay recovered in return water. River terrace material.
15.0– 18.0	0.0	0.0	Sand, some clay; 3 pebbles (pre-tuff material). River terrace material.
18.0– 19.0	0.3	30.0	One piece of andesite.
19.0– 24.0	0.6	12.0	Core from lava fragments.
24.0– 36.0	0.4	3.3	Coarse sand from return water. Core is one piece of tuff (1 inch) and 1 piece of lava.
36.0– 95.0	0.0	0.0	Coarse sand from return water, occasional coarser fragments to 1/16 inch or more.
95.0–101.0	0.0	0.0	Finer sand and some clay.

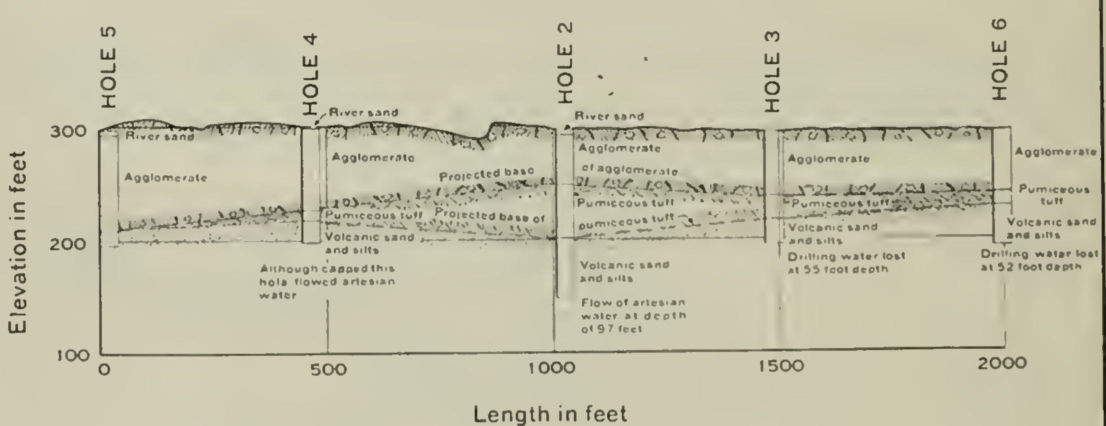
The upper 18 feet are in ancient river sand and gravel, probably representing high bench or terrace of Pleistocene age. The hole apparently does not penetrate the agglomerate of the immediate dam site although the outcrop and dip would suggest that it should be penetrated in the lower 50 feet of hole. From this stretch, no core was recovered.

Geological sections along the line of the test holes on the center line of the dam site and along the line at right angles to it on the left bank of the river are shown on Plate A-VIII, "Geologic Sections at Table Mountain Dam Site on Sacramento River."

PLATE A-VIII



GEOLOGIC SECTION ALONG LINE OF DRILL HOLES 7 TO 9
ON CENTER LINE OF DAM SITE



PROFILE ALONG LINE OF DRILL HOLES 5 TO 6
AT RIGHT ANGLES TO DAM SITE, ON LEFT BANK OF RIVER

GEOLOGIC SECTIONS
AT
TABLE MOUNTAIN DAM SITE
ON
SACRAMENTO RIVER

The Volcanic Agglomerate.

At the proposed dam site the base of the dam would rest on the volcanic agglomerate which would also form the greater part or all of the left abutment. Surface examination, aided by pits seemed to indicate that this formation is firmer and better cemented than at the Iron Canyon site, but the series of test holes, detailed above, shows that it has the same extreme and irregular variability of cementation and effective composition. While parts are firm and give reasonably good cores, some parts yield only sand, with a few small bits of lava, and cave badly. Tunnel 1, shown on Plate A-VII, was driven into the agglomerate of the left bank of the river at about elevation 325 feet. On January 25, 1931, this tunnel was about 40 feet in length. The outer 20 feet is fairly firm but the material becomes gradually softer and near the face the lava fragments may be easily picked out and the matrix crumbled by the hand. One soft plastic clay pocket was observed. It should be noted that at the top of the cliff into which the tunnel was driven there is a flat, so that depth from surface varies but slowly with length of tunnel. As the hardening of the agglomerate often seems related to the surface, this may account for the fact that the change in firmness takes place more slowly than in the Iron Canyon tunnel. The great variability in firmness of the agglomerate makes it an unsatisfactory foundation for a rigid type of dam.

The Upper Tuffs and Sands.

The upper tuffs form the right abutment and are encountered high in the slopes of the left abutment. They are distinctly stratified, different layers varying in grain from sandy to earthy or clayey. As stated above, they in general have the coherence of a very soft sandstone, although some of the layers are distinctly stronger. Certain of the layers are very pervious and allow of the rapid percolation of water. Special field percolation tests were made in tunnel 2 cut into the tuffs on the right bank at about elevation 375 feet, as shown on Plate A-VII. This showed that the tuff absorbed water readily. A layer of soft sand was exposed in this tunnel, and other layers of soft porous volcanic sand were observed in the base of the cliff downstream from the center line, and higher up the cliff, upstream from the center line. Here the tendency was observed for the sand to wash out giving rise to holes in the layer and a bench-like recess with overhang of the firmer layers of tuff. It is believed that it would be very difficult, if not impossible, to prevent percolation through the tuffs with possible weakening of the abutment.

Pumiceous Tuff.

In five of the holes along the river (1, 2, 3, 4 and 6) a pumiceous tuff was observed below the agglomerate. This is a rather soft moderately firm tuff that yielded from 6 to 36 per cent of core. In two of the holes (5 and 6), a sand layer appears to be between the base of the agglomerate and the top of the tuff. Whatever the composition, a very porous layer was encountered which caused all the water to be lost.

Sands and Tuffs (?).

Below the pumiceous tuff only sand was recovered and no core except for 0.6 foot in hole 1 and 1.6 feet in hole 2, of fine silty-clayey sand. In three of the holes (1, 2 and 4) these sands yielded warm, sulphuretted, artesian water that rose to the top of the hole and flowed out. In hole 2 this was measured as 29 gallons per minute. It is not known whether this water was struck in other holes, although it might be expected in 3, 5 and 6 as the same strata were encountered. In hole 4, the artesian water was not observed at the time the hole was completed, but was noted January 25, 1931, leaking out in a considerable stream. As all the holes were capped it may be that some of them were tight enough to prevent leakage. The smearing of the hole with clayey material during drilling operations may have prevented the immediate rise of water when the holes were first drilled.

Conclusion.

The irregular variation in the cementation of the agglomerate, and the occurrence in it of weak and permeable masses make it in our opinion unsuitable as a foundation for a concrete dam. The occurrence of very pervious layers above and below the agglomerate render it doubtful whether it would be practicable to cut off leakage around and under the dam.

GENERAL SUMMARY AND CONCLUSIONS

So far as geological conditions are concerned, the Kennett site is practicable for the construction of a safe and effective dam.

The Iron Canyon site and the Table Mountain site are unfavorable for the construction of concrete dams, and the doubt whether leakage around and under a dam at either of these localities could effectively be prevented or controlled makes them unsatisfactory for any type of dam.

George D. Louderback

F. L. Ransome

APPENDIX B

REPORT

ON

IRON CANYON, TABLE MOUNTAIN AND KENNETT DAM SITES

ON

SACRAMENTO RIVER

By

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Engineering Advisory Committee for Sacramento River Basin Investigations

January, 1932

TABLE OF CONTENTS

REPORT ON IRON CANYON, TABLE MOUNTAIN AND KENNETT DAM SITES ON SACRAMENTO RIVER

The strategic position of a reservoir near Red Bluff has long been recognized. It is unfortunate that at this point, the head of the great central valley of California, no site for a reservoir has been found. Some 2600 square miles of drainage area lie below Kennett dam site and the run-off from this area should be regulated.

IRON CANYON DAM AND RESERVOIR

This project has been before the public for many years. A report by the United States Reclamation Service bears date of October, 1914. This report was reviewed by a Board of Review, appointed by the Secretary of the Interior, which board submitted a report under date of November, 1914.* A report by the United States Reclamation Service, in cooperation with the State of California and the Iron Canyon Project Association, was submitted by Homer J. Gault, of the United States Reclamation Service, and W. F. McClure, State Engineer of California, under date of May, 1920. A further report by the United States Bureau of Reclamation, in cooperation with the State of California and the Sacramento Valley Development Association, is published in Bulletin No. 13, Division of Engineering and Irrigation, State Department of Public Works, being an appendix to the Summary Report to the Legislature of 1927 on the Water Resources of California and a Coordinated Plan for their Development.

The project as outlined in the last report included a concrete gravity dam at the lower dam site, Location III, in Iron Canyon, raising water 152.5 feet above low water and creating a reservoir of 1,121,900 acre-feet. Irrigation of a gross area of 276,900 acres was proposed. Power development was also proposed.

The dam site was investigated by a Board of Engineers and plans for the construction of a masonry dam were approved. This feature alone is considered herein, although attention is called to the size of the reservoir, which is less than 20 per cent of the size required to properly regulate the stream. It should also be noted that the amount of land to be irrigated is relatively small in comparison with that proposed in connection with the present State Water Plan.

The first site selected for a dam, at Location I, was near Paynes Creek. This site was rejected when Professor Andrew C. Lawson, in reporting ** upon the foundations, reported as follows regarding sand layers underlying the agglomerate No. 1:

> "The water entering these sands of the river trench under the head established by the reservoir would partly pass out under the surrounding country and escape at distant points, but would tend chiefly to escape by the shortest outlet which would be at the downstream toe of the dam. Judging by the incoherence of the sands, their coarse texture, their caving in the drill holes, the artesian flow from some of them and the strong undercutting of the river banks below low water, it seems probable that this escaping water at the lower toe of the dam, under high pressure, would acquire sufficient velocity to scour the sand at the points of escape. If this were so, then a process making for the undermining of the dam and its ultimate failure would be inaugurated, since the scouring would retreat upstream below the dam."

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* "Report on Iron Canyon Project," United States Reclamation Service and Iron Canyon Project Association, 1914.

** "Report on Iron Canyon Project, California," by Homer J. Gault and W. F. McClure, Department of the Interior, and State of California, 1920.

Location II, about a mile and a half downstream, was then examined and rejected because the foundation material consisted of pervious sands and tuffs below which was a thin layer of agglomerate underlain by more sands and tuffs.

Location III, about a mile and a half downstream from Location II, was then examined and selected as the site for a dam. The foundation was the agglomerate No. 1 found at Location I, although the abutments of the dam were against the overlying sands and tuff. It was recognized that the entire safety of the structure depended upon the integrity of agglomerate No. 1, of which the report* says:

"Here Agglomerate No. 1 is not as hard as at Location I, but its bearing power is sufficient to withstand the pressures from a properly designed masonry dam. The dip of Agglomerate No. 1 and the formations both above and below it is downstream, hence the removal of material from beneath Agglomerate No. 1 by percolating water is not possible."

"The principal reason for the selection of Location III was explained in previous paragraphs to be the existence of a mass of agglomerate 110 feet in thickness below the river channel at the dam site. This material where exposed at the surface is a natural concrete which is probably water-tight and has considerable hardness and great bearing power, in every way satisfactory as a foundation for a high concrete dam. The records of borings, however, are not nearly so favorable. The fine binding material in the interior of the mass is rather soft, so that but a small percentage of core was produced. In a drift in the east abutment of the dam also the material becomes rather soft away from air exposure."

That the engineers were aware of the questionable features of the location is evident from the following extracts from the report:*

"The artesian flow from various bore holes indicates that the sandstone will permit slow flow of water. The most dangerous places in such cases are usually the planes of contact between different beds. Contact wherever examined seems to be perfect. The flow proceeds probably from the coarser layers which may not be extensive although pockets may occur with great frequency."

"We believe that danger from a rapid flow establishing itself along certain lines under the dam, such as might begin carrying material and ultimately leading to the undermining of the dam, would be very serious to the extent of causing condemnation of the dam site if it were not for the fact that these sandstone layers below the dam are overlaid by a heavy capping of reasonably dense agglomerate dipping in a downstream direction."

"We conclude, therefore, that while conditions for a dam at the best site available are far from ideal a safe dam can be constructed at this point, Location III, but it must be admitted that the item of contingencies to guard against all dangers which may become apparent upon opening up the foundation may be greater than usual and that the total for this dam, including also overhead expenses, estimated at 25 per cent, may be exceeded."

"It is possible that a greater credit may be secured for power, against which there is also the possibility that requirements as to unquestioned safety of the dam may compel large additional expenditures over those estimated."

These quotations are not reproduced to discredit the Board of Engineers. They are given to show that the board had serious doubts regarding many subjects even though the plan was approved.

In 1930, the undersigned members of the Engineering Advisory Committee for the Sacramento River Basin Investigations visited the dam site and additional borings, test shafts and tunnel were suggested. It appeared advisable to the members of the committee to determine how far downstream the layer of agglomerate No. 1 extended as its continuity was one of the basic elements upon which the conclusions of the report of the previous board were based. However, it was not possible to obtain additional borings but two test shafts were sunk near the water edge on the left bank, one 15 and the other 36 feet in depth, and the tunnel excavated in 1920 was extended farther into the

* "Report on Iron Canyon Project, California," by Homer J. Gault and W. F. McClure, Department of the Interior, and State of California, 1920.

side hill. These open shafts and tunnel permitted a visual examination and tests of agglomerate No. 1 in place. Certain trenches were also excavated to develop the geological formation of the strata above the agglomerate. Cores from the previous drilling operations were also examined and a discussion was had at the site with Professor George D. Louderback and with Professor Frederick L. Ransome, geologists. It is of interest here to quote from the report* of Geologists Louderback and Ransome as follows:

"The drill records at the Iron Canyon dam site, which are given in a previous report, confirm the conclusions drawn from the inspection of the tunnel and shaft. It is obvious from the records and from a brief examination of the cores, that the agglomerate, as penetrated in drilling, is by no means the hard, impervious rock surface exposures might indicate. It is prevailingly soft and loose. Caving is frequently recorded and practically the only core obtained came from embedded blocks or fragments of lava.

"Instead of constituting a saving feature of the Iron Canyon dam site, the agglomerate, in our opinion, is less uniform and less trustworthy material than the generally fine-grained tuffs and tuffaceous sandstones which overlie and underlie it.

"The tuffs, which make up the greater part of the formation overlying the agglomerate, are only slightly permeable, and the conglomerate contains much interstitial tuffaceous material which prevents free water percolation. Some of the volcanic sand layers are coarsely porous and poorly cemented. They are capable of transmitting water and under its influence may break down into sand and be subject to erosion. In general, they are lenticular and probably would not be effective water carriers where long distances are involved as in the foundation for the Bend embankment. They would present a very serious problem of cutting off leakage around or under the dam at the main site."

Having in mind the information obtained from previous investigations and that from our own, it is the opinion of the undersigned that a masonry dam built at Iron Canyon Location III would be dangerously unsafe, and that the project should be abandoned. The foundation material is largely a loose permeable volcanic sand which has been called agglomerate in which are embedded blocks of basaltic lava. On the surface, the material appears hard, but a few feet below it is found to be soft. It is variable in hardness and in places can be scooped out by hand. While in some spots it may have bearing resistance, in others it has not. Water can pass through the material. Underneath the agglomerate is a layer of very pervious sands and tuffs. Drill holes show artesian water is present. No information is at hand to show how far downstream the layer of agglomerate extends, or its thickness, although its continuity and integrity was a vital condition of the approval given by the Board of Engineers of 1920. On the flanks or abutments of the dam, the structure would rest on pervious sands and tuffs.

Even if foundation conditions were favorable, and they have been shown not to be, the dam site is a very poor one. The crest of the main dam would be about a mile long and there would be a secondary dam nearly 70 feet high and three-quarters of a mile long. The reservoir which has been proposed is relatively small and would not eliminate the necessity of a large reservoir at Kennett.

TABLE MOUNTAIN DAM SITE

After investigations had fully disclosed adverse conditions existing at Iron Canyon dam site attention was directed to Table Mountain dam site and particularly Site B, which is about 11.5 miles by river upstream from Iron Canyon. The site is fully described in the geo-

* Appendix A of this bulletin.

logical report* of Professor George D. Louderback and Professor Frederick L. Ransome and the description will not be repeated here.

At this site, a dam raising the water surface 170 feet, with spillway lip at elevation 461 feet, would form a reservoir with capacity of three million acre-feet. First impressions of some of the members of the Engineering Advisory Committee were favorable. However, after exploration by means of test pits, two tunnels, driven into the tuff and agglomerate abutments, and drill holes sunk into the foundations, opinion was unanimously adverse to the construction of a dam at this location.

As in the case of Iron Canyon dam site, the undersigned are of the opinion that this site is dangerously unsafe for the location of a masonry dam and that this project should be abandoned. As a reservoir site, aside from unsatisfactory foundation conditions for a dam, Table Mountain is much superior to that of Iron Canyon Location III. The foundation material, however, is substantially the same as that at Iron Canyon. The agglomerate is volcanic sand in which are embedded boulders of basaltic lava. Except on the surface, where it is superficially hard, the agglomerate is soft, easily picked and in most places can be taken out by hand. Water enters it freely. In the bed of the river the drill holes passed through agglomerate, basalt block, tuff and loose sands. Three holes immediately under the location proposed for the dam developed warm artesian water rising several feet above the river bed. The agglomerate is overlain on the right bank by volcanic tuff appearing as a cliff. This stratum is variable in character, pervious to water in places and intersected by sand layers. All of the foundation material is defective and forms the basis of the conclusion recited above.

While the capacity of the projected reservoir, 3,000,000 acre-feet, is large, it is not of sufficient size to regulate the available stream flow and an additional reservoir at Kennett, or other location, would still be required.

It is also the opinion of the undersigned that it would be dangerous to build any form of earth or rock fill dam at either the Iron Canyon or Table Mountain site.

It is possible that other dam sites may be found upstream from Table Mountain. If such can be found, the importance of a reservoir in this region warrants further surveys and exploration. It is believed, however, that such location must be in other material than the recent volcanic flow which includes Iron Canyon and Table Mountain sites.

KENNETT DAM SITE

The proposed dam at the Kennett site on the Sacramento River will form the largest reservoir of the proposed plan for the development of the waters of the state. Dams ranging up to 620 feet in height

* Appendix A of this bulletin.

have been proposed, impounding water up to 10,000,000 acre-feet. It appears probable that the ultimate dam will be 520 feet in height, giving a reservoir capacity of nearly 6,000,000 acre-feet. The importance and size of the proposed dam can be appreciated from these figures.

Investigations at Kennett reservoir and dam site began in 1922 and in 1924 instrumental surveys were made. Explorations of the dam site were begun in 1925, since which time cores were obtained at the dam site from twenty drill holes, of which eight were vertical and twelve were inclined. The length of the drill holes varied from 53.7 feet to 434.8 feet, the aggregate length of drill holes being 4299 feet.

The engineering investigations of the Kennett dam site have been made in conjunction with a complete geological survey of the territory by the United States Geological Survey and of the immediate problems of the site by Professors George D. Louderback and Frederick L. Ransome, whose report* is contained in this bulletin. The site has been examined in company with the geologists and we have had the benefit of their comment and explanations.

The locations of the drill holes and exploration tunnels are shown upon plans forming a part of the geologists' report.

In April of 1930, a detailed examination was made of the cores recovered from the drill holes. This was done for the double purpose of a study of the character of the rock and to determine the amount of stripping of the dam site that would be necessary to secure satisfactory foundations for a high masonry dam.

While the drill cores furnished much information regarding the nature of rock, it was believed that the size and importance of a dam at the Kennett site warranted the driving of tunnels wherein the rock might be examined in place and the amount of overburden determined with greater certainty. At our suggestion this was done.

Three tunnels, two on the right and one on the left bank, were driven. Tunnel No. 1 was driven into the right abutment at an elevation about 120 feet above stream bed for a distance of 514 feet. Tunnel No. 2 was driven into the same abutment about 80 feet higher for a distance of 445 feet. Tunnel No. 3 was driven into the left abutment at about the elevation of Tunnel No. 1 for a distance of 373 feet.

After the tunnels were driven, the entire site was examined again and a detailed study made of the nature of the dam site.

The site is an excellent one for a dam. The foundation material is a hard compact greenstone, termed by the geologists a metamorphosed andesite. Very little stripping is necessary in the bed of the river and the area immediately adjacent thereto. On the abutments it will be necessary to do considerable stripping—in some areas possibly up to 120 feet in depth—but the exploration drill holes and the tunnels indicate that satisfactory rock will be found at all elevations.

Basing our opinion upon an examination of the site and having in mind the conclusions of the geologists, we are of the unanimous

* Appendix A of this bulletin.

opinion that the foundation material at the Kennett dam site is suitable for a masonry dam of the height proposed.

B. A. Etcheverry

John D. Galloway

F. H. Herrmann

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J. B. Lippincott.

Fred H. Tibbetts

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Sacramento River Basin Investigations.

APPENDIX C

GEOLOGY OF THE SACRAMENTO RIVER CANYON BETWEEN COTTONWOOD CREEK AND IRON CANYON

by

CHESTER MARLIAVE

Engineer-Geologist

March, 1932

TABLE OF CONTENTS

GEOLOGY OF THE SACRAMENTO RIVER CANYON BETWEEN COTTONWOOD CREEK AND IRON CANYON

During investigations made by the State and the United States Bureau of Reclamation, search has been made for a dam site suitable topographically and geologically for the construction of a dam which could create a reservoir of large capacity, in the lower canyon of the Sacramento River between Red Bluff and Redding. Three sites in Iron Canyon, immediately above Red Bluff, and one at Table Mountain, about 11 miles farther upstream, were explored by drifts, shafts, and core drillings. Geological studies* were made of these sites and of others in the vicinity of Table Mountain during the last two years by eminent geologists. The suitability of the sites for the construction of a dam also was studied and reported** upon by the Engineering Advisory Committee for the recent Sacramento River Basin investigations. Information developed at the sites explored and studied has led the geologists and engineers to conclude that the foundation conditions at these sites are unsatisfactory for any type of dam.

In order to determine whether there is any other site on the Sacramento River between Redding and Red Bluff with formations geologically different from those in Iron Canyon and in the vicinity of the explored Table Mountain site, which might provide foundations suitable for a dam, it appeared desirable that a general geological examination be made of this stretch of the river. The examination, on which this report is based, was directed primarily toward a comparison of the geological formations from Balls Ferry Bridge to Iron Canyon with those studied in detail in Iron Canyon and at the Table Mountain site. No studies were made of formations between Redding and Balls Ferry Bridge since there are no suitable dam sites from a topographic standpoint in that stretch of the river.

The Sacramento River leaves its mountain gorge about two miles east of the town of Redding. Emerging from the confines of the hard metamorphic igneous rocks, the river debouches upon the flat undulating Quaternary deposits which are geologically known as the Red Bluff Formation. In winding its way out over the floor of the Sacramento Valley, the river has had little difficulty in scouring its channel through these incoherent gravelly sediments with the result that the flood channel is wide. Only in the stretch from Cottonwood Creek to Iron Canyon along this course, has the river encountered what appears to be a rather resistant formation. The resulting topography indicates suitable constrictions for the erection of a dam to impound the flood waters of the river.

In meandering over the Quaternary deposits, the river in places has cut its present channel through the overlying sediments of the Red Bluff Formation exposing the underlying formations along its banks and occasionally in its stream bed. These exposures are in general composed of tuffs, conglomerates and fine volcanic breccia which offer possibilities as a foundation for a dam. In addition to these tuffaceous sediments, the section of the canyon between Cottonwood Creek and

* Appendix A of this bulletin.
** Appendix B of this bulletin.

Red Bluff has been subjected to volcanic effusions coming from the vicinity of Mount Lassen in rather recent geologic times. This volcanic material ran down the slopes of the mountains covering the valley floor below, including the channel of the river. At the present time, most of this volcanic material has been removed along the river bottom but some of it is still imbedded with the tuffaceous sediments along the stream banks, while a few thin beds of lava capping still protect some of the bluffs along the river from erosion.

The area under consideration, extending from Balls Ferry Bridge down stream to within five miles of Red Bluff, has an actual air line length of only about 14 miles, while the distance along the course of the river is about 26 miles. In traversing this distance, the river makes four oxbow bends. This tortuous course is primarily due to the presence of the coarsely interbedded volcanic agglomerates and lava sheets which once poured down upon this portion of the valley floor making the degradation of a new channel more difficult than the scouring out of the finer alluvial sediments and tuffs.

The areal geology of this region is shown upon the accompanying Plate C-I, ''General Topographic and Geologic Features of Lower Sacramento River Canyon from Cottonwood Creek to Iron Canyon.'' The formation in general is alternating beds of tuffs and sands interbedded with conglomerates and volcanic agglomerate. The remnants of several thin basaltic lava flows are found capping this formation, becoming more extensive toward the east where they approach their source in the region around Mount Lassen. The alignment of the river not only serves as the western front of the coarse volcanic detritus, but it roughly represents the eastern edge of the Red Bluff Formation in this locality. The coarse gravels and sands of this deposition rest upon tuffs and form the rolling hills to the west, but along the river bank they are often entirely eroded. In the course of cutting its channel, the river has previously scoured most of these incoherent gravels and sands off of the low lying terraces leaving only scattered remnants strewn over the older and more coherent tuffaceous sediments.

The structure of the region is flat and undulating, giving rise at various intervals to long low anticlinal folds. Where these anticlinal folds are accompanied by exposures of agglomerate in the stream bed or on opposite sides of the river, the canyon is generally constricted and offers possibilities for dam sites.

As a historic background, it might be stated that the underlying tuffs of the region were nearly all laid down when the area was under water. These tuffaceous beds were composed of fine particles from volcanic eruptions in the form of ash, dust and small fragments that were carried in suspension in the air and water currents, and became distributed rather uniformly over the valley floor. The drainage into the valley at the same time distributed clays, sands and gravels which diffused with the volcanic detritus so that a thick deposition accumulated upon the old valley floor. During portions of this period, volcanic activity in the vicinity of Mount Lassen resulted in coarse agglomerate flows extending westward into the trough of the valley mingling with the sediments. Occasionally a sheet of lava rolled over the slopes or down some ravine and also became imbedded with the other detritus.

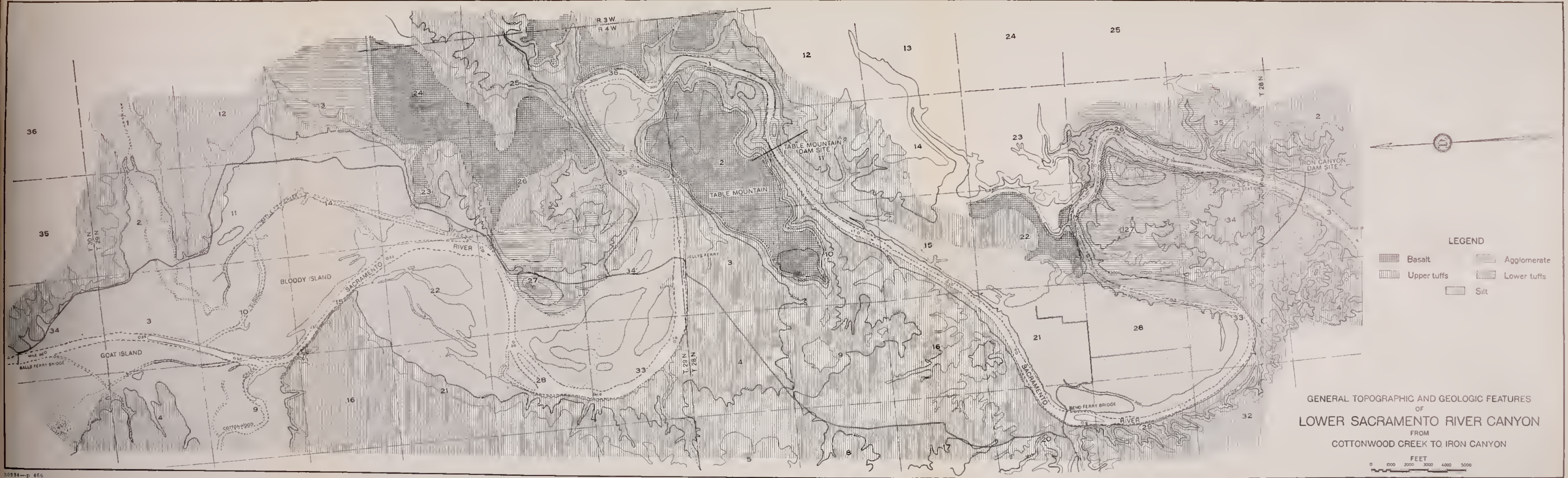
R 3 W.
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TABLE MOUNTAIN DAM SITE
TABLE MOUNTAIN
IRON CANYON DAM SITE
BLOODY ISLAND
GOAT ISLAND
BALLS FERRY BRIDGE
JELLYS FERRY
SACRAMENTO RIVER
BEND FERRY BRIDGE
COTTONWOOD
T 30 N
T 29 N
T 28 N
LEGEND
Basalt
Upper tuffs
Agglomerate
Lower tuffs
Silt
GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES
OF
LOWER SACRAMENTO RIVER CANYON
FROM
COTTONWOOD CREEK TO IRON CANYON
FEET
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With the cessation of volcanic activity, gravels, sands, and clays were laid down in large quantities over the area, forming what is now known as the Red Bluff Formation. Later during the process of degradation, some of these gravels, tuffs and interbedded volcanics were eroded, the stream in the meantime meandering back and forth trying to deepen its channel.

Brief descriptions of the geologic formations along the Sacramento River from Balls Ferry Bridge to a point about five miles above Red Bluff are given in the following paragraphs. In the descriptions, the sides of the river are referred to as right and left while facing downstream. The mile points referred to are shown on Plate C-I.

In the vicinity of Mile 26.30, which is the location of Balls Ferry Bridge, the stream occupies the left side of its flood plain. The channel here is about 500 feet across, while its flood plain is about a mile in width. The flood plain rises to approximately 50 feet above stream level and is undoubtedly composed of a thick deposit of gravel and sand overlying the tuffaceous bedrock. The flood plain being wide means that the flood velocities are not as great as where the plain is more constricted, so that large deposits of silts are strewn over it. These alluvial deposits are for the most part under cultivation. At the right edge of the flood plain there is a small abrupt rise of about 30 feet which marks the edge of the red terrace gravels. This wide, gently sloping terrace was eroded for the most part by the meanderings of Cottonwood Creek at an earlier stage of its history. The left bank of the river opposite Balls Ferry Bridge rises abruptly for almost a hundred feet, the formation being composed of tough yellow tuffaceous deposits overlain by heavily bedded conglomerates.

At Mile 25, the conditions are similar to those noted at Balls Ferry Bridge except that the river occupies a position midway in its flood plain.

Opposite Mile 24.50, Battle Creek joins the main flood plain from the left. The flow of this stream is normally confined to its southern channel so that its alluvial flood plain which is about 2500 feet wide where it merges into the flood plain of the Sacramento River is under cultivation. The slopes adjoining Battle Creek rise up rather steeply for several hundred feet and within the confines of Plate C-I are composed of tuffaceous sediments heavily bedded with conglomerates.

At Mile 23.75, Cottonwood Creek joins the Sacramento River from the right after meandering over its flood plain which is more than 5000 feet wide at its confluence with the main drainage. The alluvial deposits on this flood plain are chiefly sand and gravel and the area is given over almost entirely to grazing.

At Mile 23.50, just below the confluence with Cottonwood Creek, the channel of the Sacramento River reaches the right side of its flood plain where it is diverted by the steep bluffs along which it clings for about a mile. These bluffs are composed of tuffs and tuffaceous sands with thin beds of conglomerates near the base, but the higher portions grade into the terrace gravels and clays of the Red Bluff Formation which occupies the region of rolling hills for several miles westward. The flood plain opposite the bluff near Mile 23 is about 8000 feet wide, the major portion of it being gravel and sand overlain by silt, and is under cultivation. On the extreme left side at this point, the hill

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Between Miles 22.50 and 17.25, the flood plain of the river gradually decreases in width from about 6500 feet to 3000 feet. At the beginning of this stretch, the river shoots straight beyond the end of the tuffaceous bluffs, which it has been crowding, to a point on the left side of the flood channel where it comes in contact with an agglomerate formation which is quite resistant to scouring and deflects the stream back to the right bank again. From this point at Mile 19.50, the channel continues to follow the right side of the rivers flood plain along the tuffaceous banks for about three miles.

The entire right side of the river's flood plain between Miles 22.50 and 17 is composed of the tuffs heretofore mentioned. Where the normal river channel runs along the edge of the bluffs, the lower slopes show exposures of tuffs, clays, sands and conglomerates. From Mile 22.50 to Mile 18.50, the tuffaceous sediments at the edge of the flood plain are mantled by high rolling hills composed of the Red Bluff sediments which extend for many miles to the west, but from Mile 18.50 to Mile 17 the tuffaceous bluffs are about 75 feet high while the overlying formation is practically all eroded, the river at a previous stage having had its course over this area and eroded the Red Bluff terraces leaving the country almost flat and void of alluvium.

It may be noticed on Plate C-I that between Miles 22 and 17 the formations to the left of the flood plain are somewhat different. Interbedded with the tuffs is a horizon of agglomerate. This appears to be the same deposition noted at other places farther down the river. In the vicinity of Mile 20.50 this agglomerate forms the prominent knoll, but it dips downward in a general westward direction under the gravels in the valley floor. Behind the knoll can be seen the underlying tuffs which appear to be the same as those found farther up the river. There is considerable river gravel in the saddle behind the knoll indicating that the river waters ran through this pass at some previous stage in its history. To the east of the gap, near Mile 20.50, the agglomerates are in evidence along the hillside but disappear under the clay tuffs farther up the slope. Still farther to the east will be noted a capping of basalt. This lava flow is probably not over eight feet thick but forms a protective capping to the area which it covers. Its areal extent is shown on Plate C-I. It at one time formed a continuous sheet. Before the river scoured out its present channel, this lava capping was continuous with that on Table Mountain and extended eastward toward its source near Mount Lassen. The lava capping is nearly horizontal over the area shown, and being void of any overlying sediments, forms the mesas or plateaus of the vicinity.

It might be noted that on the left side of the valley floor opposite Mile 22 the agglomerate also is encountered and extends over the hills to the east beyond the limits of Plate C-I. The lava capping is present in this area and a few continuous lenses of lava rock are found scattered through the agglomerate.

Commencing at Mile 17, the river starts a five-mile circuitous course through a rather narrow stretch where the flood plain is very limited and where the canyon sides rise rather precipitously. Along this portion of the river are numerous sites which from a topographic standpoint offer possibilities for the location of a dam.

Beginning at a point which is a short distance downstream from Mile 17 and about a half mile below Jellys Ferry, the agglomerate formation rises in the stream bed and continues along the river channel to Mile 15 where it disappears again beneath the sediments in the river bottom. At Mile 15.75, the agglomerate shows its maximum height above stream level of about 20 feet with an exposed width of about 700 feet across the channel. This location probably represents a slight anticlinal rise in the formation. Above the agglomerate, the bluffs on either side show thick bedded sediments of tuff and at an elevation of about 150 feet on either side of the canyon the thin eight-foot layer of basalt capping forms the top of the plateau.

A similar but narrower constriction exists at Mile 14.25 but the agglomerate at this point has dipped down and is not visible along the river bottom.

At Mile 13.50, the agglomerate rises again in the stream bottom making an anticlinal fold in the vicinity of Mile 13 and again disappearing below the river bottom just above Mile 12. Immediately downstream from Mile 13, the tuffs underlying the agglomerate are exposed along the stream bed. The agglomerate exposure shows a thickness of about 135 feet at this locality. Above the agglomerate are found the tuffaceous sediments and still higher up, about 200 feet, is found the thin cap of basaltic lava. The tuffaceous sediments in this locality take on the same anticlinal structure as the agglomerate. The vicinity of Mile 12 is the Table Mountain dam site which has been subject to special investigation. Reports on the site are given in other appendixes* of this bulletin.

At Mile 11.50, there is again a small outcrop of agglomerate appearing above the stream bed and it is very likely that this formation continues downstream just beneath the sediments on the flood plain.

From Mile 12 to Mile 10, the flood channel is narrow with gently sloping canyon walls all of which are composed of sediments of tuffaceous origin.

At Mile 10, the river starts on a circuitous loop about six miles in length in order to gain a distance of about 1.4 miles. The area enclosed by this loop is an old flood plain and a large portion of it is now under cultivation. The river keeps close to the right-hand bluff all along this course and there is exposed along the cliffs a continuous formation of horizontally bedded tuffs and sands of varying proportions and degrees of coherence with occasional strata or lenses of gravel and conglomerate. Along most of this stretch the tuff beds rise to a height of 200 feet, but in the vicinity of Miles 8.50 to 9.50, the local drainage has reduced the hills to more gradual slopes leaving the bluffs adjacent to the river only about 75 feet high. Just below Mile 6 there is a gap, approximately 125 feet higher than the stream bed, in the bluffs along the right side of the river. Topographically, this gap offers a strategic point to by-pass flood waters from the river. It has received considerable attention as the location of the "Bend Embankment" in the Iron Canyon investigations. As elsewhere along the bluffs upstream from this point, the formation is composed of rather

* Appendixes A and B.

incoherent beds of clay, tuffs, sands and gravels. These beds have a gentle southern dip and their areal extent continues beyond the southern edge of Plate C-I. The higher portions of the hills adjacent to the river are covered with loose gravels and clays which are a part of the Red Bluff Formation.

The area between Miles 6 and 0 constitutes that portion of the river covered by the Iron Canyon geological investigations. Various dam sites have been studied along this stretch and the geological conditions pertaining thereto are recorded fully in previous publications and other reports which form appendixes* to this bulletin. A few general statements, however, will be given here so that the formations in this vicinity may be correlated with the others found on Plate C-I.

Immediately downstream from Mile 6 and continuing along the channel to Mile 0.50, there is a continuous deposit of agglomerate which was probably laid down contemporaneously with that near Table Mountain. This coarse volcanic breccia came from the region to the east where it is profusely distributed over the western slopes of Mount Lassen. Its western edge seems to terminate in the river channel near Mile 6, although it may continue farther under the sediments in the valley.

Commencing at Mile 3.75 and continuing down to Mile 1, which is the United States Geological Survey gaging station, there are a series of volcanic sediments underlying the agglomerate. These sediments are very similar to the tuffs heretofore mentioned but in some previous discussions of Iron Canyon geology they have been referred to as the "Upper Sands," and in others as "Lower Tuffs." As they are very similar to the other tuffs of the region they are here considered as the lower tuffs to designate their position as being under the agglomerate. These lower tuffaceous sediments occupy a position for approximately 200 feet above stream bed near Mile 2.50, flanking the walls of the canyon for a width of over 1500 feet. On the left side of the river near Mile 3, these sediments are exposed for a much greater width, while on the right side the lower tuffs are overlain by agglomerate which in turn is capped by a remnant of the upper tuffs.

In the vicinity of Mile 2.50, there is an anticlinal structure across the river channel which gives a domelike flexure to the sediments in this locality. On the left bank of the river near Mile 4, there is the end of an old basaltic flow which at one time came down Paynes Creek choking its channel and discharging into the Sacramento River channel. This lava rock is now entirely eroded from the river channel but a remnant of it is perched along the left bank of the river.

As a result of this study of the geological formations along the Sacramento River from Balls Ferry Bridge to the lower end of Iron Canyon, it is concluded that the agglomerates and tuffs found at the Iron Canyon and Table Mountain dam sites extend throughout the entire stretch of the stream examined, that these materials are practically the same in physical characteristics in all locations, that no other formation exists which could be utilized for the foundation of a dam, and that the formation at the Table Mountain site is superior geologically to that at any other location in this stretch of the river.

* Appendixes A and B.

APPENDIX D

GEOLOGIC REPORT

ON

FAIRVIEW DAM SITE

ON

TRINITY RIVER

By

George D. Louderback
Consulting Geologist,
Professor of Geology
University of California

August, 1930

TABLE OF CONTENTS

GEOLOGIC REPORT ON FAIRVIEW DAM SITE ON TRINITY RIVER

The Fairview dam site is located on the Trinity River, in Trinity County, a few hundred feet above the mill of the old Fairview Mine, in Township 34 North, Range 8 West, M. D. B. and M. The topography of the site and adjacent territory is shown on the Weaverville quadrangle of the United States Geological Survey and on a detail contour map prepared by the Division of Water Resources, State Department of Public Works, the latter of which is reproduced herein as Plate D-I, "Topography and Geologic Features at Fairview Dam Site on Trinity River."

The following report is based on a geological field examination without the aid of exploratory borings, shafts or tunnels, except for a mine adit on the Fairview property, several old prospect and mine dumps on the east side of the canyon and a few drill holes made by a dredging company in the river gravels.

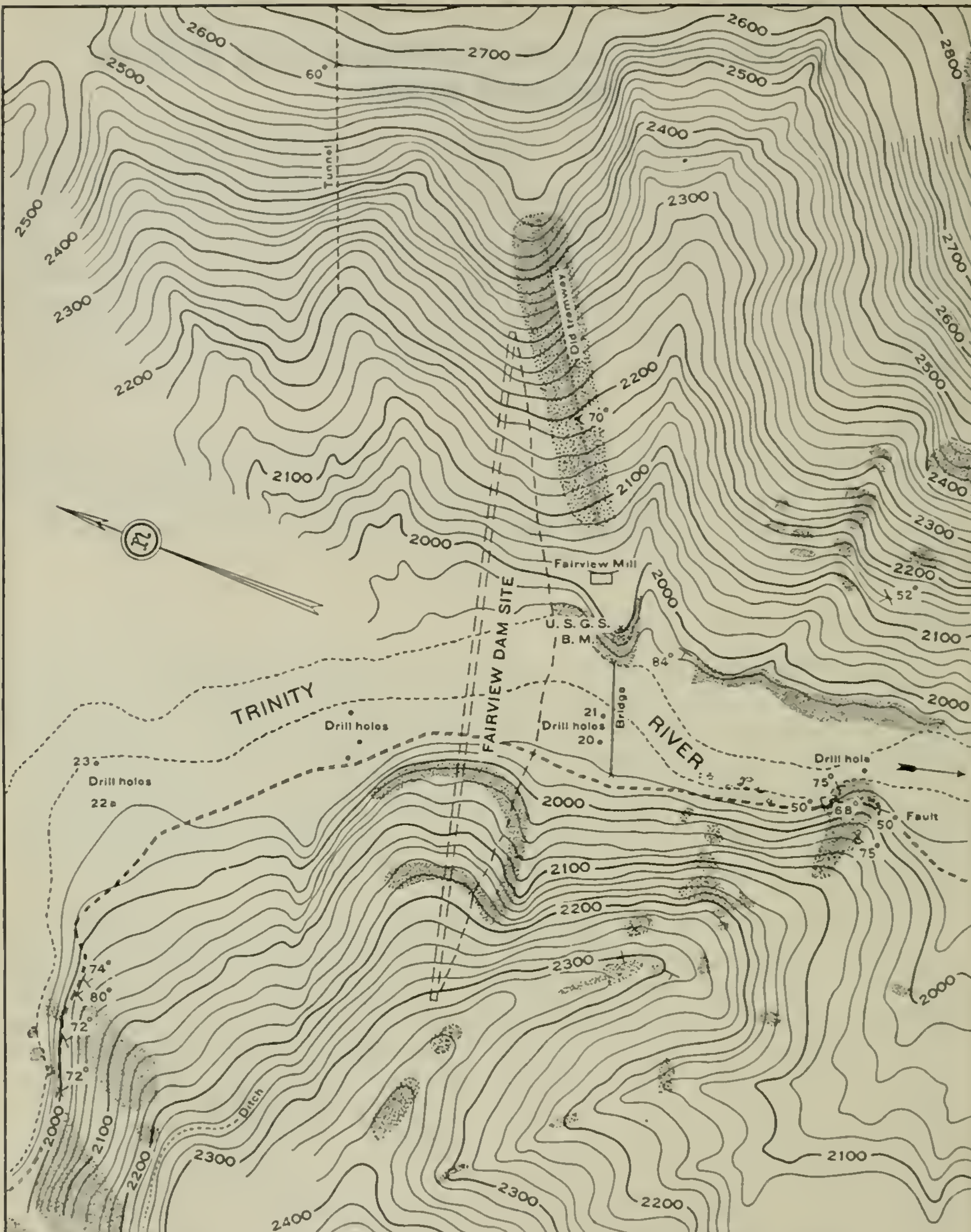
General Geology of the Area.

The bedrock formation of the dam site and of the rest of the area is a series of metaandesites which also make up the main bedrock formation of the Kennett dam site on the Sacramento River. It is believed to be the same as the formation designated as the "Copley metaandesite" on the Redding folio of the United States Geological Survey. In that area the age was determined by J. S. Diller, geologist for the Geological Survey, as "pre-Devonian." This rock has been described in Appendix A.

The metaandesites of the Fairview dam site region represent original volcanic tuffs, agglomerates and possibly lava flows with the prevailing rock type being augite andesite. In the course of geologic time important changes have taken place in the formation. The layers, which originally lay approximately horizontally, have been tilted or folded and now show high dips throughout. The loose ashes and other fragmental types have been compressed and indurated, so that now they are characteristically dense and fairly hard firm rocks. Metamorphism has produced alterations in mineral composition and texture closing up the original voids between the fragments, and the formation now is a series of more or less typical greenstones.

The layers in general strike in a northwesterly direction (actual measurements taken varied from north 42 degrees west, to north 70 degrees west, magnetic), with dips from 60 degrees northeast to vertical (possibly in some cases high to southwest). The rocks are rather generally traversed by joints and other fractures and have been subjected to a certain amount of local shearing and minor faulting. No important faults or shear zones were recognized in the course of the field work. In some places a series of approximately parallel joints occur over a limited area and these may dominate the structural appearance to such an extent as to give the impression that they represent the original stratification. They often trend at high angles to the strike of the strata. For example, along the old ditch line shown in the lower

PLATE D-I



TOPOGRAPHY AND GEOLOGIC FEATURES
AT
FAIRVIEW DAM SITE
ON
TRINITY RIVER

FEET
0 400 800

LEGEND
Dip and strike
Rock out crop

left corner of Plate D-I the layers strike north 50 degrees west, magnetic, while marked jointage strikes north 48 degrees to 56 degrees east, with a vertical dip. On the west side spur that runs out to the two most northerly drill holes, a fracture system has produced a platy structure in the rock. It strikes north 30 degrees east, magnetic, and has a vertical dip. In the agglomerate on the east side of the river, below the Fairview suspension bridge, a distinct jointage strikes north 50 degrees east, magnetic, and dips 65 degrees northwest. Other jointage regularities were observed, but the above will serve as typical examples. No attempt was made to map the joint systems of the whole area as the task would have been very difficult and time consuming and not of commensurate value.

Where fracture surfaces are well developed the rock masses naturally separate along them, and where a series of closely spaced joints occur the rock will break out in plates or slabs. Most commonly however, the rocks of the area characteristically break out (by weathering or hammering or picking) into irregularly bounded small and more or less angular fragments because of the many irregularly arranged small joints with which they are intersected. This irregular close-spaced jointage predominates in certain areas. It is more marked at and near the surface than deeper.

All of the area shows more or less rock weathering. Moderately weathered rock exposures are not uncommon, but some of the area directly underlain by bedrock is covered by a heavy layer of badly decomposed material, with surface soil, and shows little or nothing in the way of rock outcrops. The thickness of the layer of advanced decomposition (and hill creep) is not always possible to estimate. In some places it is evidently 25 to 30 feet deep, followed downward by moderately decomposed rock for some distance before fresh undecomposed bedrock is reached.

The bottom of the canyon carries a river deposit of gravel and sand which, along the center line of the proposed dam, is about 350 feet wide. Test drill holes put in by a dredging company show a maximum depth of gravel of 50 feet in a hole about 400 feet upstream from this line. The test holes, shown on Plate D-I, give the following depths:

Hole number	*Elevation, in feet*	*Depth of gravel, in feet*	*Location, referring to bridge*
23	1952	23	About 1800 feet upstream
22	1959	40	About 1800 feet upstream
--	1948	50	About 900 feet upstream
--	1950	18	About 900 feet upstream
--	1952	18	About 900 feet upstream
21	1952	40	Just above bridge
20	1956	36	Just above bridge
In river bed	not indicated	33	900 feet downstream

A small amount of residual river detritus also is found on some of the old stream terrace flats, as at the old Fairview camp north of the mill.

Engineering Relationships.

Foundation.—I am satisfied the bedrock underlying the dam site is suitable as a foundation to support a dam. Stripped of the surficial soil and weathered rock it should present a firm, strong mass, practically impervious to water seepage and not subject to disintegration or trouble-making alteration by weathering or water action within the life of any type of dam. Water can seep through the metaandesites only along joints or fissures and since there are no permeable layers, any such flows that may be present in the stripped foundation should present no unusual trouble or difficulties in handling by grouting.

A rock-fill dam has been suggested for this location, and I think there is no doubt the foundation would be satisfactory even for a high structure of such type. In fact, the field examination gave no reason to suspect it would not be entirely suitable for a high masonry dam.

Stripping.—In the absence of test pits or borings the amount of stripping is difficult to estimate. In the 350-foot wide flood plain of the river, the drill holes indicate a maximum depth of gravel of 50 feet. The condition of the bedrock below the gravel is not known. It may be fresh and firm at the gravel base, or it may have a decomposed surface zone.

Along the rest of the dam location part is covered by soil, hill creep material and decomposed rock, but a fairly good portion of it shows moderately weathered rock exposures, some of which stand up prominently above the general surface.

As a preliminary estimate, 20 to 50 feet may be offered as a probable range. The rocks are apparently not so fully weathered at Fairview as in the Kennett region.

Abutments.—The canyon slope on the east side runs up about twice the probable height of a dam. On the west side, however, there is a comparatively narrow ridge. The top of this ridge is 2300 to 2400 feet in elevation, or about 360 to 460 feet above the river level. The crest line height can not be considered available as some stripping undoubtedly would be necessary. The width of the ridge at elevation 2300 feet is about 75 feet. One hundred feet down, it is about 550 feet through.

Considering the relation to the reservoir and the dam, the structure of the ridge is satisfactory. The stratification runs not far from parallel to the longitudinal axis of the ridge (about north 55 degrees west, magnetic) and dips high to the northeast (one measurement, 66 degrees). With any reasonable percolation distance it is not believed there would be any serious leakage.

Spillway.—The canyon to the southwest of the west abutment ridge has been considered for a spillway channel. I have seen no estimates of the amount of water it would be expected to carry, but if only a moderate depth is involved, say less than one-third the depth of the canyon, I would say the preliminary geological study suggests it would be entirely satisfactory. Naturally some erosion of the weaker overburden would take place and the channel would be widened, but there seems to be no reason to believe the integrity of the ridge, either as an abutment for a dam or as a natural dam flanking the reservoir, would be endangered. Inasmuch as the water would have to drop down the canyon side slope on a high grade to reach to creek channel, the slope should be artificially protected.

Materials for Construction.—If a concrete dam were to be built, probably the best material for aggregate would be river gravel, which has been shown to lie in the bottom lands in thickness up to 40 to 50 feet and a width of 300 feet and more. A considerable amount has been dredged and lies, with much of the fines washed out, in heaped-up ridges for several miles below the dam site. This material also might be of use for a rock fill type of dam. At least the pebbles and boulders are prevailingly of hard, strong, fresh and resistant rock material. I have made no survey of the quantity available for such purpose, but Chester Marliave has made a rough estimate and believes there is a supply adequate for this purpose.

For a rock fill type dam, the availability of a sufficient quantity of suitable material derived from the bedrock in close proximity to the dam site is difficult of prediction in the absence of exploratory workings. In fundamental nature, the material of the fresh meta-andesite is dense and strong, probably with greater strength to resist crushing than the run of average good granite. Most of the rock exposed at the surface, however, is cut through by numerous irregularly placed joints or incipient joints, so that it weathers down or breaks into small irregular angular fragments and some of the hill slopes are covered with such fragments. Experience with rocks of this type shows that where such condition occurs at the surface it does not always persist underground in the fresh material. On excavation to fresh rock, some belts become platy or even slaty while others become massive and break into coarse strong chunks. At present there is no sure method of predicting, in all cases, the characteristics as to breaking of the fresh rock from the appearance of the weathered portion; only excavation will give definite information.

In order to test the more likely places, it would be necessary to run drifts or otherwise open the rock masses to direct observation. As the rocks run in layers or belts, a quarry opened in satisfactory material might pass into less satisfactory or even undesirable material if it worked into a belt of different physical characteristics. Futhermore, a quarry might yield much suitable material that would have to be sorted or selected from less suitable or undesirable material in the general run.

The long drift now working in the Fairview district (shown at 2200-foot contour on Plate D-I) gives no satisfactory information that can be applied in other parts of the district, as the miners are following a veined zone that has been sheared and disturbed.

The more promising areas, as judged from surface studies, and which appear at least worthy of exploratory examination may be noted, as follows:

1. On the west side at the river bend below the forks and south of the old concrete power house, rock exposures are numerous and the rock rather massive. Even at surface it breaks by weathering into fairly coarse chunks. This condition holds to about 300 feet downstream from the small side creek and extends up hill at least 200 feet vertically. Below this, in the river, are a number of coarse projecting blocks and a rocky ridge runs up from a rocky point and may carry some satisfactory rock material.

2. On the east side about 900 to 1000 feet east of south of Fairview mill, a series of rocky outcrops occur. Exposures are reached up to about the 2450-foot elevation. A quarry might be started at the

south side of the gulch at about 2200-foot elevation (or somewhat lower). Under natural weathering many chunks are over six inches in diameter and some one to two feet.

3. On the shoulder above the Fairview mill and between the 2200 and 2400-foot contours, rock exposures indicate a possible source of material, but it looks less massive than the other two locations. If the dam were located against this shoulder, it naturally could not be used as a quarry site.

If the above mentioned locations do not yield satisfactory material for a rock fill, I would be inclined to believe that no nearby quarry location would be satisfactory for the purpose.

Summary.

On the basis of field examinations, without exploratory excavations, the bedrock of the dam site is believed to be satisfactory as a foundation for a rock fill or masonry dam. Before actual construction of such a dam, however, exploration of the particular location chosen should be undertaken to determine the depth of stripping and local structural features that may affect or modify the construction plans.

Satisfactory material for concrete aggregate is obtainable. Material for rock fill may be present in sufficient amounts. Exploratory work and measurements would be necessary to determine this with certainty.

George D. Louderback

APPENDIX E

GEOLOGIC REPORTS

ON

DAM SITES

IN

SACRAMENTO RIVER BASIN

by

HYDE FORBES
Engineer-Geologist

June, 1930

TABLE OF CONTENTS

GEOLOGIC REPORTS ON DAM SITES IN SACRAMENTO RIVER BASIN

OROVILLE DAM SITES ON FEATHER RIVER

Geography and Topography.

The Feather River drains the northerly portion of the west slope of the Sierra Nevada in California. It enters the Sacramento Valley at Oroville, and flows southerly through a wide stream trench cut in its predeposited alluvial fan onto a wide flood plain area. About three miles upstream from Oroville, the river leaves its mountainous drainage area where the erosive development in the stream trench varies with the resistance of the rock. This erosive development in many places has been such as to provide the narrow canyons with steep side slopes topographically suited for use as dam sites. Within the eight-mile stretch upstream from Oroville there are several sites suitable for low dams. In the top tier of sections in Township 19 North, Range 4 East, there are two adapted to use for high structures, namely, the "Lower Oroville" site and the "Upper Oroville" site.

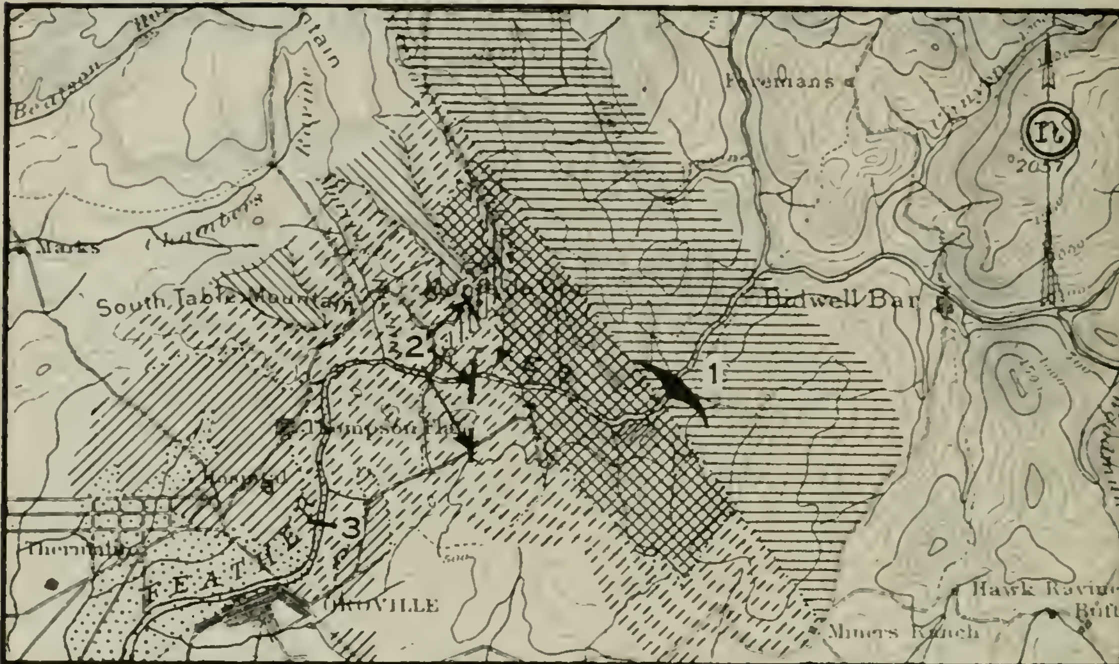
The topographic development is geologically recent. The present drainage was established subsequent to the Tertiary uplift of the Sierra Nevada and resulted in the building up of a broad alluvial fan or delta north of Oroville and extending westerly to the Sacramento River north of the Marysville Buttes. Subsequently, and probably through piracy, the stream was caused to take an abrupt right-angle turn to the south at the mouth of its canyon and the erosive action has carried the present stream bed some one to two hundred feet below its Pleistocene elevation. The Pleistocene deposits are found along the channel as small isolated terraces which overlie the basement complex formation into which the stream has and is actively intrenching itself.

The topographic development is closely related to the geology of the region in that it is the result of differential erosion upon a crystalline rock mass, the different phases of which present varying degrees of resistance to corrosion and weathering. This crystalline mass consists of massive diabase which has, in certain regions, been altered to amphibolitic rock. Where the alteration has been such that the hardness and compactness of the original rock has been increased through recrystallization of the constituent minerals due to compressive forces, as at the Upper Oroville site, the river channel occupies a steep-sided and relatively narrow gorge. Where the compressive force has caused an alignment of crystals developing schistose structure, the rock is less resistant and horizontal corrosion and weathering has widened the stream trench and produced gentle side slopes.

General Geology.

The relation of topography and geology is indicated upon Plate E-I, "General Topographic and Geologic Features in the Vicinity of Oroville Dam Site on Feather River." The Feather River has cut its canyon through a complex crystalline rock mass in which mineral components, crystalline texture and physical rock characteristics of many

PLATE E–I



GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES
IN THE VICINITY OF
OROVILLE DAM SITE
ON
FEATHER RIVER

SCALE OF MILES
0 1 2 3 4

LEGEND

Recent alluvium
Pleistocene gravels
Tertiary lavas
Massive amphibolite
Schistose rock
Massive diabase
Slate and limestone

1 – Upper Oroville Dam Site 2 – Lower Oroville Dam Site
3 – Oroville Afterbay Dam Site

kinds exist in complex association. The earliest rocks of the Sierra Nevada, originating in part as marine sediments, in part as intrusive igneous masses and in part by extrusion and expulsion from volcanoes, have all been more or less changed during a period of granitic intrusions and a later mountain-making epoch through being subjected to strong dynamic action attended with extensive chemical alteration of the rock. The area mapped as "massive diabase" is a portion of the early crustal rock. It is both massive and fragmental. Along the stream bed and in the railroad cut exposures, it shows some indication of flow structure and may have been an extrusion of great thickness. It also has characteristics indicative of intrusive origin, such as vesicular zones along the contact with slates on the north side of the river below the lower dam site and upstream from the lower dam site near an extensive quartz outcrop. Whatever the origin, the rock at the Lower Oroville dam site is a finely crystalline, dark green diabase, massive in structure.

It is sufficiently resistant to the attack of the weather and erosion to have developed steep side slopes and a narrow stream bed.

Upstream from the Lower Oroville site the alteration of the rock has produced first a series of schists, talc schist and amphibolite schist, with diabase and amphibolitic rock intervening, then a rock mass containing a large amount of green aluminous hornblende, sometimes referred to as greenstone but more correctly included in the term amphibolite. This massive amphibolite is the result of the recrystallization of basic igneous rock. The crystalline rock, both the diabase of the Lower Oroville site and the amphibolite of the Upper Oroville site, are of massive structure, continuous in rock character to great depth. Their present surface was hundreds or thousands of feet below ground surface as it existed during Tertiary time. The Tertiary gold bearing gravels are the beds of streams occupying the deep canyons of that age. The Tertiary lavas occupied the valleys and capped the gravels. These formations now exist on top of the ridges and the present river system has cut its canyon since they were laid down. It is not improbable that the Tertiary surface exposures of the massive rocks having the same physical and chemical characteristics were some two or three thousand feet higher over the present stream bed exposures, but it is highly improbable that the rock character will change at two or three hundred feet below present stream bed exposures.

The formation mapped as Pleistocene gravels consists of the ancient alluvial fan of the Feather River north and south of Oroville through which the present stream has cut to intrench itself in the underlying diabase. Along the lower stream remnants of "Pleistocene gravels" exist as terraces occupying old bends and channels below which the present stream has cut two to three hundred feet. While the continuation of the Pleistocene stream can not be definitely traced because much of the material has been removed through subsequent erosion, it was ascertained that it did not lie so as to effect drainage from the proposed reservoir sites.

Geologic Structure.

The structural features of the region accompanying the great granitic intrusion of Jurassic time are not of consequence in the present study, with the possible exception of the "banding" of the rocks brought about by the tremendous pressures exerted. The faulting which took place with the intense folding and metamorphism of the then existing crustal rocks is long "dead," and the fault and sheer zones completely healed, and the rocks, irrespective of origin, now exist as a deep seated crystalline mass from which millions of yards of material several thousand feet thick have been removed through ordinary erosive processes. During the long sustained and general California mountain making disturbance of Tertiary time, the Sierra block was raised on the east and tilted southwest at a fairly gentle slope. The compression under which the westerly flank rocks were put during this movement caused them to joint along a series of planes at diverse angles to each other. The jointing is a deep seated structural feature, but unaccompanied by any movement of the joint walls in relation to each other or parting of the joint walls except at the surface, where the feature is accentuated by weathering. Under the influence of weathering and undercutting erosive action of streams, the massive rock is caused to break up into joint blocks, which part from the mass and gravitate downward.

In a state of nature, the joint planes at short distance below ground surface are tight features. The joint walls are sound, and, while showing water stain, have not weakened through attack by circulating water. These observations, however, in no way obviate the necessity for grouting tests, and these and the subsequent grouting should be made under rigid specifications and inspection.

Detailed Geology of Lower Oroville Site.

The Lower Oroville dam site is included in a stretch of stream channel made up of the basic igneous rock diabase, consisting principally of minute crystals of augite, magnetite, and plagioclase. On the axis, the granular diabasic texture of the rock and the apparent flow structure, which now dips south 30 degrees, west 40 degrees, suggest that this section of the mass was the slow cooling interior of a thick basic flow. The finely crystalline fabric is such that it has resisted weathering, and rock outcrops, for a limited width, the full height of the proposed dam. Upstream and below the axis outcrop, the texture is more coarsely granular, certain zones in the rock are vesicular, and it contains original shrinkage joints filled with quartz. These sections are more subject to weathering and the diabase at the exposed faces in the railroad cut and up the slopes exhibits extensive disintegration due to atmospheric and ground water attack.

The whole mass is considerably jointed, the main joint systems dipping north 30 to 40 degrees, east about 50 degrees and north 30 to 40 degrees, west about 80 degrees. At the surface, large joint blocks are found slightly displaced. This is a superficial feature and the joints should be found tight and closed at relatively shallow depth. The diabase, when fresh and sound in the mass, is a rock of great strength. Certain portions or rock zones of the mass examined, however, have been subjected to comparatively rapid disintegration due to the attack of the weather and ground water upon the basic mineral constituents. It is probable fresh and sound rock can be reached with but comparatively shallow stripping at the outcrop area on the south abutment and along the ridge of the north abutment. Topographic draws have developed along less resistant zones and where joint planes were so inclined as to allow loosened joint blocks to gravitate to the stream bed. The joint planes at stream bed exposures are hair line features, along which the rock cleaves when struck with a hammer, but are closed and tight in the mass. It is probable no open joints will be found upon careful stripping of the abutments or below stream bedrock surface.

The stream has cut a narrow gorge trench through which the river flows at high velocity preventing excessive gravel deposits. It is probable some pothole development will be found upon dewatering.

The site, in so far as foundation material is concerned, is entirely satisfactory for the construction of a concrete dam about 300 feet high.

Auxiliary Dam Sites and Spillway.—A dam over 250 feet high at the Lower Oroville site would necessitate the construction of two auxiliary dams. The northerly dam could be used as a spillway. The site for this structure occupies a topographic saddle which marks the contact between diabase and slate (mapped in Plate E-I). The material brought to the surface at the mine workings in this location consists of fresh diabase and black micaceous slates with some quartzite lenses and mineralized quartz veins. The slate on the surface was found to include limestone which carried some minerals. This body of materials was found to cover a small isolated area surrounded by diabase and having mineralized quartz veins at the contact. It is probably a remnant of extremely old crustal rock into or over which the diabase poured. Mine workings along the contact show extensive disintegration of the diabase. It is possible for the rock decay to have penetrated to 40 or 50 feet below ground surface at the spillway site. The site would have to be drilled to determine the depth to firm rock and the location of the mine workings, and the factor they would be in the problem of making the reservoir water-tight.

The southern auxiliary dam would occupy a topographic saddle that has developed in the diabase. Subsurface exploration would be less important here if an earth fill structure were used.

Afterbay Site.

From the Lower Oroville site downstream to Oroville, the river has intrenched itself in the diabase to sufficient depth below the Pleistocene gravel formation to provide sound fresh rock as foundation for low height dams.

Detailed Geology of Upper Oroville Site.

In passing upstream from the Lower Oroville site, the rock is found to vary from the massive fine textured diabase through vesicular diabase to the quartz outcrop one mile above the lower site. Then the stream follows a series of fragmental diabase, in part altered to amphibolitic rocks and schists, which in turn give way to the banded massive amphibolite one-half mile below the upper site. The pressures which effected the metamorphism producing the amphibolite caused the rock to band, with the banding dipping northeasterly about 70 degrees. Some bands are decidedly schistose, with the schistosity planes taking tortuous courses, slightly faulted, the whole resembling a healed shear zone. Other bands are massive, but are of limited width and interspersed with the schistose bands to within 1000 feet of the dam site.

At the dam site, the stream has cut a deep and comparatively narrow gorge through a series of massive amphibolite bands which strike almost at right angles across the stream and dip upstream. The schistose bands are negligible in extent and the massive resistant formation makes up both abutments to their crest, presenting a mass of great strength in the most favorable attitude to receive the weight and thrust of a concrete dam.

The massive bands are jointed by two principal systems dipping south 50 degrees, east about 35 degrees and north 60 degrees, east about 75 degrees, and a complex system of minor joints. In the new road cuts along the north abutment, the shooting has caused the parting of the rock along joint planes. Some of the joint walls are water stained, but the joint walls are not weathered nor parted to any extent at the surface. The joints are closed features in the fresh exposures of the stream bed, and it is unlikely that open fractures will be found which might effect uplift on the dam or allow leakage under the dam. Test grout holes will probably reveal the fact that sealing by grouting will be negligible.

In the bottom of the canyon, the river has cut a narrow gorge trench through which the water flows at high velocities preventing excessive gravel deposition except in potholes which probably will be found in the rock.

There is no natural spillway location so the spillway must be part of the dam structure. It would be preferable to locate it in the north abutment where the overflow may be retained from working around to the toe of the dam and passed down a draw developed in a schistose band.

The Pleistocene and Recent gravel beds north of Oroville provide a nearby source of construction material.

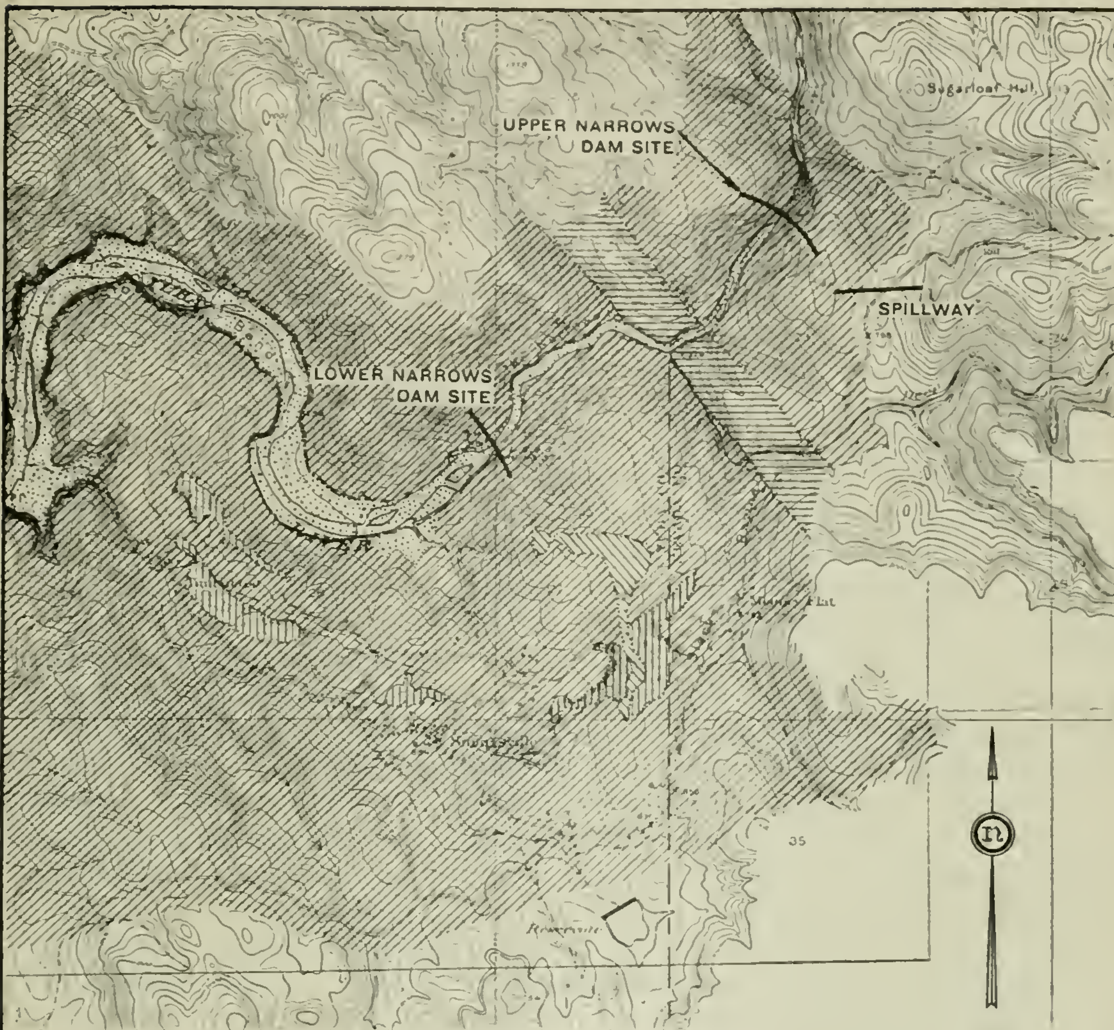
NARROWS DAM SITES ON YUBA RIVER

Geography and Topography.

The Yuba River drains the northwesterly flank of the Sierra Nevada and joins the Feather River at Marysville, near the east central border of the Sacramento Valley. For nine miles upstream from Marysville the river has cut a wide stream trench through its preexisting alluvial delta to Daguerre Point and Hammonton, above which the erosive development has been in bedrock, the stream channel narrowing from one and a quarter miles between bedrock banks at Hammonton to one-eighth of a mile, five miles upstream at Parks Bar Bridge.

The topographic development of this section of the Yuba River has been greatly modified by placer mining activities. The eroded stream trench has been filled and choked with mining debris. This process changed the gradient of the stream for several miles upstream through deposition of sand and gravel which, since cessation of mining activities, is gradually being carried down the channel with a continuous readjustment of base levels. The thickness of this deposited material raised the stream bed and separates the steep sloping rock canyon walls to such an extent that suitable dam sites are not available below a point just upstream from the Timbuctoo and Smartsville mines. At the United States Geological Survey gaging station in the southwest quarter of the southwest quarter of Section 22, Township 16 North, Range 6 East, and about at the center of the south line of Section 14, same township and range, are located close walled gorges in which the detrital filling has been and is in the process of rapid removal. The first mentioned location is designated the ''Lower Narrows'' site and the second the ''Upper Narrows'' site. At both sites, the narrow gorge and steep cliff profile development provides ideal topographic conditions for dam construction.

PLATE E–II



GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES
IN THE VICINITY OF
THE NARROWS
ON
YUBA RIVER

SCALE OF MILES
0 1 2

LEGEND

Recent alluvium and mining debris
Tertiary stream gravels
Diabase and augite porphyrite
Tertiary lava cap
Amphibolitic rocks

General Geology of the Region.

Both dam sites lie in a section of the river where it traverses a dark green basic rock mass comprising a closely related series of augite porphyrites and diabase which, in some localities and downstream from

Parks Bar bridge, has been more or less altered to amphibolitic rock. Where the alteration is complete the amphibolite is given a distinctive legend on the accompanying map, Plate E-II, "General Topographic and Geologic Features in the Vicinity of the Narrows on Yuba River." Otherwise the series is mapped as a unit. The diabase presents phases of finely granular resistant rock which make up the dam sites. At these points, the stream has cut a narrow gorge with cliff profile to 200 to 300 feet above stream bed, above which rise comparatively steep upper side slopes with rock outcrops.

Upstream from the Lower Narrows site, the rock changes gradually from the fine grained diabase to a medium grained rock, which in turn merges with a porphyritic diabase or augite porphyrite showing abundant tabular feldspar crystals. This latter or more coarsely crystalline rock makes up the Middle and Upper Narrows (not the Upper site used in this report) sites as mapped in 1898 by the United States Engineer Department. The rock is less resistant to weathering than the diabase first described and is subject to more rapid erosion. Consequently, those sites occupy positions where the stream trench is wider, side slopes more gentle and the soil cover heavier than at the Lower Narrows site. Further upstream and along Deer Creek, the augite of the porphyrite has been converted into secondary hornblende producing fine grained, banded, dark green amphibolitic rocks similar to those found along the Feather River.

At the Upper Narrows site reoccurs the fine-grained resistant diabase found at the Lower Narrows site and similar to that found along the axis at the Lower Oroville dam site on the Feather River, but of much greater width. A mass of amphibolite one to two miles in width at Long Bar, and containing schistose bands which have weathered out in a pronounced manner at Brady's Ranch road, strikes across the stream here. The other formations mapped are the Tertiary stream beds or gold-bearing gravels of the mines, with a limited andesite cap above Mooney's Flat. These gravel deposits lie over diabase above 800 feet elevation so they will not be a means of reservoir drainage. At the base of the mountains west of the limits of the map was found the gravel deposits comprising the fan or delta of the Pleistocene Yuba River. The recent stream alluvium and mining debris are undifferentiated on the map.

Geologic Structure.

In common with the entire west flank of the Sierra Nevada, the main, or bedrock, formations of the region are banded due to the intense crustal pressures they were subjected to during the early or Jurassic granitic intrusion, and folded, faulted and metamorphosed as a result of this pressure and the heat and gases accompanying the deep-seated intrusives. The banding follows the general trend of the ridges from northwest to southeast, dipping north 30 to 40 degrees, east about 75 to 80 degrees and crossing the stream at right angles to its course in the dam site sections. During the succeeding time to Mid-Tertiary, the faults, fractures, shear zones and other rock weakness were entirely healed through the deposition of secondary infiltration products, principally quartz, and the bedrock formations lie as a perfectly crystalline mass in which texture changes and changes in mineral components occur with gradual transitions.

During the great mountain-making epoch starting in Mid-Tertiary time, the rock mass of the Sierra Mountain block was subjected to intense compression along its western flank which caused the rock to develop a complex system of joint planes. The general movement was accomplished without distortion and there was no faulting in the region investigated, nor displacement along the joints. The joints exist in the mass as cleavage lines, along which the rock parts from the mass under the action of weathering, unbalanced loding or shock. While the joints are structural weaknesses, which are persistent to great depth and over wide areas, they are not to be considered as detrimental to the use of the mass as foundations for engineering structures.

This crystalline mass has been worn down through the attack of the weather and running water. Through erosion, the Yuba River has been and is actively engaged in widening its gorge, and joint block after joint block has parted from the mass along joint planes to leave suspended overlying rock blocks. These eventually fall from the higher mass, breaking and carrying with them, as small landslides in some localities, the previously dropped detritus on the slopes. Some of these dislodged and fallen blocks, still on the slopes, are of considerable size, yet the feature is purely superficial in character. In this manner thousands of feet of material have been removed and the surface cut down until the present stream canyon is deep into the mass which made up the ridges flanking the present high-lying Tertiary bed of the Yuba River. This fact alone would be sufficient to warrant the conclusion that the crystalline mass exposed at the present ground surface is part of a deep-seated mass, having similar rock characteristics throughout, from which thousands of feet of material have been carried away and which is not subject to change vertically to great depth. Other geologic evidence supports this conclusion.

Detailed Geology of Lower Narrows Dam Site.

The Lower Narrows dam site occupies the downstream extremity of a gorge designated on the map and known locally as "The Narrows." The width of stream bed detritus varies from 300 to 350 feet between the rock walls which rise precipitously on the left bank to 300 feet above stream bed and with a steep slope on the right bank and upper left bank to 900 feet elevation. This topographic development occurs in massive diabase which, at the dam site, is a fine-grained, dark green, basic rock, massive in structure and having great strength. About 500 feet upstream from the gaging station, the rock is somewhat vesicular and coarser grained, shows phenocrysts of plagioclase, and contains irregular shrinkage joints now entirely filled with quartz deposition. Upstream from this point for a distance of one-half mile, the rock is coarser textured augite porphyrite and is less favorable for high dam construction.

The rock is considerably jointed, the main persistent joints dipping south 50 to 60 degrees, east 55 to 60 degrees; north 40 degrees, west about 65 degrees; and due west 80 to 85 degrees, and being intersected by a complex system of minor joints. Up the slopes, the joints are opened by weathering and large joint blocks are displaced. The gravitation of these joint blocks down the slopes have developed surficial landslides, previously described. These features do not indicate lack of strength in the mass, but present a problem in connection with stripping best solved by locating the dam as suggested on Plate E-III, "Topography and Geologic Features at Lower Narrows Dam Site on Yuba River." In the fresh exposures at stream-bed level the joints are closed and tight and it is probable test grout holes would reveal no necessity for extensive grout preparation.

PLATE E-III

TOPOGRAPHY AND GEOLOGIC FEATURES
AT
LOWER NARROWS DAM SITE
ON
YUBA RIVER

FEET
0 100 200 300

LEGEND
Surficial landslide areas
Detrital fill in stream bed

Rock outcrops over both abutments with soil and disintegrated rock above the cliff line and between outcrops. Careful stripping and removal of loose joint blocks should result in a moderate depth of excavation provided the dam location avoids landslide areas. The depth of stream gravels here is influenced by the mine tailings dumped into the stream above and below the site. In 1898 test borings showed a maximum depth of 100 feet of gravel above bedrock. Recent surveys show the maximum depth to be 70 feet and with continued stream activity the rate of removal will increase.

The site is well adapted to construction of a high concrete dam. There is no natural spillway location available, so spill would have to be made over the structure, preferably at the right abutment and down the topographic draw now occupied by a landslide.

Abundant construction material is available in the gravel bars at and below the site.

Detailed Geology of Upper Narrows Dam Site.

The Upper Narrows site, situated about three-quarters of a mile above the mouth of Deer Creek, occupies a gorge cut in the same massive diabase as that at the Lower Narrows site. The left abutment has developed a cliff profile to from 200 to 300 feet above stream bed, above which the rock outcrops though it is considerably jointed. The two sites are geologically similar and the description of the bedrock character, structure and jointing for the Lower Narrows dam site applies also to the Upper Narrows site. The Upper Narrows site is topographically the better as no draws, down which landslides have moved, have developed and the flood stages of the stream have swept the channel clear of much of its detrital cover. Because the stream bed is closer to rock bottom, the canyon walls at water level are closer than at the Lower Narrows site and a dam having the same crest length as that proposed for the Lower Narrows would rise higher above stream bed.

There is a natural spillway, shown on Plate E-II which could be used to discharge into Deer Creek and back to the river. A pit dug near this location showed top soil and disintegrated rock to about 12 feet below ground surface with open-jointed diabase lying below to the bottom of the pit to a depth of 15 feet.

CAMP FAR WEST DAM SITE ON BEAR RIVER

Geography and Topography.

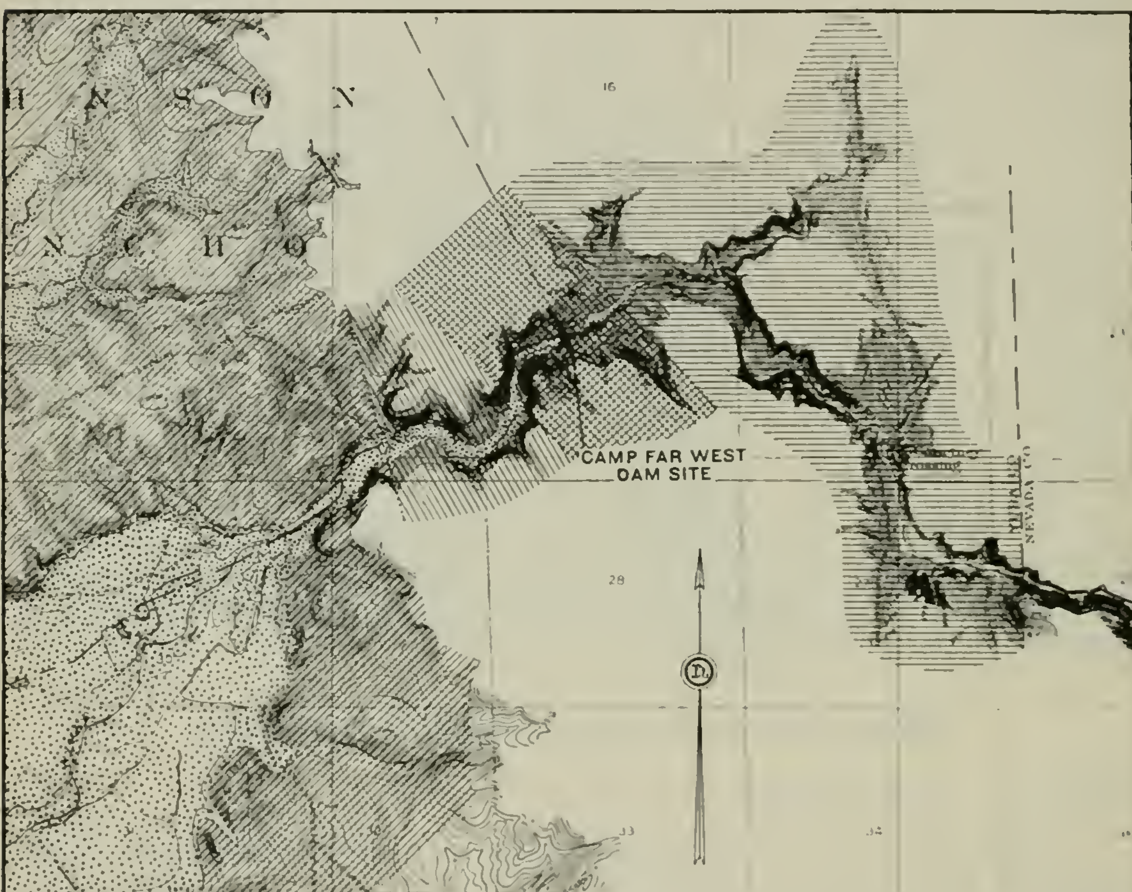
The Bear River drains the lower Sierra Nevada between the drainage areas of the Yuba and American rivers and enters the Sacramento Valley at Wheatland, joining the Feather River near Nicolaus. The topographic development of the lower river channel suggests that during the stream's history it drained a much larger and higher lying area, possibly some of that now drained by the South Fork of the Yuba River.

Upstream from Wheatland, the foothills comprise an extensive fan built up by the Bear River during Pleistocene time. The Bear River, deprived of much of its water and sediment load, now has cut through the predeposited alluvium and into the underlying bedrock. This process has developed a narrow stream canyon at low (about 100 feet) elevation upstream from the west line of Section 29, Township 14 North, Range 6 East. The narrow canyon developed in the southwest quarter of Section 21, same township and range, provides topographical conditions utilized as the site of the present Camp Far West Dam.

General Geology.

The erosive development of the Bear River has exposed the border portion of a granitic intrusion of Jurassic time, which is cut into by the American River from Folsom to the vicinity of Auburn and which probably is buried by Pleistocene and recent alluvium northerly to Oroville. The body of the intrusive mass is the medium grained grano-diorite, consisting largely of quartz with hornblende and feldspar, being extensively quarried at Rocklin. This rock becomes more

PLATE E-IV



GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES

IN THE VICINITY OF

CAMP FAR WEST DAM SITE

ON

BEAR RIVER

SCALE OF MILES

0 1 2

LEGEND

Grano-diorite — Amphibolitic rocks

Gabbro-diorite — Pleistocene alluvium

Recent alluvium and mining debris

coarsely crystalline near its borders or as the old crustal rocks, into which it intrudes, are approached. The general geologic map, Plate E-IV, "General Topographic and Geologic Features in the Vicinity of Camp Far West Dam Site on Bear River," shows the portion of this rock exposed by the removal of the Pleistocene alluvial covering and its more coarsely crystalline border phase as its contact with the metamorphosed older crustal rocks is approached. The transition is gradual and is a texture change without apparent change in mineral constituents.

The old crustal rock of the region is probably the same extensive massive and fragmental diabase, in places altered to amphibolitic rock, that is found along the lower stretches of the Feather and Yuba rivers. Between the Camp Far West Dam and Grass Valley, four separate granitic intrusions in diabase were noted. The diabase was found to have border zones, altered to schists and amphibolite less resistant to weathering and along which the northwest-southeast drainage lines have developed. The central zones comprised the ridges made up of massive amphibolite in limited areas and of a fine grained resistant diabase.

Geologic Structure.

The geologic structural feature of importance in relation to engineering structures is the jointing of the massive rock at the Camp Far West Dam site. No faults were found in the region examined. The jointing is a structural weakness of the rock mass emphasized at the surface through weathering processes and therefore a factor to be considered in relation to stripping methods and quantities, but not a factor in reducing the strength of the sound rock mass below the weathered zone.

Detailed Geology.

The Camp Far West Dam is founded on a massive dark green, coarse-textured rock exposed as rough brown outcrops above the abutments to the ridge crest on both sides of the stream. Just below the dam is found a medium-grained granodiorite consisting largely of hornblende with quartz and feldspar. As this rock merges gradually with the coarsely granular rock of the dam site, the latter may be properly designated a gabbro-diorite or hornblende gabbro. It is a heavy rock having a specific gravity of close to 3.0. It is massive in structure, being comprised principally of large interlocking crystals of hornblende, stable and strong.

The complex system of joints, prevalent in all the rocks making up the west flank of the Sierra Nevada, is present in the mass. Over the upper surfaces, the jointing has allowed the ready parting of the rock and the weathering processes to effect rapid disintegration. At stream bed exposures, the joints are closed features and it is probable no joints will be found below stream bed excavation which will persist as open fractures to the extent that they will allow uplift on a dam structure, loss of water from the reservoir, or necessitate excessive pressure grouting.

The attack of the weather upon the coarsely crystalline rock has produced comparatively gentle upper slopes with a soil cover estimated to be 12 feet deep on the average and spotted with rough brown rock outcrops. The left abutment grades from the coarse textured rock at stream bed back to medium textured granodiorite at the crest. The right abutment is made up entirely of the coarse textured rock. It frequently is found that rock of coarsely crystalline texture allows disintegration to depths of 50 feet or more over surfaces long exposed to temperature changes and other factors effecting weathering. The right abutment appears to have a comparatively shallow zone of disintegrated rock underlying the soil cover, with large areas of jointed, but sound, rock outcrop to the crest of the ridge. This type of rock, however, is so variable that test pit exploration is necessary before a reasonable prediction can be made as to depth of stripping necessary.

The rock is one entirely satisfactory upon which to found a gravity or arch concrete structure. The design would be dependent entirely upon the height of dam desired and the way it would fit the topography. If a dam were designed to fit the limits of the site as to height, a natural spillway appears to be available on the north side. Otherwise the spillway would be part of the structure.

DAM SITES ON AMERICAN RIVER

The region investigated is one in which occur the oldest of the Sierra rock masses. The formations consist largely of metamorphic rocks derived through dynamic-metamorphism. Intense movement and pressure have altered the original ancient sediments and basic igneous rocks over a wide region. The alteration has effected an increase in crystallization, thus changing the texture and generally increasing the hardness. Within the region younger masses of granitic and other igneous rocks, intrusive in the metamorphics, have caused, due to the great heat of and the escaping vapors from the molten intrusion, a border zone of increased metamorphism or further alteration to exist along the contacts. Consequently the complex nature of the formations derived through these processes requires a field study of a wide area surrounding, as well as a detailed study of the proposed dam sites, in order that a thorough understanding of the rock characteristics may be had.

Waldemar Lindgren, in the earlier publications of the United States Geological Survey, includes the metamorphics and intrusive igneous masses in a broad classification as "Bedrock series" or pre-Jurassic age. Sufficient for the present purpose is the fact that the rock formations are ancient, that no major faults have been found in the Bedrock series, and that minor shear zones, faults, and joints have been closed and the mass consolidated through the deposition of secondary quartz in the ages since movement has taken place.

Amphibolite and Amphibolite-schist.

The United States Geological Survey classifies the metamorphics, which make up the greater portion of the region examined, as amphibolite, which designation embraces all phases and modifications within the rock mass. Dynamic metamorphism acting upon basic igneous rock, whose chief bisilicate was pyroxene, caused it to pass into hornblendic rocks with more or less development of schistosity. The formation is "banded" through the variation in texture and mineral constituents which occur within relatively short distances, all phases being, however, perfectly crystalline. The trend of the banding is northwest to southeast and the bands dip almost vertically.

Some of the bands are decidedly laminated or foliated due to the parallel arrangement of hornblende crystals. Others present a massive appearance with the schistosity hardly discernable. Certain bands of the hornblende schist have passed into more finely laminated, green chlorite schist which softens to a scaly mass and weathers to the rusty colored clay soil characteristic of the region. Variation of the massive and schistose texture is irregular. The massive phase resembles the original igneous rock, is very hard, durable and resists erosion and weathering. The bands of massive amphibolite therefore mark the highest mountains and the most continuous ridge spurs.

The general characteristics of the amphibolite and amphibolite schist are shown on Plate E-V, "Characteristic Rock Formations at Dam Sites on North and South Forks of American River."

Topographic Development.

Both the North and South Forks of the American River cross the amphibolite over the greater portion of the sections examined as shown on Plate E-VI, "General Topographic and Geologic Features in the Vicinity of Dam Sites on North and South Forks of American River." In the erosive development of the streams they have met the massive bands to turn and follow the southwesterly strike of the less resistant schistose bands for short distances before cutting southeasterly across the trend of the massive bands. The side streams are developed along the schist bands. There, slopes are gentle and soil covering is the heaviest. Thus the topographic development has resulted in draws marking the schistose bands and ridges marking the more resistant massive bands. Where the massive bands have been crossed by the rivers, the hard resistant rock stands at steep angles above stream bed, outcrops of rock make up a large portion of the slope and soil covering is shallow. Geologically and topographically the most desirable dam sites will be located at points where the streams cross the spurs of massive amphibolite.

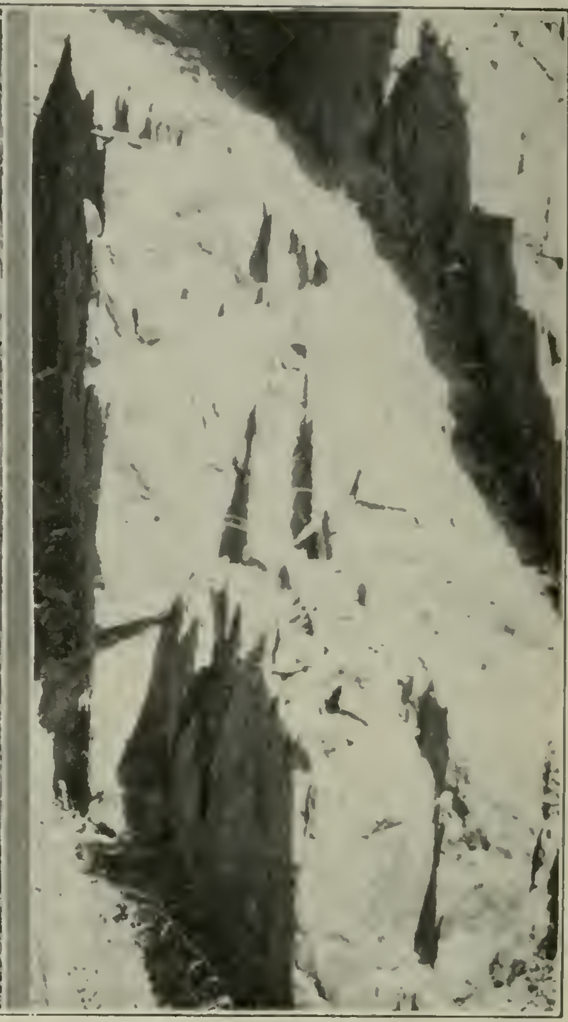
Auburn Dam Site.

At the junction of the Middle Fork with the North Fork of the American River lies a body of slate containing siliceous layers resembling chert and limestone deposit which has been extensively quarried. The black slates merge with the green amphibolite downstream. Over a distance of approximately 1000 feet, the rocks have developed a marked schistosity and the prevailing rock bands are amphibolite schist which has, in some places, altered to chlorite schist, a green flaky mass on the canyon sides which has weathered to a reddish clay soil.

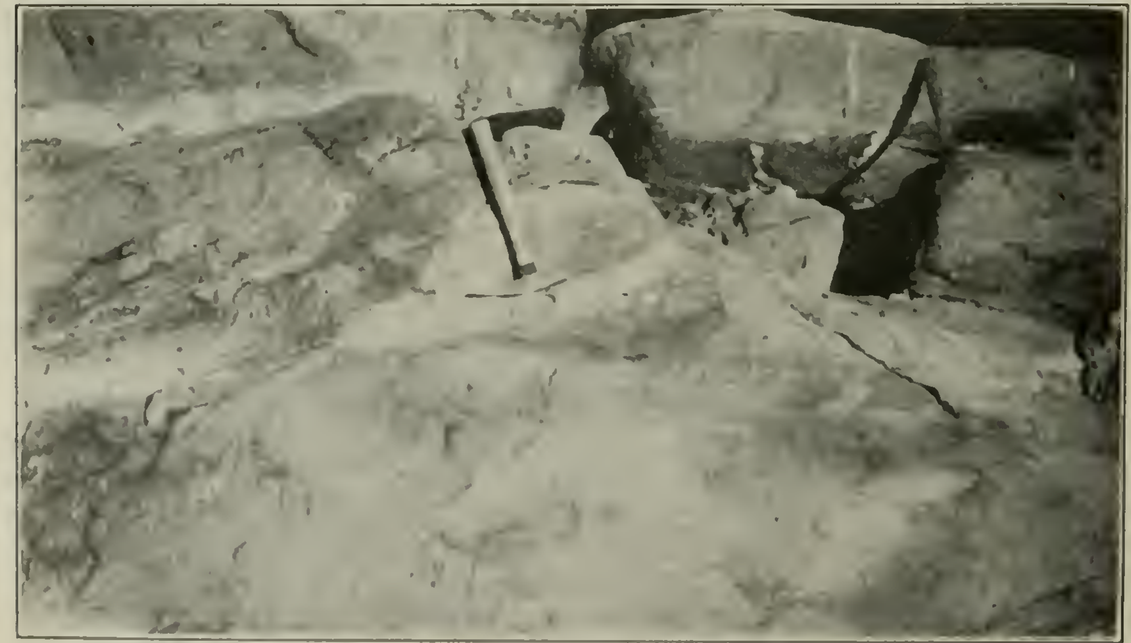
In passing downstream, the same material, in bands, occurs with the green chlorite schist bands becoming less pronounced. The stream cuts across the bands at right angles to their strike for about a mile and a quarter below the junction. At three-quarters of a mile, a band

PLATE E-V

Typical amphibolite schist



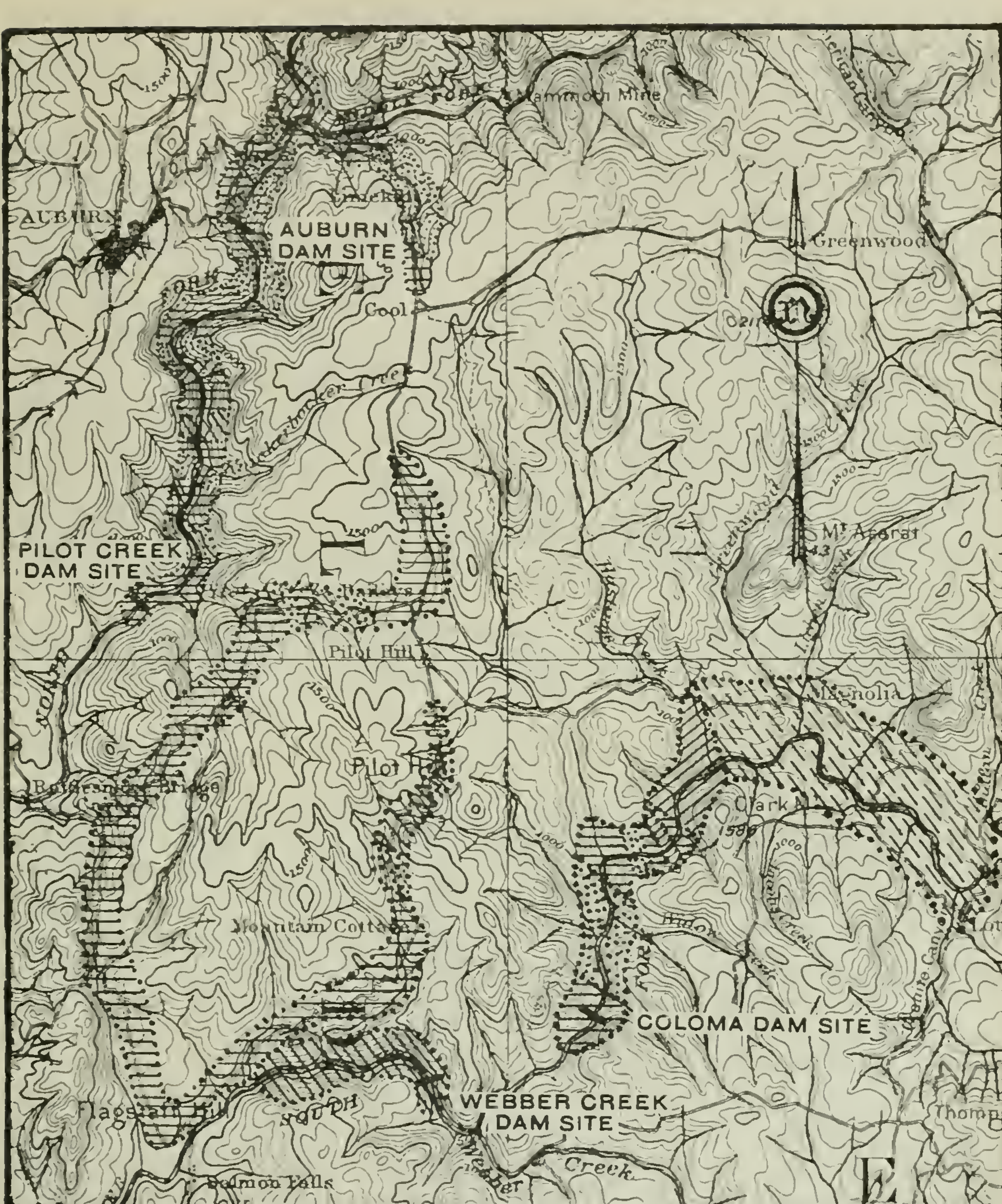
Jointed massive amphibolite



Massive amphibolite—Schistose development (at hammer). Quartz vein fillings.

Characteristic Rock Formations at Dam Sites on North and South Forks of American River.

PLATE E-VI



GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES

IN THE VICINITY OF

DAM SITES ON NORTH AND SOUTH FORKS

OF

AMERICAN RIVER

SCALE OF MILES

0 1 2 3 4

LEGEND

Amphibolite

Amphibolite schist

Granitic igneous intrusion

Basic igneous intrusion

Slates and related rocks

NOTE.—Investigation limited to areas included within dotted boundary lines.

of fully developed chlorite schist is exposed which merges into amphibolite schist. From this point to beyond the Auburn dam site the schistosity is not so marked, nor is there parting along joints, and the rock has resisted erosion.

The massive phase of the amphibolite predominates and a massive band some 500 feet in thickness, in which the rock resembles the original rocks, occurs at the dam site. Portions of this band have developed schistosity. The whole has been so thoroughly indurated by the deposition of secondary quartz that it has been the controlling feature of the topographic development. The canyon sides are precipitous, rock outcrops continuously and soil covering is shallow.

Just below this spur occurs a more schistose band. The stream turns to the southwest along its strike and side canyons have been developed. Above the spur, the stream bed drops less than 20 feet to the mile, while in the four-mile stretch below it drops 120 feet. The topographic development suggests waterfall conditions during the erosive history of the North Fork of the American River at this point. It is probable that potholes of some extent will be found in the rock bottom of the stream.

It is believed the geological and topographical conditions at this point combine to make an excellent site and foundation for a major structure.

Pilot Creek Dam Site.

The most conspicuous topographic feature of the region examined is the high ridge which strikes northwest-southeast across the region, the highest point of which is Pilot Hill. This spur is crossed by the North Fork of the American River at Pilot Creek. From the dam of the North Fork Ditch Company downstream to Pilot Creek, the topographic development in the bands of more fully developed schistosity and jointing have produced gentler slopes and numerous draws. Few massive bands exist and these have not sufficient width extent to become important until the Pilot Hill spur is reached.

Pilot Creek has eroded the southerly wall of the American River canyon where it crosses the massive amphibolite, but just below the junction of Pilot Creek with the river there is an excellent site for a dam. The canyon walls rise at steep angles from a narrow stream bed. Stripping should be small and firm rock should be found at shallow depth below stream bed.

Coloma Dam Site.

An area of granitic rock lies intrusive in the metamorphics along the South Fork of the American River from Coloma downstream to Hastings Creek. Such intrusions are the most effective agents of contact metamorphism and, as is of common occurrence, there is found a zone of highly metomorphosed rock along Hastings Creek and in the vicinity of its junction with the South Fork of the American River. The metamorphic rocks of this zone are composed of a number of lesser zones or bands of rock in which the alteration decreases in passing downstream from the intrusion. Physical changes, due to baking, as well as complete chemical changes, are apparent in very limited distances.

Downstream from the highly metamorphosed zone above described are found slates, chert and siliceous beds resembling quartzite. Some diabase also is found. About two-thirds of a mile downstream, chlorite schist crosses the stream bed. The stream to this point follows the strike of the cleavage of the slate. A resistant band of amphibolite turns the stream about one mile below the junction of Hastings Creek with the South Fork, but the topographic development prohibits its use as a dam site.

Amphibolite, resembling closely that found along the North Fork of the river, continues with no suitable dam sites for a distance of three and one-quarter miles below the mouth of Hastings Creek. At that point, the Pilot Hill spur is cut diagonally across the strike of the band by the South Fork. The formation is the massive phase, described in connection with the Pilot Creek dam site on the North Fork. It has here resisted erosion so that the stream bed is narrow and the canyon walls rise abruptly from a stream bed elevation of about 550 feet to over 900 feet above sea level. It is believed the topographic and geologic conditions here obtaining provide an excellent dam site.

Geologic Structure.—The massive amphibolite is banded with the bands striking north 60 degrees west. Subsequent to the stresses which caused the banding, the rock has been subjected to additional stresses which caused a jointing of the mass. The main jointing consists of a nearly vertical joint system striking south 50 degrees west and a horizontal joint system dipping south 50 degrees, west about 20 degrees. Joints are fractures or lines of weakness in the rock mass along which no displacement has occurred, while faults are joints along which there has been movement of one wall of the joint plane in reference to the other, which movement may or may not have produced an irregular fracture or crushed and brecciated zone.

The topographic draws in the vicinity of the dam site are indicative of the occurrence of rock weaknesses. About 500 to 900 feet downstream from the axis of the proposed dam is a draw which has developed along a minor fault. This fault is of great age, long dead, and the fractured zone thoroughly healed through deposition of secondary quartz. The brecciated zone only has important width through a schistose band and there has been deposited a quartz vein about three feet wide. A few hundred feet upstream from the axis of the proposed dam, a draw has developed along a joint carrying no indication of movement or brecciation along the joint walls. Between these two draws occurs a band of massive amphibolite which is the proposed dam site. Through this band, the stream trench is a ''V'' shaped notch, narrow at stream bed and with rock outcrops rising as cliffs to about 150 feet above stream bed. Rock continues to crop out up the slopes and the soil consists of small rock fragments rather than the heavy soil cover resulting from completely broken down rock characteristic of the slopes farther upstream.

The jointing is emphasized through weathering at the surface and some large joint blocks have been displaced, but as a whole the location, taking advantage of the massive rock ridge, is adapted to the construction of a concrete dam.

Webber Creek Dam Site.

The South Fork of the American River was examined from Salmon Falls upstream to locate a site for a low dam to develop the power drop between Coloma dam site and the Folsom reservoir site. Just above the Salmon Falls bridge, the river has cut its course through an area of intrusive igneous rock which continues, with varying phases of texture and mineral constituents, upstream as far as the investigation went.

The igneous mass is a dark green rock of granitoid texture whose main mineral constituents are pyroxene, hornblende and plagioclase. Quartz is present as a secondary mineral in the lighter phases. The mass contains areas composed almost entirely of hornblende, which may be primary. These areas make up the more resistant portions and mark the narrow gorge and precipitous walled portions of the river course. Beginning at about stream bed elevation 430 and continuing upstream for several hundred feet the river cuts westerly across such an area. The stream bed is narrow and the side walls rise abruptly above it for some 200 feet. The rock is hard and durable and is difficult to break under blows of a hammer. Detailed surveys will reveal the best topographic location for a dam site within an extensive area whose rock will afford an excellent foundation for a dam, require a minimum of stripping and should present shallow depth of stream bed materials. The site takes its name from Webber Creek which enters the South Fork above the dam site location.

Folsom Dam Site.

The Folsom dam site is located on the American River below the junction of the South Fork with the North Fork and a short distance above the point where the river leaves an extensive area whose country rock has been designated granodiorite by the United States Geological Survey.

The term granodiorite is a contraction of granite-diorite employed to distinguish the intermediate rock between granite and quartz diorite. The latter strongly resembles granite, physically and chemically, and for the purpose of this report the rock will be referred to by its local name in general use, granite.

The dam site lies wholly within the granite area with topographic differences due largely to the effect of erosion and attack of the weather upon rock of fairly uniform characteristics. There are no evidences of major lines of structural weakness in the vicinity. Contrary to the popular conception, granite is one of the least durable of the crystalline rocks. The constituent mineral crystals of the granite at the dam site are mainly hornblende, the mica biotite, quartz and feldspar. As the original molten mass cooled, these relatively large crystals formed, interlocking with each other, until the whole became converted into a mass of interlocking crystals, firmly knit together into a strong crystalline rock mass. However, this crystal fabric is subject to breakdown as the tenacity or bond of the fabric is overcome by the forces of weathering. Temperature changes cause the rock surface to break down through unequal contraction and expansion of the component crystals. Minute cracks open as the crystals part from each other

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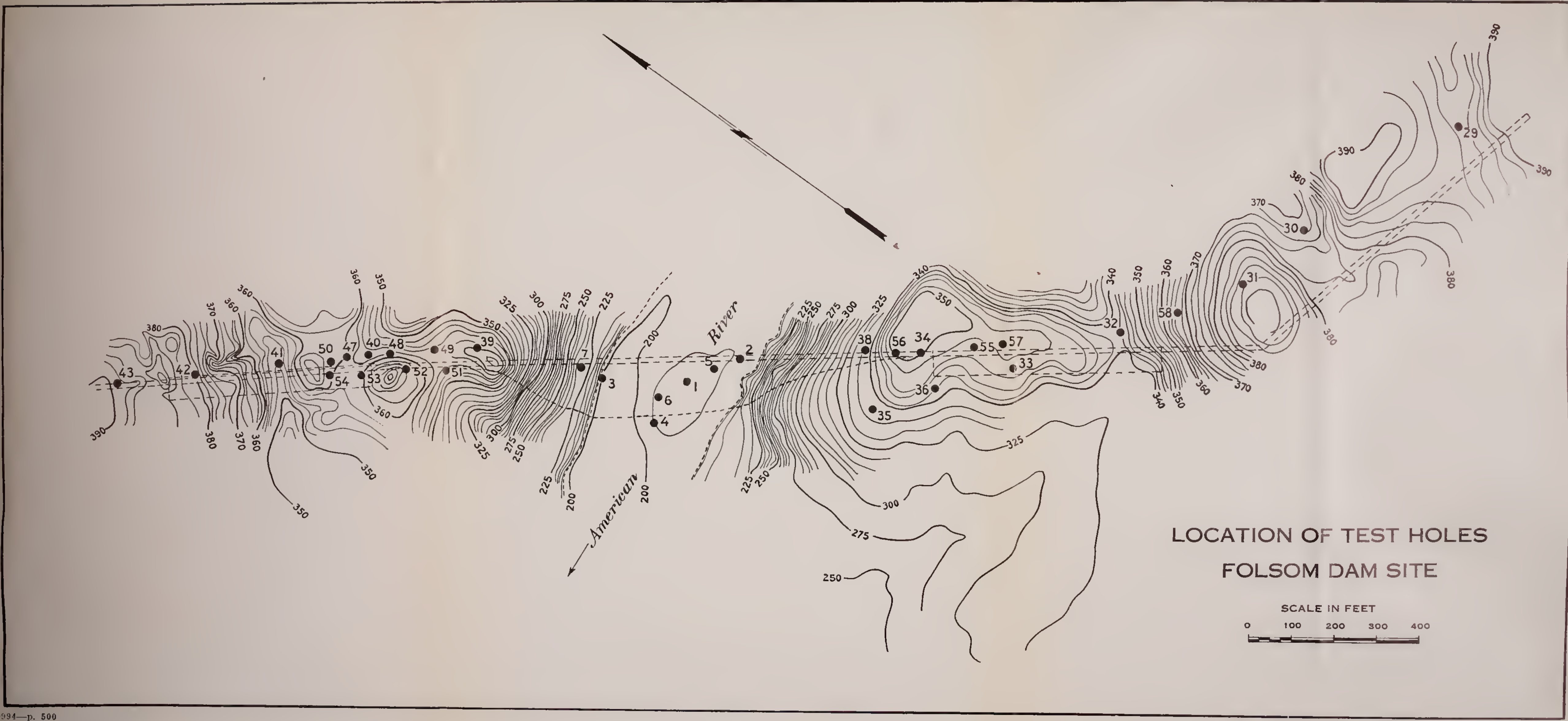
LOCATION OF TEST HOLES
FOLSOM DAM SITE
SCALE IN FEET
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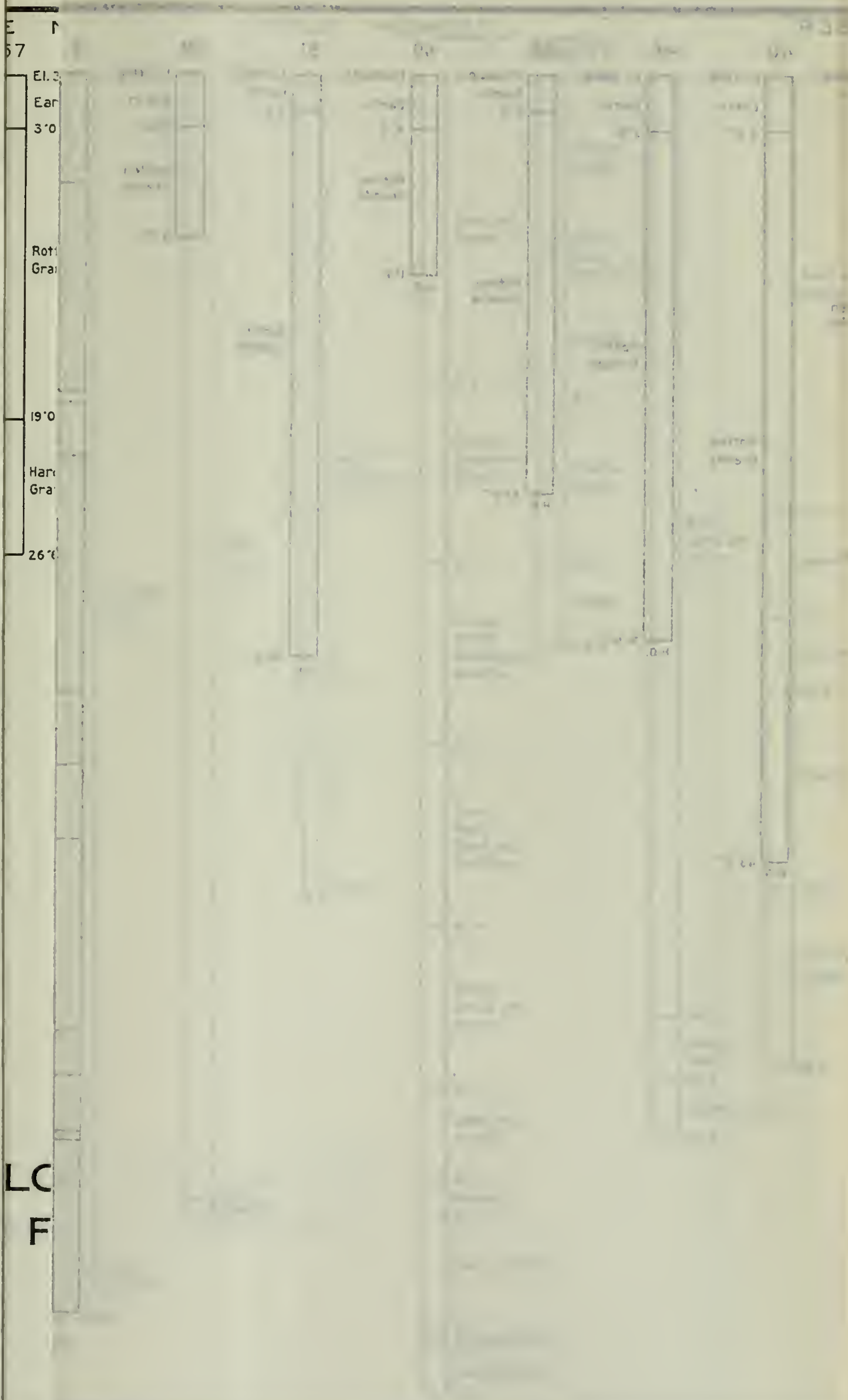
American River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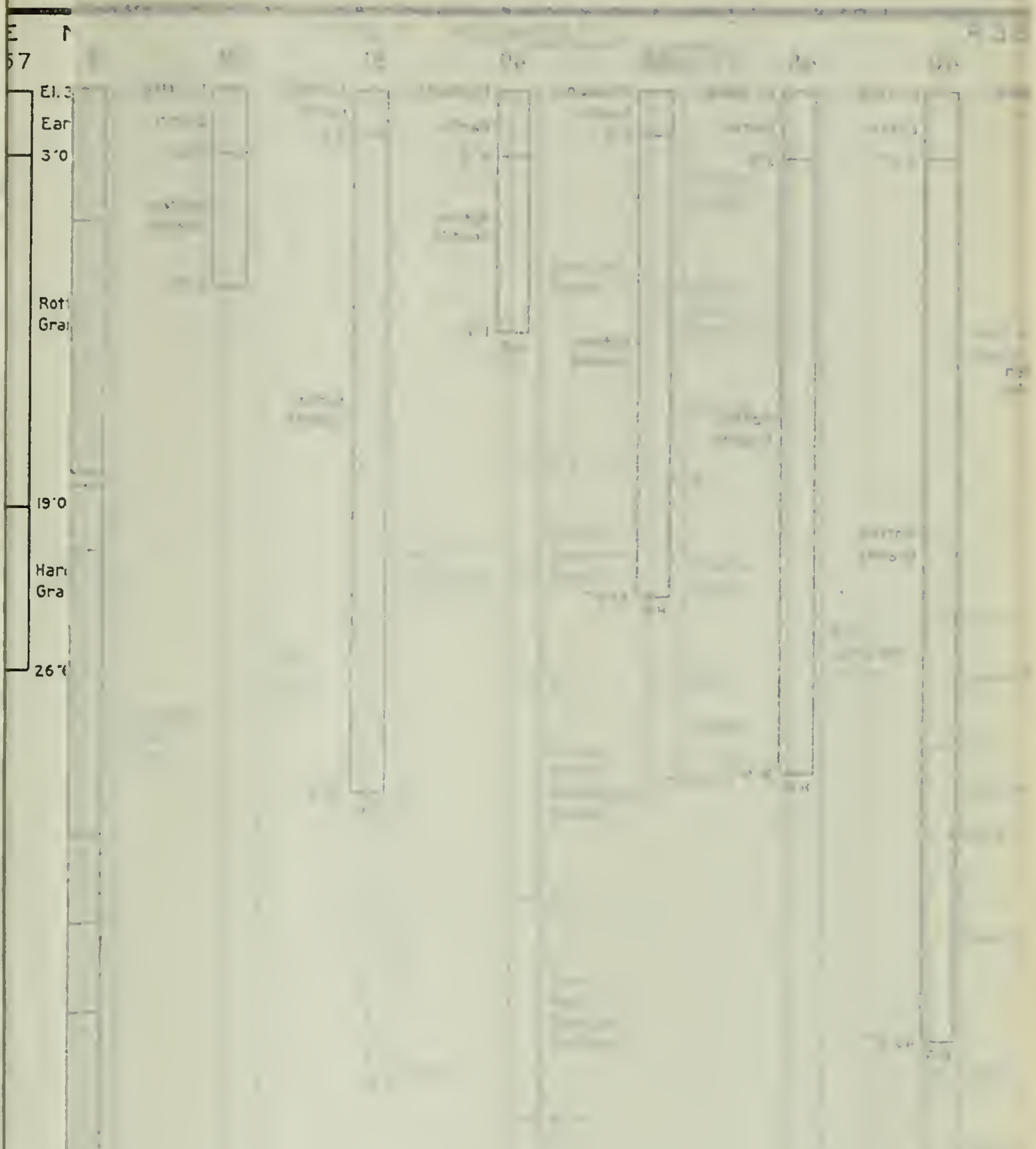

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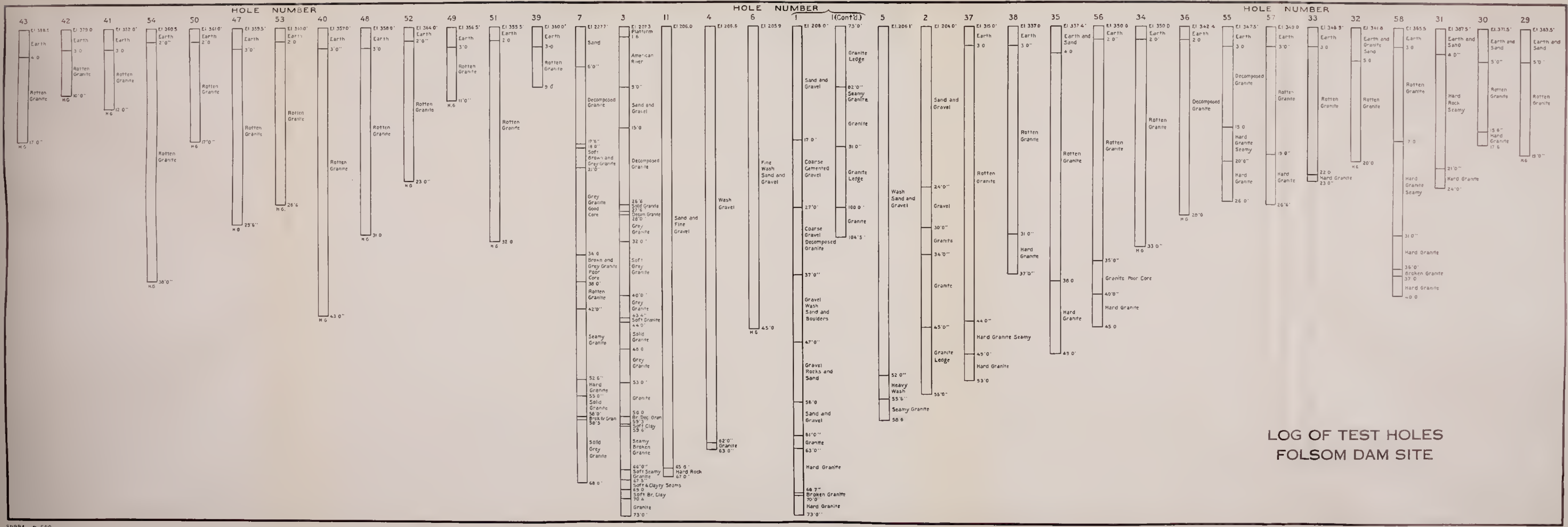
HOLE NUMBER
43 42 41 54 50 47 53 40 48 52 49 51 39 7 3 11 4 6 1 1(Cont'd.) 5 2 37 38 35 56 34 36 55 57 33 32 58 31 30 29
LOG OF TEST HOLES
FOLSOM DAM SITE

and surface moisture, penetrating through these openings, enlarges them and further weakens the rock through the removal or alteration of some of its mineral constituents. This process of disintegration may continue to some considerable depth below the ground surface, the residuum or so-called rotten granite, remaining in place over the unweathered portions. Such material is a physically weak crumbly mass, subject to penetration and percolation of water and readily eroded.

The surface of the dam site is spotted with outcrops of unweathered granite, but the larger portion of the dam site surface is made up of the rock in varying stages of disintegration, ranging from the completely broken down and altered product, clay soil, to rock which may be broken down with a hand pick. The locations of test holes bored across the dam site are shown on Plate E-VII, "Location of Test Holes, Folsom Dam Site," and the driller's logs are given on Plate E-VIII, "Log of Test Holes, Folsom Dam Site." The logs show the disintegration to be uneven as to depth, increasing generally from upstream to downstream, with a maximum depth to solid rock of 43 feet on the west and 38 feet on the east abutment. All of this residuum must be removed in stripping the dam site and a dam keyed in to the firm unaltered granite to depths of at least five feet.

The residuum is rapidly carried away through erosion on the slopes and bottom of the gorge at the dam site and the unweathered granite, exposed below elevation 325 on the east and 340 on the west abutment, is firm. The rock mass has developed three major systems of joints; one striking southwesterly, diagonally across the dam site but parallel to the stream course just above the site, and dipping 75 degrees from the horizontal; one striking southeasterly making about an 80-degree angle with the first and dipping 75 degrees from the horizontal; and an intersecting horizontal joint dipping north 75 degrees about 25 degrees. At the surface these joints are opened, and in many places a weathered zone (rotten granite) ranging from one to eight inches in width borders the joints.

The presence of secondary quartz filling in the joints in the freshly eroded granite at stream level and considerable quartz float in the soil indicate that the older and larger seams and joints below the weathered zone are probably closed to the passage of water. However, the diamond drill core records show "seamy" and rotten granite zones and an examination of the cores reveals joints, which persist to depths in excess of 50 feet, through which water has circulated and whose wall material has disintegrated. It therefore will be necessary to carry out a systematic program of pressure grouting over the dam site, the location, number, depth and direction of the grout holes being dependent upon the joints revealed when the site is stripped.

Sites for two flood spillways, one on each abutment of the dam, were examined. These lie along the flatter portions of the dam site where disintegration has progressed to the greatest depths. It would be necessary to strip and treat the foundation over these stretches as carefully and fully as the stretch upon which the gravity dam section would be founded. The wasteway to the river from the spillway crest may require a "cascade" treatment of the natural rock slopes. The waste discharge over each spillway may equal 100,000 cubic feet of

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MILLSITE DAM SITE ON STONY CREEK

Geography and Topography.

Stony Creek drains about 700 square miles of the east flank of the Coast Range lying largely in Glenn County and joins Sacramento River west of Chico. Upstream from Orland, the creek has built up a sandy loam alluvial plain in a wide trench cut in a predeposited alluvium which rises as flat topped gravelly benches bordering the plain. The lower foothill region consists of low rounded sandstone and shale hills. North and east of Stony Creek, above its junction with the North Fork, flat table land, ridges and hills rise higher than the surrounding hills as uneroded remnants carrying a protective lava capping. The topographic development of the higher foothill region is the result of diffierential weathering and erosion upon a series of steeply dipping shale, sandstone and conglomerate beds striking northwest-southeast across the region. The occurrence of the most resistant conglomerate beds and somewhat resistant sandstone beds in the series is marked by topographic ridges, while the valleys have developed along the shales with rounded hills in line marking the occurrence of minor sandstone beds.

Stony Creek has followed generally the trend of these ridges in a northerly direction to its junction with Grindstone Creek, diagonally crossing the strike of the shale beds and widening its trench or flood plain, to be turned by, and at infrequent intervals crossing, the more resistant rock beds. At these crossings a narrow stream trench, the bottom of which is a "V" shaped notch, has been developed in resistant bedrock.

The most conspicuous topographic ridge of the foothill region extends southeasterly from a point west of Newville. Its development is due to a thick conglomerate bed topped by heavy beds of sandstone. Where Stony Creek crosses this ridge in Section 1, Township 21 North, Range 6 West, the standstone has been partially eroded away and the conglomerate, exposed on both sides of the stream, forms the Millsite dam site.

General Geology.

The gravelly terraces and low hills rising above the recent alluvial plain are the remnants of the great Pleistocene stream deltas having extensive counterparts on the east border of the Sacramento Valley. The low hills rising above the terraces consist of Tertiary (Miocene) sandstone, shales and conglomerate beds loosely cemented with lime, which carried a lava capping, now left in small areas, of a later Tertiary period. These formations dip toward the valley at an angle of about 35 degrees.

Underlying the Tertiary formations is an older (Cretaceous time) series of sandstone, shale and conglomerate beds dipping more steeply than the overlying beds in the same general direction. The Cretaceous series are the more indurated, stronger and resistant rocks.

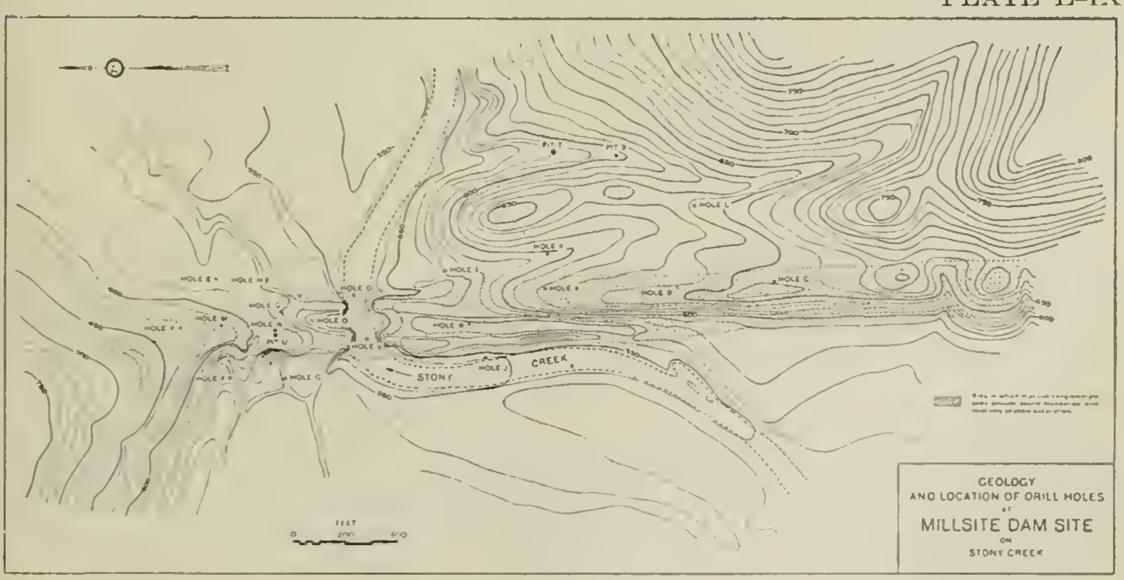
Geologic Structure.

The important geological structural features in relation to engineering structures are limited to the bedding of the series and the jointing resulting from displacement. The whole series is distinctly bedded with sandstone and conglomerate beds of varying thickness interbedded in a great thickness of shale. In the vicinity of the Millsite dam site, the whole series has been tilted easterly about 60 degrees from the horizontal. This displacement has been accomplished without folding in the region and with but little jointing. No fault of considerable displacement passes near the dam site.

Detailed Geology of Millsite Dam Site.

The Millsite dam site occurs at a point where Stony Creek, in its erosive development, met and was turned northeasterly by a thick (about 200 feet) resistant mass of sedimentary rock comprised principally of several relatively thick conglomerate beds separated by thinner sandstone and shale beds. The stream crossing of the mass is about 800 feet in width between steeply rising hills, with the stream bed notch being limited to about 100 feet width and rising about 30 feet above stream bed. The topography and geology of the site are shown on Plate E-IX, "Geology and Location of Drill Holes at Millsite Dam Site on Stony Creek."

PLATE E-IX



The conglomerate consists of gravel, ranging upward from pea size to boulders of several inches diameter in a matrix of fine sand. The gravel is covered by a thin coating of iron oxide (limonite), which acts as a cementing material in the sand grains. The rock is substantial in character, being made up of water worn fragments of hard rock which, though oxidized and readily broken at weathered surfaces, is not readily affected by ordinary weathering agencies at shallow depths below the surface. The cementing material that binds the mass together is a secondary deposit which has developed in the course of a great period of time due to the penetration of water carrying oxygen of the air alternately collecting the products of oxidization and depositing it in the interstices of the material as a coating around the component fragments and materially strengthening the formation as a whole. The interbedded sandstone and shale are more easily or rapidly affected by weathering and erosive agencies, which has allowed the development of troughs or draws between the conglomerate outcrops. However, beyond the zone of surface weathering the rock is substantial, well cemented and in better physical condition than the average sandstone. In series with the conglomerate, the whole presents a mass entirely satisfactory as a foundation for a multiple arch or flat slab type dam.

The geologic structure is important in relation to the keying in of a dam. The dip of the beds is such that in the topographic draws the indurated conglomerate is found at short vertical distances below ground surface (holes Q, O and R on Plate E-IX). The dip is downstream so the resultant thrust of the buttresses would be parallel to the bedding, while the upstream slab would meet the bedding at about a 45 degree angle. The foundation excavation then should be stepped into the rock, beyond the requirements to reach sound rock, in order to procure a most favorable bearing. The stripping requirements would be uneven, but should not exceed 20 feet on the average over the abutments, with probably an average depth of 50 feet over stream bed.

The dips were found to be consistent throughout the region examined and no fault displacement was found at the dam site. The region has been subjected to considerable tilting, probably along a fault line lying to the west. Minor inconsequential faults, now dead, might be found upon more detailed examination.

The records of exploratory drilling by the United States Reclamation Service at the dam site are given in the following Table E-1 and the locations of the drill holes appear on Plate E-IX.

The main jointing of the formation is at right angles to the bedding. Crevices in the formation are reported to depths of 18.7 feet in Holes A and B, 16 feet in Hole C, 65 feet in Hole D, 37.5 feet in Hole V, 28 feet in Hole G, 56 feet in Hole O, 32.5 feet in Hole Q, 20 feet in Holes H and E, and 7 feet in Hole I. These crevices are probably formed by parting along bedding planes and where joints intersect those planes. The rocks are stable, containing no water soluble constituents and no material readily soluble in five per cent solution cold HCl. It is probable, therefore, that the openings are clean and may be readily grouted. Deep pressure grouting would be necessary at stream bed, and it would be advisable that all grout holes be carried to at least 100 feet in depth below rock line.

A spillway could be located between Holes B and C, Plate E-IX, but control works would be required to prevent the overflow water from following down the contact between the conglomerate and the less resistant sandstone and to carry it past this contact to the draw in which test pits T and S are located. A concrete apron would be required for a distance of 100 feet downstream from a line between Holes B and C to prevent excessive erosion.

Gravel bars upstream and downstream from the dam site would provide an adequate nearby source of concrete aggregate through washing and screening. This material unwashed should also be suitable for the downstream portion of an earth fill, as it appears to contain a sufficient amount of silt. The soil derived from the shale and the shale itself would be suited to rolling in a relatively tight embankment.

TABLE E-1

LOGS OF EXPLORATORY DRILLINGS AT MILLSITE DAM SITE BY UNITED STATES RECLAMATION SERVICE

LOG OF HOLE P

Surface elevation 632.1 feet

Depths, in feet	*Thickness, in feet*	*Description of formations*
0.0– 8.0	8.0	Soil and boulders
8.0–27.8	19.8	Sandstone
27.8–30.0	2.2	Loose material (sand and gravel)
30.0–31.0	1.0	Conglomerate
		From 11 to 13 feet sandstone was soft and decomposed. Lost water at 13 feet

LOG OF HOLE E

Surface elevation 582.7 feet

Depths, in feet	*Thickness, in feet*	*Description of formations*
0.0– 6.5	6.5	Soil and gravel
6.5–45.8	39.3	Sandstone
		Lost some water in crevice at 17 feet. Sandstone was all solid. Larger cores obtained as hole went deeper

LOG OF HOLE M

Surface elevation 609.9 feet

Depths, in feet	*Thickness, in feet*	*Description of formations*
0.0–20.0	20.0	Soil and gravel
20.0–24.5	4.5	Shale
24.5–34.0	9.5	Soft conglomerate, pebbles tear loose and choke bit
34.0–38.0	4.0	Sandstone containing some pebbles
38.0–74.5	36.5	Conglomerate, mixture of sandstone and shale, all containing pebbles, many of which tear loose and choke bit. Hole was water tight all the way down

LOG OF HOLE F

Surface elevation 561.4 feet

Depths, in feet	*Thickness, in feet*	*Description of formations*
0.0–10.0	10.0	Soil, boulders and gravel
10.0–25.5	15.5	Shale, breaks up badly into small pieces
25.5–27.5	2.0	Sandstone
27.5–79.0	51.5	Shale, seamy, short cores
		Hole is water tight

LOG OF HOLE H

Surface elevation 556.1 feet

Depths, in feet	*Thickness, in feet*	*Description of formations*
0.0–14.1	14.1	Soil, rocks and gravel
14.1–18.0	3.9	Sandstone; short cores
18.0–19.0	1.0	Seam of coarse gravel; losing some water here
19.0–23.0	4.0	Sandstone; short cores
23.0–33.0	10.0	Shale; broken, short cores; more solid and longer cores below 25.0 feet
33.0–53.0	20.0	Sandstone; long cores

LOG OF HOLE Q

Surface elevation 582.5 feet

Depths, in feet	*Thickness, in feet*	*Description of formations*
0.0–3.0	3.0	Loose boulders and gravel
3.0–12.0	9.0	Very hard conglomerate
12.0–13.0	1.0	Hole caving; yellow dirt and sand. Lost water at 12 feet; crevice cemented
13.0–45.1	32.1	Very hard conglomerate
		Crevice at 32.5 feet; lost all water for about 2 minutes then half flow returned; water all ran out of hole at crevice when hole stood idle

LOG OF HOLE N

Surface elevation 590.4 feet

Depths, in feet	*Thickness, in feet*	*Description of formations*
0.0–12.0	12.0	Sand and gravel
12.0–14.0	2.0	Shale
14.0–18.0	4.0	Conglomerate, very soft, pebbles tear loose and congest bit, making drilling almost impossible so that hole was abandoned at 18.0 foot depth

LOG OF HOLE G

Surface elevation 556.3 feet

Depths, in feet	*Thickness, in feet*	*Description of formations*
0.0–17.0	17.0	Soil and some gravel
17.0–45.1	28.1	Shale, seamy, short cores. Lost water entirely at 27 to 28
45.1–49.5	4.4	Sandstone
49.5–61.1	11.6	Shale
		Cores from 27 to 28 feet where water was lost show rust color at ends. Test made to determine if water ran out at 27 to 28 feet and found that water came to within 10 feet of top of hole. This is about the level of the water in the creek at this time. Casing was driven tight into shale at 17.8 feet indicating that water must be coming into hole at crevice at 27 to 28 feet

LOG OF HOLE O

Surface elevation 558.5 feet

Depths, in feet	Thickness, in feet	Description of formations
0.0– 1.5	1.5	Soil and loose sandstone
1.5– 5.0	3.5	Sandstone. Lost water at 5 feet; hole cemented
5.0– 8.0	3.0	Broken shale
8.0–12.0	4.0	Shale and sandstone
12.0–16.5	4.5	Shale
16.5–39.0	22.5	Conglomerate
39.0–51.0	12.0	Mixture sandstone and shale
51.0–76.8	25.8	Conglomerate with some cores of sandstone. Lost water at 55.8 feet. Unable to cement crevice. Water rose in hole to approximate water surface of creek. Except for crevices at 5 and 55.8 feet, hole was all solid drilling

LOG OF HOLE D

Water surface 544.0 feet

Depths, in feet	Thickness, in feet	Description of formations
0.0– 4.0	4.0	Water of river
4.0– 35.0	31.0	River sand and gravel
35.0– 50.0	15.0	Detached mass of conglomerate
50.0– 58.0	8.0	Small boulders, river sand and gravel
58.0– 67.0	9.0	Conglomerate. 61.8 to 62.2 feet, open crevice, lost water. Unable to cement, casing blasted down and water returned
67.0– 72.5	5.5	Mixture sandstone and shale with some conglomerate
72.5– 73.0	0.5	Soft material, would not core; drilled with chopping bit; lost water, unable to cement. Blasted casing down to 73 feet
73.0– 93.0	20.0	Conglomerate
93.0– 96.0	3.0	Soft shale
96.0–107.0	11.0	Conglomerate
107.0–110.0	3.0	Mixture sandstone and shale
		Hole tight below 73.0 feet to bottom of casing

LOG OF HOLE V

Water surface 544.0 feet

Depths, in feet	Thickness, in feet	Description of formations
0.0– 0.5	0.5	Water of river
0.5–28.0	27.5	River sand and gravel
28.0–31.5	3.5	Soft conglomerate
31.5–37.5	6.0	Hard conglomerate
37.5–39.5	2.0	Sandstone
39.5–69.0	29.5	Shale
		Lost water at 37.5 feet; reamed hole and drove casing down to 48.0 feet. Hole tight below 37.5 feet

LOG OF HOLE I

Surface elevation 570.8 feet

Depths, in feet	Thickness, in feet	Description of formations
0.0– 2.5	2.5	Soil
2.5–26.0	23.5	Sandstone
26.0–32.5	6.5	Mixture sandstone, shale and conglomerate
		Lost water at 7.0 feet; crevice cemented. Hole tight below 7.0 feet.

LOG OF HOLE R
Surface elevation 565.9 feet

Depths, in feet	*Thickness, in feet*	*Description of formations*
0.0– 8.0	8.0	Soil
8.0–11.6	3.6	Sandstone
11.6–33.0	21.4	Very hard conglomerate
		Hole is water tight

LOG OF HOLE J
Surface elevation 548.3 feet

Depths, in feet	*Thickness, in feet*	*Description of formations*
0.0–12.0	12.0	Sand, gravel and boulders
12.0–16.0	4.0	Shale
16.0–33.0	17.0	Sandstone

LOG OF HOLE K
Surface elevation 595.3 feet

Depths, in feet	*Thickness, in feet*	*Description of formations*
0.0– 5.0	5.0	Broken, loose sandstone
5.0–24.0	19.0	Solid sandstone

LOG OF HOLE A
Surface elevation 620.7 feet

Depths, in feet	*Thickness, in feet*	*Description of formations*
0.0– 2.0	2.0	Loose rocks and soil
2.0– 9.0	7.0	Brown and gray sandstone
9.0–68.0	59.0	Very hard conglomerate
		Lost water at 11.0 feet and 18.7 feet; both crevices cemented
		Hole is tight below 18.7 feet

LOG OF HOLE B
Surface elevation 644.1 feet

Depths, in feet	*Thickness, in feet*	*Description of formations*
0.0– 9.5	9.5	Sandstone
9.5–12.5	3.0	Conglomerate
12.5–20.5	8.0	Sandstone
20.5–24.5	4.0	Mixture sandstone and shale
24.5–41.0	16.5	Conglomerate
		Gravel seam at 8.0 feet; casing driven down to stop caving. Lost water at 12.0 feet and 18.5 feet; both crevices cemented
		Hole is tight below 18.5 feet

LOG OF HOLE L
Surface elevation 642.0 feet

Depths, in feet	*Thickness, in feet*	*Description of formations*
0.0– 6.5	6.5	Yellow soil
6.5–26.5	20.0	Sandstone

LOG OF HOLE C
Surface elevation 653.3 feet

Depths, in feet	*Thickness, in feet*	*Description of formations*
0.0– 1.0	1.0	Soil
1.0–16.3	15.3	Sandstone
16.3–18.8	2.5	Conglomerate
18.8–28.0	9.2	Sandstone
28.0–34.4	6.4	Conglomerate
34.4–38.5	4.1	Mixture conglomerate and hard shale
38.5–44.7	6.2	Conglomerate
		Lost water at 5.0 and 16.0 feet; both cemented. Hole is tight below 16.0 feet

LOG OF TEST PIT U
Surface elevation 592.0 feet

Depths, in feet	*Thickness, in feet*	*Description of formations*
0.0– 3.0	3.0	Top soil
3.0– 5.4	2.4	Clay and gravel
		Conglomerate below 5.4 feet

LOG OF TEST PIT T
Surface elevation 572.7 feet

Depths, in feet	*Thickness, in feet*	*Description of formations*
0.0– 0.5	0.5	Soil
0.5– 5.4	4.9	Soft shale
		Shale lies in inclined formation

LOG OF TEST PIT S
Surface elevation 591.7 feet

Depths, in feet	*Thickness, in feet*	*Description of formations*
0.0– 1.0	1.0	Soil
1.0– 5.3	4.3	Soft shale
		Shale lies in inclined formation

CAPAY DAM SITE ON CACHE CREEK AND MONTICELLO DAM SITE ON PUTAH CREEK

Geography and Topography.

Cache Creek and Putah Creek are the two most southerly major streams draining the Coast Range into the Sacramento Valley. The topographic development of the region has been controlled by faults, along which the southeasterly trending Capay and Monticello valleys have developed, and the occurrence of heavy resistant beds of sandstone and conglomerate in a steeply dipping series of sedimentary rocks.

The streams, in their erosive development, have produced comparatively wide valleys in the weakened rock of the fault zones. Obstructed by resistant beds in their effort to achieve a direct route to the lower valley area, they have cut comparatively narrow gorges to reach a wide stream trench cut through a less resistant sedimentary series which has weathered down to rolling hills and low ridges. Their sediment load has been deposited as broad alluvial fans built up on the floor of the Sacramento Valley.

Cache Creek leaves the upper Capay Valley, about two miles easterly from Brooks post office or Eckhard, through a canyon it has cut in a nonresistant series of rocks to return to the lower Capay Valley a mile or so downstream. The Capay dam site is located near the head of this short canyon in the southwest quarter of Section 5, Township 10 North, Range 2 West.

Putah Creek leaves the Monticello Valley through a gorge six or seven miles long at the center of which, in Section 29, Township 8 North, Range 2 West, occurs a constriction, with rugged rock ledge walls, called the Devil's Gate, which forms the Monticello dam site.

General Geology.

Sedimentary rocks, mapped generally on Plate E-X, "General Topographic and Geologic Features in the Vicinity of Capay Dam Site on Cache Creek" and Plate E-XI, "General Topographic and Geologic Features in the Vicinity of Monticello Dam Site on Putah Creek," underlie both reservoir sites and make up the dam sites so the region traversed by Cache Creek and Putah Creek in their lower elevations may be treated as a unit geologically.

Cache Creek debouches from its foothill area at Capay and passes over the wide recent alluvial fan it has built up on the Sacramento Valley plain. The same physiographic and geologic conditions prevail along Putah Creek east of Winters. West of Winters and Capay, the country rock consists or Tertiary (probably Eocene) sandstone, shale and conglomerate. The shale formation is relatively soft and weathers readily. The low rounded hills and ridges consist of the more indurated sandstone and conglomerate beds of the series, in which the component grains or pebbles are bound together by lime carbonate. The Capay Valley has been cut out of this formation, which has been further weakened through faulting, but east of Capay Valley and north of Cache Creek the hills are more rugged and resistant to weathering, with the bedding distinctly visible from a distance. The area west of Capay Valley comprises an older (Cretaceous time) series of shale, sandstone and conglomerate beds. The western contact between these two formations strikes southeasterly and intercepts Putah Creek about five miles upstream from Winters. On Putah Creek, from the contact upstream to the Monticello Valley, the stream has cut its gorge through the Cretaceous series of sediments.

The Cretaceous shale, when fresh, is a dark greenish gray laminated rock, essentially an indurated sandy shale whose laminated structure is formed by the parallel arrangement of flaky grains and bituminous matter. At the surface, and for some depth below ground surface, due to its lack of coherence, weathering has entirely broken it down to shale flakes, which in turn break down to a brown sandy soil. The sandstone of the series in fresh stream bed exposures has a more greenish color. The sand grains are firmly bound together by induration through the introduction of secondary alteration products and the rock is as hard and as physically strong as sandstones run.

The weathering out of shale beds between the sandstone beds has left almost vertical "ledges" of sandstone projecting from the gorge walls along Putah Creek. Those rock ledges have been long exposed to the weather and oxidation has changed the rock color to a light brown. The oxidation has penetrated into the rock variable distances, due to the absorption by the rock of moisture carrying oxygen. This process has produced an iron oxide (Limonite), which apparently acts as efficiently as a binder as the original mineral constituents as the rock is hard and almost as sound in its oxidized state in the ledges as in stream bed exposures. This characteristic has an important bearing upon the depth of stripping that would be necessary. The conglomerate of the series is comprised of water worn gravel and boulders of older rock fragments imbedded in a matrix of fine sand, the whole being thoroughly indurated through introduction of iron oxide and possibly some lime carbonate.

Geologic Structure.

The Coast Range region is one of heavy faulting. However, faults of any considerable displacement do not pass through the dam sites and there is no record of any movement having taken place upon the faults in recent time. The easterly contact between the Cretaceous and Tertiary formations is a fault contact. It is not an important feature in relation to the structures proposed, as other considerations dictate an earthquake resistant structure at the Capay dam site on Cache Creek, which site lies closest to the weakened zone along the contact. The Monticello site lies about midway between two approximately parallel faults occurring about six miles apart. Renewed activity along either or both, approximately parallel to the axis of the dam, would be unlikely to occur, but if it should it would not affect a rigid structure midway between.

The sedimentary beds have been uplifted and tilted from their original horizontal position until the Cretaceous series dip easterly, toward the valley (north 50 to 60 degrees east and therefore downstream) about 75 degrees at Putah Creek. With such amounts of displacement, it may be expected that the beds are jointed and possibly minor slips would be found if the Monticello dam site were stripped.

The rocks are stable, so the joint walls should be found in close contact, and, where minor slippage has occurred, no measureable thickness of clay gouge should have developed.

The Tertiary beds are tilted northerly about ten degrees. Within the fault zones they exhibit considerable crushing and minor faulting.

PLATE E-X

GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES
IN THE VICINITY OF
CAPAY DAM SITE
ON
CACHE CREEK

SCALE OF MILES
0 1 2 3 4

LEGEND
Alluvium
Tertiary sedimentary rocks
Cretaceous sedimentary rocks
Faults found
Faults indicated but not determined
Dip and strike

Detailed Geology of Capay Dam Site.

Cache Creek has developed a fairly wide valley through the weakened and little resistant Tertiary sediments in the vicinity of Brooks post office and swings southeasterly, with the strike of the bedding of the formation, to the high hills making up the dam site, where it crosses the bedding of the sandstone and shale at nearly right angles to the strike, but with the dip. There are no outcrops of rock in place at the dam site, and the larger sandstone blocks in the stream bed and on the abutment slopes are erosion remnants which have gravitated to their present position. The surface of the dam site consists of a sandy soil, the result of the complete breaking down of a rock formation whose shaly, loosely cemented character lends it to deep weathering. It is probable that ground water penetration along the joints and bedding planes may have weakened the rock so that rock in substantial enough form for acceptable foundation for even a hollow type concrete structure could be reached only at considerable depth. The formation is considerably jointed and it contains the constituent lime, and probably gypsum, subject to solubility. The joint spaces thus may have been enlarged and it is likely the permeability of the foundation material or reservoir bed would increase with the change in ground water conditions resulting from the reservoired water. The formation, however, is entirely acceptable for earthern embankment construction since the path of percolation with this type of dam is relatively long.

The character of the soil, the small percentage of sandstone blocks as float and the appearance of somewhat resistant ribs on the weathered slopes to the north of the site indicate the rock consists mainly of a thick series of sandy shales carrying some infrequent loosely cemented sandstone beds. The soil cover, therefore, will be found relatively heavy, with the top one to two feet carrying a high humus content. Stripping of the site would necessitate the removal of top soil. The cut off excavation should reach about six feet below rock line at the crest line, increasing to at least 10 feet below rock line at stream bed, making a possible total excavation of 30 to 40 feet across the stream bed.

Ample construction material for the downstream portion of an earth-fill dam is available in the sand and gravel bars upstream and downstream from the site. The weathered shale and sandy soil should satisfy the requirements of a tight-rolled fill.

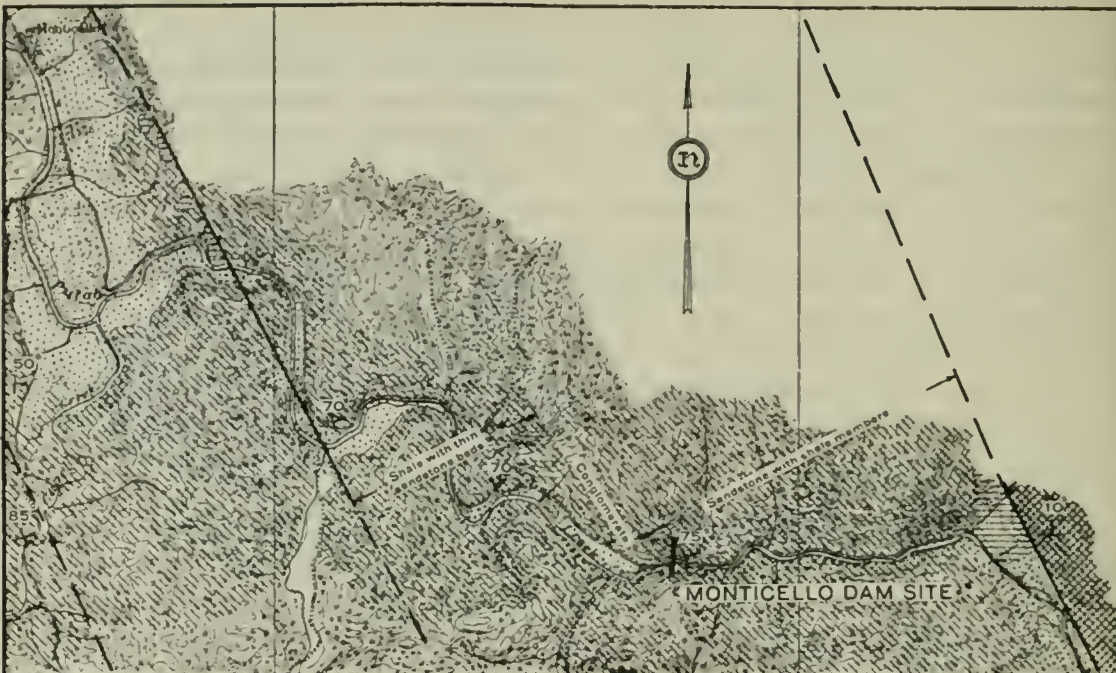
The height of the main dam probably would be affected by the necessity for auxiliary dams in two saddles lying to the west of the creek channel, and between the upper and lower Capay valleys, the low points of which are about at elevations 360 and 400 feet, respectively, or about 100 and 140 feet above the stream bed at the dam site.

Detailed Geology of Monticello Dam Site.

The rocks in the vicinity of the Monticello dam site are in the main heavy bedded Cretaceous sandstone separated by thin beds of sandy shale. Just upstream from this series a bed of conglomerate, overlying a thick series of shale and shaly sandstone, occurs. The rock of the projecting sandstone ledges is brown in color, due to oxidation previously described, and the fresh unaltered rock in the stream is greenish gray in color. It is believed both color phases present a well-indurated substantial rock and, when stripped of the superficial more weathered portions, would be physically strong enough to satisfy the requirements of a concrete dam having a height of 180 feet above stream bed.

The heavy sandstone beds show considerable jointing at the surface, but the rock is stable and does not effervesce in dilute acid. Neither does it carry minerals likely to cause disintegration along joint walls and the joints should be found reasonably tight features at short distance below the surface or subject to sealing with the usual grouting.

PLATE E-XI



GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES
IN THE VICINITY OF
MONTICELLO DAM SITE
ON
PUTAH CREEK

SCALE OF MILES
0 1 2 3

LEGEND

Alluvium
Tertiary sedimentary rocks
Tertiary lavas
Cretaceous sedimentary rocks
Faults found
Faults indicated but not determined
Dip and strike

The beds strike diagonally across the dam site and dip downstream about 75 degrees from the horizontal. The interbedded shale is more rapidly affected by weathering and its removal by ordinary weathering processes has left the sandstone beds as almost vertical ledges in a rugged topographic development. It is probable superficial weathering has weakened the shale beds to greater depth below ground surface than occurs in the sandstone beds. The stripping would be uneven on that account, but it is unlikely it would be necessary to strip beyond an average of 20 feet over the whole site, including stream bed excavation, to reach sound rock.

Hyde Forbes

APPENDIX F

GEOLOGY AND UNDERGROUND WATER STORAGE CAPACITY OF SACRAMENTO VALLEY

by

HYDE FORBES

Engineer-Geologist

September, 1930

TABLE OF CONTENTS

GEOLOGY AND UNDERGROUND WATER STORAGE CAPACITY OF SACRAMENTO VALLEY

The primary purpose of the investigation and study of the geology and underground water storage capacity of the Sacramento Valley was to estimate as accurately as possible, within a limited time, the location, extent, amount, and availability of underground storage in the valley, with a view to its utilization in the ultimate development of the land and water resources. The study did not include any estimates of the yields from these underground reservoirs under either present or ultimate conditions of development. It was confined strictly to an estimate of the capacities of these reservoirs which would be practicable of utilization if charged and drawn down as required.

The report is divided into two parts; one deals with the general geology of the region through which the potential underground storage areas can be broadly delineated, and the other presents the results of more detailed studies of local areas and sets forth estimates of the water storage capacities of the underground basins which are considered practicable of utilization.

The material which forms the basis of this report consists of a map showing the surface physiographic features and general soil characteristics, five days time being spent mapping the area in the field using the large scale United States Geological Survey sheets as a base; soil survey bulletins of United States Department of Agriculture; the penetration records of some three hundred wells, scattered widely over the area, as obtained from drillers and various published reports; reports of water levels, well discharges, and pumped ground water quantities obtained from the same sources and from records on file with the Division of Water Resources; and records of tests made as to the drainage factor of alluvial materials as given in published reports and obtained from unpublished data in personal files.

GENERAL GEOLOGY

The Sacramento Valley, as herein designated and mapped on Plate F-I, "Physiographic Units of the Sacramento Valley as Related to Ground Water Storage," is the northern portion of the Great Central Valley of California extending as an alluvial plain of varying width from Red Bluff to Suisun Bay, a distance of approximately 150 miles. It is bounded on the east by the Cascade Range and Sierra Nevada and on the west by the Coast Range and varies in altitude from 300 feet above to slightly below sea level. The Marysville Buttes, remnants of an ancient volcanic vent, project above the valley plain to about 2000 feet above sea level in approximately its center. Physiographically the plain is divided into five units as follows:

(I) The uplands of older alluvium, or higher lying areas which, although of alluvial origin, have become somewhat indurated through age, so that much of the rainfall upon their surface runs off and drainage patterns have developed through run-off erosion, and depressions and border lands have been filled or covered with the modern sediments as a thin veneer reworked from the older alluvium.

(II) The low plains and alluvial fans extending toward the trough of the valley from the east and west border lands, in part from the uplands and in part from the mountainous border. They are modern alluvial fans of the major streams and a combination of fans of the minor streams.

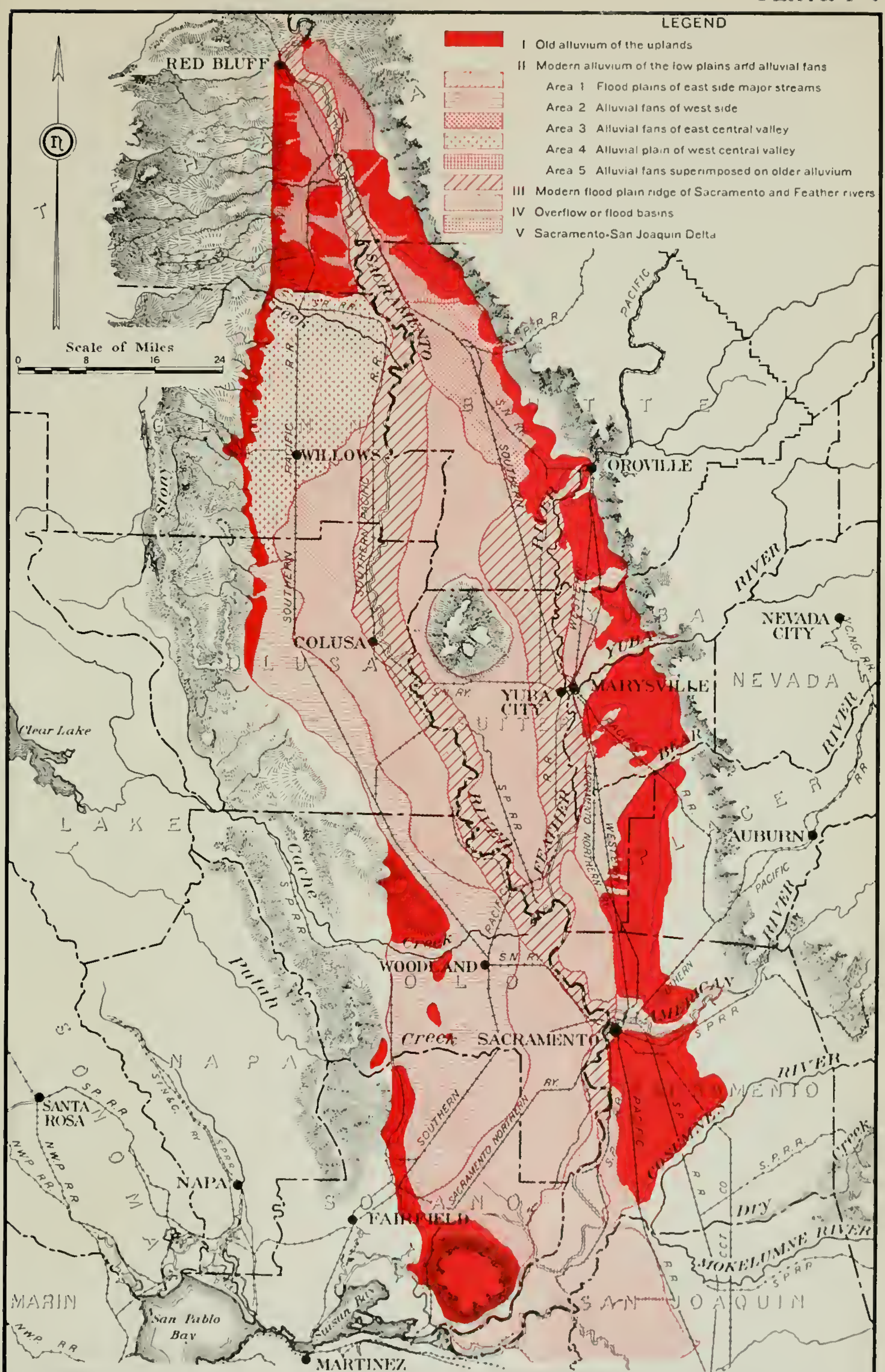
(III) The modern flood plain ridges of alluvial deposits of the Sacramento and Feather rivers. These streams have entrenched themselves in the uplands and have extended their broad alluvial flood plain ridges through the valley trough.

(IV) The overflow or flood basins which have been formed by various ridges. The extension of the flood plain ridge of the Sacramento River north of Marysville Buttes to meet the alluvial plain built up from the east produced a barrier to the free drainage of flood flows which consequently back up as a temporary water body over Butte Basin. The extension of the Cache Creek fan to meet the Sacramento River ridge at about Knights Landing produced another barrier north of which is formed the Colusa Basin. The confluence of the Feather and Sacramento River ridges produced the Sutter Basin. Minor basins were formed in a similar manner at the confluence of the Yuba with the Feather River, the Marysville Basin; at the confluence of the American with the Sacramento River, the American Basin; and at the confluence of the Mokelumne-Cosumnes drainage with the Sacramento River, the Sacramento Basin. Heavy alluviation above Suisun Bay from the Sacramento and Mokelumne River drainage basins brought the delta region to sea level and produced the barrier which forms Yolo Basin.

(V) The delta region, much of which originally existed as an extensive tule covered swamp. This region is now mostly reclaimed islands.

These physiographic units are geologically modern distinctions which are largely controlling in the occurrence of ground water in the Sacramento Valley and in the distribution of surface soil and subsoil types involved in economic ground water replenishment and recovery. Certain deep wells, and areas over which shallow ground water is not a dependable supply, derive ground water from more ancient formations and their distribution and characteristics should be considered in this connection.

Since early geologic (Jurassic) time the Great Central Valley of California has been a depression which generally has been sinking as the bordering mountain ranges have been rising and into which have been carried and dropped the sediments carried by the streams from the bordering mountainous areas. The enclosure of the Sacramento Valley, except at its southern end, was accomplished at the close of Cretaceous time by the folding and uplifting resulting in the Coast Range. The Cretaceous beds then can be considered as impervious bedrock upon which has been laid down sediments which vary in the characteristics which form productive aquifers. The sediments carried into the gulf-like depression during Tertiary time consist of the fine grained tuffs, sands, clay and coal beds now exposed along the east border as the Ione Formation between the Mokelumne and American rivers, and the sands, conglomerate, and clay shale beds flanking the west slope of the mountains north of Oroville. Similar materials make



PHYSIOGRAPHIC UNITS OF THE SACRAMENTO VALLEY
AS RELATED TO GROUND WATER STORAGE

up the east slope of the Coast Range and are found uplifted in the Marysville Buttes. During the period of sedimentation, the Sierra Nevada and Klamath mountains had a low relief and their streams deposited much of the coarse sediment in channels now found at elevations above the modern stream channels and known as the auriferous river gravels. This period of sedimentation was brought to a close by a period of active volcanism which produced the great lava and ash fields in the Lassen region, and the lava, breccia, and mud flows which passed down the Sierra Nevada mountain slopes filling canyons and capping the existing stream channels and extending, in places, into the valley. Clouds of volcanic ash were carried over the valley to be deposited as tuff during this period. Of these Tertiary formations the coarser sand beds of the sediments may carry water and yield it freely to wells. The coarser tuff beds and same lava beds of the volcanic series and also gravel beds which mark the channels of streams passing over volcanic materials between periods of activity provide aquifers along the valley borders and at depth beneath the valley.

The great period of intense volcanic eruption was followed by a period of crustal adjustment which resulted in the uplift of the Sierra Nevada and Coast Range to their present altitudes. This brought about the rejuvenation of drainage along new lines, with the resultant heavy erosion in the mountain areas and along the borders of the valley and the building up, during Pliocene and Pleistocene time, of great stream fans and a valley plain through deposition similar to that now being carried on over the valley depression. Continued uplift of the Coast Range caused a warping of the valley region in adjustment and the Pleistocene or older alluvium is found as great alluvial fans, uplifted and dipping slightly toward the valley from the east, between the Mokelumne and Feather rivers and plunging rapidly below the younger alluvium from the west, due to faulting, south of Stony Creek. North of Stony Creek on the west and Chico on the east, the older alluvium occupies the greater portion of the surface area in which the Sacramento River has entrenched itself.

The modern or recent period of alluviation has resulted in the physiographic conditions previously described. Within Recent time continued volcanism (the last being the 1915 eruption of Mount Lassen) and crustal adjustments as well as climatic changes have influenced the character of the sediments deposited and the topographic form of the present valley plain, which are important in the consideration of ground water reservoirs or aquifers.

Ground Water Reservoirs or Aquifers.

The distribution and characteristics of ground water reservoirs or aquifers in the Sacramento Valley are discussed in the following paragraphs.

(I) *The Old Alluvium of the Uplands.*—The period following the Sierra Nevada uplift has been one of alluviation in the Sacramento Valley. Climatic conditions and steeper stream slopes in the Sierra Nevada favored greatly increased rates of alluviation during late Pliocene and into Pleistocene time. The depositions of this period vary throughout the valley in character and thickness with the variation in stream flow from the mountainous borders. That area lying between the Mokelumne and Feather rivers received the drainage from a large and high Sierra Nevada watershed, the stream flow from which was perennial. The volume of stream flow, and consequently the detrital load and point of deposition, fluctuated but in the main the streams from this area have carried water in such quantity that the bulk of their detrital load has been carried far from the mouths of the canyons, and between the mountains and the valley trough the principal water-bearing materials consist of sands dropped in times of channel overflow. Such conditions are attested to by the driller's logs of wells drilled in the region.

North of the Feather River and east of the Sacramento River, the drainage area consists of the westerly slope of a broad range of mountains which is covered by thick flows of lava and tuff. The streams are comparatively short and have entrenched themselves deeply in this material, but the drainage pattern consists of steep walled canyons in contrast to the heavily eroded slope development of other parts of the Sierra Nevada. The watershed materials are highly absorptive and act as a regulator to a stream flow which is less subject to fluctuation in volume and drains largely underground rather than over the surface. Their detrital load was, therefore, light and the resultant alluvial deposits are not thick.

The Sacramento River and its northwesterly tributaries brought a mass of detrital material consisting of gravel, sand and silt to the valley depression, forming a broad stream fan which stretched entirely across the northern end of the valley. The more southerly of the western tributaries drain a watershed comprised of less resistant rock and their detrital loads have consisted in part of clay and fine sand which was carried to and built up the trough of the valley.

The Coast Range region has been subjected to continued crustal movements through Pleistocene time to the present, with the result that the central trough has been depressed along a series of normal faults which strike northwest-southeast, causing the older alluvium of the eastern border to be uplifted somewhat and dip slightly toward the trough. The more easterly of the Coast Range faults passes through the old alluvial fan of Cache Creek and between this fault and the mountains the older alluvium lies uplifted and dipping more steeply toward the valley. The old alluvium of the northern end of the valley appears to have warped upward in adjustment with the depression at the southern end.

The surface soil of the older alluvium has a characteristic red color which distinguishes it from the younger alluvium, but in drill samples the differentiation is difficult if at all possible, because both produce sands consisting of quartz grains with undecomposed fragments of feldspars and flakes of mica. The decomposition or oxidation of the ferro-magnesium mineral flakes contained in the older alluvium near its surface provided the iron oxide which gives it the characteristic color and acts with calcium carbonate as a cementing material which has caused the formation of an "iron" hardpan in the upper thicknesses. Beyond the reach of oxidizing agencies the color is not marked, except where ground water circulation through certain gravel and sand channels or members has carried on the cementing processes, sealing otherwise good aquifers. As a whole, the formation is not one which absorbs water readily, nor does it yield water freely to wells.

Aggradation of the valley plain has continued with sediment derived through the erosion of the older alluvium as well as that brought by the streams from their mountainous watersheds. Alluviation has gradually decreased in rate, with the gradual development of a more mature topography, gentler slopes in the mountainous area, and climatic changes. The choking of the lower end of the valley through alluviation to Suisun Bay has caused the modern deposits to take on characteristics not marked in the ancient deposits in the central portion of the valley, but the characteristics of the modern or younger alluvium of the bordering low plains areas are much the same though not indurated as the older alluvium. It forms a generally highly absorptive mass of unconsolidated sands, gravels and silt whose water-bearing and water-producing properties vary with physiographic type, but in the main it comprises the most important ground water reservoir of the valley

(II) *Modern Alluvium of the Low Plains and Alluvial Fans.*—The depression of the valley floor subsequent to the deposition of the older (Pleistocene) alluvium allowed the sea water to reach up the valley. Contemporaneous alluviation kept pace with the depression and confined the water body, but in general the origin of the modern alluvium of the low plains is as delta deposits. These deposits over the Sacramento Valley vary greatly in physical characteristics with the character of stream flow building them up and the type of material supplied to the delta-forming stream by its watershed, so for convenience they will be treated under the same heading as separate areas.

The larger streams of the east side from the Mokelumne River north to the Feather River had a perennial or more constant flow which is productive of continuous upbuilding and outbuilding of a delta into a body of water with little extension of the delta formation landward. These streams, with the Sacramento and San Joaquin rivers, are responsible for the building up of the delta country above Suisun Bay and the filling of the greatest depression of the Sacramento Valley. Between the delta country or valley trough and the older alluvial uplands lies Area 1 of the low plains deposit, which is characterized by fine to coarse sand channel deposits imbedded in silt overflow deposits in the form of broad low fans.

In Area 2 are found Cache Creek, Putah Creek, and a number of lesser streams draining from the west, which vary greatly in duration and stage of flow within the year. These streams contributed their flood waters and sediment load to the Sacramento River, but in time of normal or low flow the sediment load was dropped in the channel. As the normal and low flow periods of these streams are relatively long, the deposition of material along the banks and in the beds of the channel continued until natural leveed waterways extend from the mouth of the canyons to the valley trough. With the occurrence of flood stages, the natural levees were broken over, sand and silt was deposited upon the flood plain, and, at times, new channels of steeper gradient were established and the stream history repeated. As a result, a land body has been built up and extended laterally to the bordering uplands. Over this body of land, the coarse sand and gravel ridges mark abandoned leveed channels with their intervening plains being made up of the finer sand and silt.

As the original delta country was raised above sea level, the tendency of these streams was to shift north, the larger east side streams cutting into the older alluvium in which they were intrenched due to uplift, and widening their fans. The low plains Area 1 of the east side is an alluvial deposit of considerable depth, overlying and confined by the older alluvium, characterized at any given level or stage of upbuilding by stringer deposits of coarser materials laid down in channels, bounded by fine clay deposits of the levees and coarse to fine sand deposits of the flood plain of the stream. As channel changes took place, the stringers were covered over by finer materials deposited by flood plain waters, and the whole now presents a land form in which occur permeable members imbedded in a less permeable matrix. The whole area, however, is a porous formation capable of absorbing and transmitting water, but in which well development derives its water supply through the coarser members, which in turn contain ground water derived from a common body of porous material.

The low plains of the west side, Area 2, are similar in construction. Any level presents the same conditions which appear on the present surface, namely, abandoned channels built up above the general level of adjacent country containing more permeable materials within a permeable matrix. The thickness of the west side deposit above the older alluvium is far greater, as there the downthrow occurred and the older alluvium rises to the east and toward the north.

Area 3 lies in the vicinity of Chico and comprises an alluvial fan built up by Butte, Little Chico and Chico Creeks. These creeks drain a high, well forested watershed composed of relatively durable rocks. The stream flow is more of the Sierra Nevada than Coast Range type, in that the flow is more constant, with the floods less pronounced and of longer duration. Consequently, channel deposition of heavy gravels takes place with infrequent overflow depositing flood plain silt. The deposit is highly absorptive and normal flows are greatly reduced through seepage before reaching the valley trough. The result has been the development of an extensive modern alluvial fan of considerable depth rising from the trough of the valley to bury the flanks of the volcanic ridges. This provides the best type of water container or aquifer.

Wherever there occurs a sudden or even gradual reduction in gradient, as at the base of a hill, ridge, or mountain, running water will deposit a large part of its load, deposition occurs in the stream channel and on the banks largely, and the stream, finding new courses during high stages, repeats its history. So, through continuation of this process, the deposition is caused to extend over large areas in the shape of a fan. It is usual to find a considerable depth of coarse gravels and boulders more or less homogeneous in character and having a relatively high porosity and degree of permeability at the apexes of alluvial fans. Surface channels are fewest and deepest at the apex, and, due to distribution, are more numerous and shallower below. Deposition chokes the channel of the stream and reduces its capacity so that, with recurrent high stages of flow, some of the water must make new courses to right or left of the apex of the deposit. The overflow water may be shallow, with little or no velocity, and deposit lighter material, or it may find a steeper gradient and actually erode, carrying already deposited material farther from the apex. In this manner the deposit is built up laterally, in length, and in depth, as the new gradients established check the velocity of the stream higher in its canyon allowing depositions there.

At the lower stage, or normal flow, it is usual for the running water to be confined in the latest flood stage channel. At this stage gravel is deposited in the channel and fine material at the margin, where the velocity is further reduced, building up banks and bottom. It is not unusual, when the periods between flood stages are long, for a stream to build up a channel of small capacity above the general level of the fan upon which it rests. It is evident that the first flow greater in amount than the capacity of the channel so constructed must break through the natural levees, building a new channel. Again and again the process is repeated until, with the variable work done by the stream, a ramification of channels of differing grain size of materials accumulate at every stage or level in the building up of this type of deposit.

The resultant deposit can be characterized as a heterogenous mass of fragmental rock material, containing limited lenses of well assorted sand and gravel laid down as stream channels. These channels were abandoned by the stream and their depressions were grown over by vegetation and filled in with fine, wind-transported material. They were cut at intervals throughout their lengths by subsequent surface stream erosion in the establishment of new channels and are thus left as lenticular bodies of sand and gravel imbedded in a matrix of finer or poorly assorted material. Sections of such a formation or deposit, as exposed in railroad cuts or other excavations, show no continuity of materials of like texture or grain size but rather a chaotic mass in which fairly well defined lenticular bodies of gravel will give way abruptly to bodies of finer material. In this way the deposited materials are merged, by the ramifications and cutting of surface stream channels into one unassorted alluvial fill, in whose upbuilding wind action and vegetation has also played an important part. All the material making up the deposits are porous and permeable, the degree of porosity and permeability varying widely throughout the deposited materials.

From the west, Stony Creek and Willow Creek have built up a similar fan, Area 4, except that the flow of water in the channels is less uniform and low flow periods long, favoring the extension of sediment depositing channels across the fan so that the present surface is marked by ridges and hollows in contrast to the more uniform slopes of Area 3. Also, while much of the sediment carried by the eastern creeks reached the trunk drainage, nearly all of that carried by Willow Creek and Stony Creek is deposited on the fan and little reaches the Sacramento River except in extreme flood periods. As to origin and physical properties in relation to their being water containers, the two areas are the same.

Area 5 comprises the modern alluvial cover overlying and confined by the older alluvium at the northerly end of the valley. The Sacramento River has cut its way through Iron Canyon and entrenched itself in its predeposited older alluvial deposits in attaining a base level. The tendency has been to cut into its westerly bank, and this process has enabled the east side tributaries north of Tehama to fill the stream trench with alluvial materials and produce a modern alluvial plain rising from the river bottoms to the mountain flanks.

The west bank of the Sacramento River consists of a high bluff cut into the older alluvium, broken in continuity at points where western tributaries have leveled it down to reach the river level. Subsequent filling of the Sacramento River trench has been kept pace with by the western tributaries, namely Redbank, Oat, Elder and Thomas Creek systems, so that these creeks have laid down a veneer of modern alluvium over the older alluvium, in places reaching a thickness of 100 feet or more, which absorb, retain and yield much of the water passing over their surfaces.

(III) *Modern Flood Plain Ridges of Sacramento and Feather Rivers.*—The constant passage of water down the channels of the Sacramento, Feather, Yuba and American rivers has enabled them to first entrench themselves in their predeposited older alluvium in adjusting their base levels to the depressed valley, extend their deltas toward Suisun Bay, and later deposit their sediments over their landward sections in raising them to new base levels. In following out this process the resultant land types may be classified as river bottoms.

The higher portion of the river bottoms lands is the flood plain surface lying between the older alluvium banks of the stream trench. The materials filling the trench to the flood plain level consist largely of boulders, gravel and sand which possess a degree of homogeneity, in reference to porosity and transmissibility, not found in other deposits. The interstitial space in such a deposit usually ranges from 40 to 50 per cent of the mass and seldom is it less than 33 per cent. This highly permeable deposit of better assorted detrital material underlies the surface stream way or river channel. It is more or less definitely limited at its bottom and sides by material of lower permeability. Such deposits are termed "underflow conduits," in that the ground water they contain percolates freely downstream at comparatively rapid rates under the influence of gravity alone. This percolating water, more or less definitely confined between banks, is termed "underflow" to distinguish it from the broad body of diffused percolating water characteristic to all alluvial land types.

The alluvial bottoms deposits, just referred to, have been left in the form of terraces as the stream's history advanced. These river terraces are remnants of former flood plains, below which the streams which made them have cut their channels. Terraces developed by the normal activities of a stream are always low and are subject to overflow in flood time. Except for a silt top soil it is improbable that they would ordinarily be conspicuous or have any characteristics other than those of flood plains and are usually in contact with the porous material of the existing stream channel. The higher terraces flanking the flood plain are exceptions to this rule. Their formation is the result of (1) where, in the older alluvium of the region over which an uplift occurs, the streams are rejuvenated and the remnants of their former flood plains become terraces, (2) exhaustion of a stream's excessive supply of sediments in recent time, leaving it clear and free to erode rather than deposit, or (3) a notable increase in volume of water carried, as through climatic change or piracy, without increasing correspondingly the load carried.

The upper stream way or bottom lands of these streams are continuous with the broad ridges built up in the trough of the valley. Long periods of fairly constant flow favor the deposition of material in the beds of the channel continuous with and of similar character to the upper bottom lands. The finer material is deposited along the banks, forming natural leveed waterways which extend at higher elevations widely across the landward portion of the stream delta. Thus this land type makes up a porous and permeable formation which is a ground water reservoir in immediate contact with surface water which keeps it constantly charged.

(IV) *Overflow or Flood Basins.*—With the occurrence of flood stages in the major streams the natural levees are broken over. If it were not for the fact that systems of stream ridges and the encroachment of alluvial fans into the trough of the valley have formed topographic barriers, new channels of steeper gradient would be established and more stream ridges be formed. But in the Sacramento Valley natural barriers exist which confine the flood waters to low lying basins from which, in the past, there was no free drainage. Consequently, another land type has been built up having distinctive characteristics of soil and subsoil which control the occurrence of ground water therein and its yield therefrom. These basins were flooded during high water periods of each year and remained inland lakes for periods of time depending upon the wetness of the season. This condition favored the growth of tules. The slack water dropped its suspended silt and clay. Drainage took place slowly and in considerable part through evaporation concentrating mineral salts. During dry periods and seasons, windblown sands were collected by the vegetation and with the recurrence of wet periods or seasons the surface was again flooded, vegetation rotted, and was buried by silt. The basin materials, while capable of absorbing much water, hold it tenaciously. Well development is generally impracticable and the drainage of the lands by excavated channels is in some places relatively slow and not fully effective. Prior to reclamation and drainage, evaporation from the moist surface of the basins was the source of much wastage of water.

(V) *Sacramento-San Joaquin Delta.*—The same conditions exist over the delta region, in which the islands are mostly reclaimed tule swamps and peat bogs rising a few feet above sea level along the natural channel levees, with much of the area in the centers of the tracts lying below sea level. The barrier to the free drainage of the valley surface to Suisun Bay is the constricted opening between the older alluvium of Montezuma Hills on the north and the Diablo Range on the south. It is probable that much coarse material is lodged at depth above this barrier and deep wells in the vicinity should reach an impounded body of fresh water possibly under pressure.

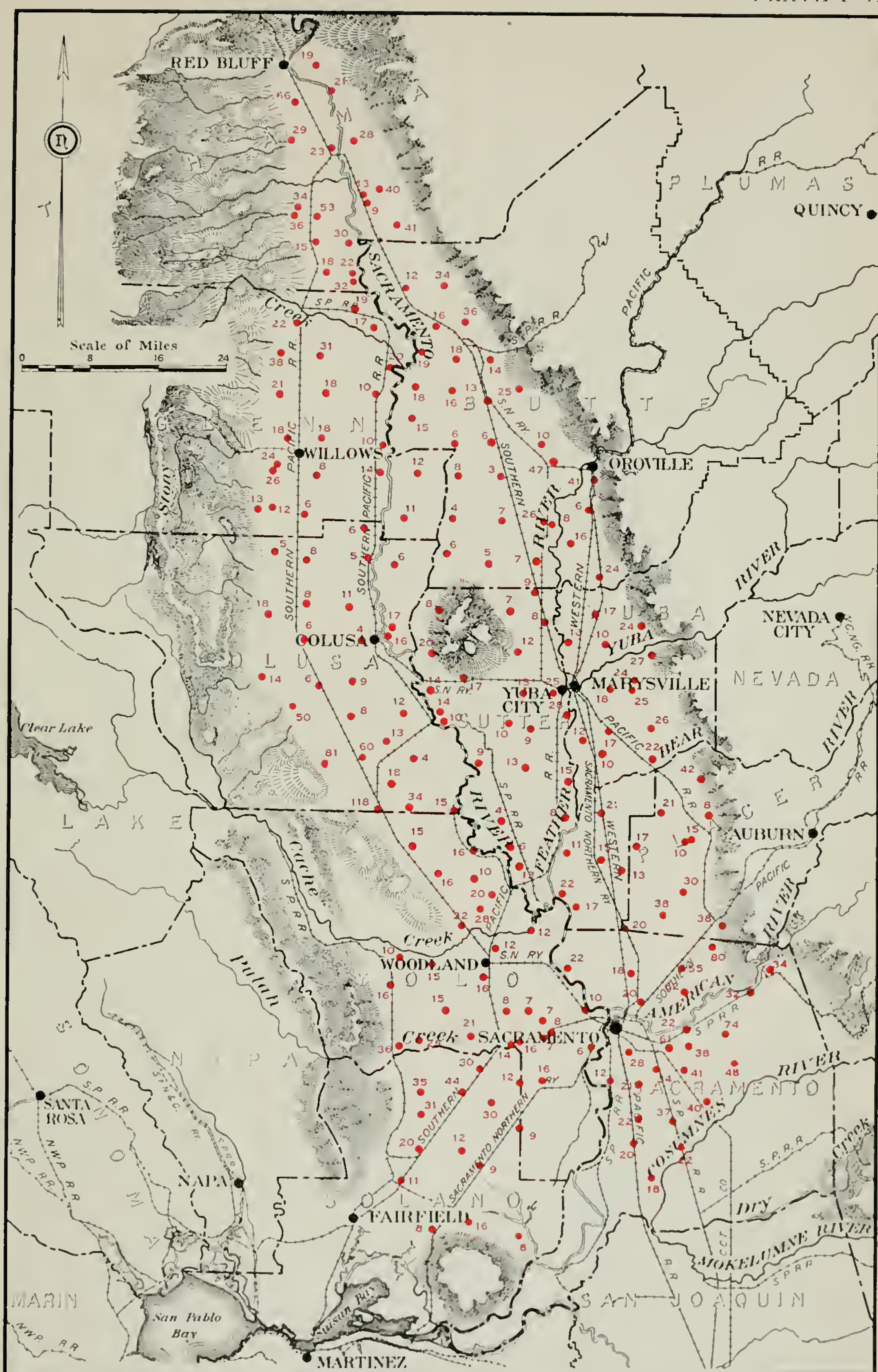
UNDERGROUND WATER STORAGE CAPACITY

The geologically modern alluvium of the low plains and alluvial fans areas, and the flood plains and bottoms of the major streams, in the Sacramento Valley provide underground reservoirs which are now and can be charged and recharged from surface stream sources. Water from these underground basins is now used quite extensively and advantageously for irrigation in some sections of the Sacramento Valley and such use may be extended in the future and become an important item in the full utilization of the waters tributary to the area. The underground waters would provide supplies during dry seasons or cycles to supplement those from surface streams and reservoirs, thereby giving a more dependable yield from all sources. Draft upon ground water usually necessitates artificial replacement measures in addition to natural seepage over the low plains and alluvial fans if dependable underground supplies are to be provided. These replacements could be made during the seasons of plentiful run-off from water which otherwise would waste into the ocean. Such replacement may necessitate the importation of surplus water from outside sources.

The depths of the ground water table below the ground surface in the fall of 1929, over the Sacramento Valley, is shown on Plate F-II, "Depths to Ground Water at Typical Wells in Sacramento Valley, Fall of 1929." These depths are somewhat the result of irrigation and reclamation activities. Ground water is accumulated within areas irrigated through surface water systems. It can be drained from these areas by pumping from wells. The history of the irrigated areas of the San Joaquin Valley served wholly through surface water systems has been a steady rise of the water table to, or close to, the ground surface over the low lying portions of the areas, rendering them unfit for cultivation and requiring drainage. The history of irrigated areas depending solely or to a large extent upon pumped ground water supplies has shown that without adequate ground water replenishment only a portion of the overlying land can be served without a progressive lowering of the water table beneath the land and the eventual exhaustion of the ground water supply lying within economic reach of pumping. Soil and subsoil characteristics which are most favorable to the absorption and transmission of water underground are found to allow only slow movement of limited quantities of water directly applied to the area, so, to accumulate ground water for storage requires an excess of absorption overdraft for relatively long periods.

Areas wholly irrigated from surface waters brought directly to the area from sources without the area, the soil and subsoil conditions being favorable, have direct replenishment to ground water storage, but unless free natural drainage is present or artificial drainage provided this storage becomes charged and water levels are brought to detrimental heights. Therefore the proper balance is maintained in irrigated areas by a combination of surface and ground water supplies. Holdover storage can be accomplished by diverting surface water from streams during periods of excess flow and spreading it widely in irrigation or other channels over lands whose type origin has resulted in masses of material which are absorptive and over these types, pumping, when accompanied by replacement measures, provides an effective and desirable means of water conservation. Without direct replenishment over the area in excess of natural stream seepage, ground water is quickly exhausted when heavily drawn upon during dry cycles.

The effective storage capacity of underground basins, possible of attainment, depends upon the area, depth and drainage factor of the



DEPTHS TO GROUND WATER AT TYPICAL WELLS

IN SACRAMENTO VALLEY

FALL OF 1929

● LOCATION OF WELL AND DEPTH IN FEET

soil column unwatered by pumping and refilled through spreading of surface water. The basins capable of absorbing water and reservoiring it as ground water are shown on Plate F-III, "Absorptive Areas in the Sacramento Valley." The surface areas of the basins outlined were determined through field examination of the physical characteristics of surface soils and the application of geologic reasoning, checked and aided by penetration records of several hundred wells showing subsurface characteristics. The depths of favorable formations also were determined in this manner. The ultimate storage capacity available is limited by the economic lift of pumping over the area and this depth has been arrived at by determining from the 1929 water table depths how much lower the water table can be drawn over the area on an average and still be within the reach of pumps over higher portions or, what limitations to the lowering is set by practical pumping considerations. The drainage factor is more open to judgment as but few actual tests on comparable material are available.

The water underground falls into three classes, namely, hygroscopic moisture which is present as a thin film encompassing each soil particle and held in contact therewith through molecular attraction, capillary water held in the interstices between soil particles through surface tension, and water which is free to drain by gravity, contained in interstices of sufficient size to accommodate a surplus over the capillary water. The drainage factor is determined by the amount of the latter or free water contained in the soil column, and this in turn is determined not by the porosity of the material but by the grain size. Fine clays are usually the most porous of natural materials, running as high as 50 per cent in void space, but the voids are so minute that the water contained therein is entirely hygroscopic and capillary water which can not be drained under ordinary pumping conditions. Therefore, the effective capacity or drainage factor of a saturated soil column increases with its content of free water, which increases with the grain size. Experiments carried on by Briggs and McLaine of the United States Department of Agriculture and the results thereof published in departmental bulletins give a yard stick by which the free water content of various soils can be gaged. Upon that basis, the materials logged in the well penetration records available were evaluated and estimates were made of the average effective capacity of the soil column per foot of water table lowering. For example, gravel and coarse sand mixtures as they occur in nature were given a moisture equivalent, or percentage of moisture remaining after drainage of 4.0; fine sand 8.0; sandy clay 20.0; yellow clay 35.0; with an assumed average porosity of 40 per cent. Blue clay is considered impermeable, with no free water. The results so obtained were checked with actual results obtained through tests in areas known to be somewhat comparable and factors were adopted.

Obviously the physical characteristics of the soil and underlying materials delimit the areas in which such conservation can be practised. The physiographic units previously described and shown on Plate F-I broadly delimit the ground water storage areas. These broad units necessarily are subject to subdivision.

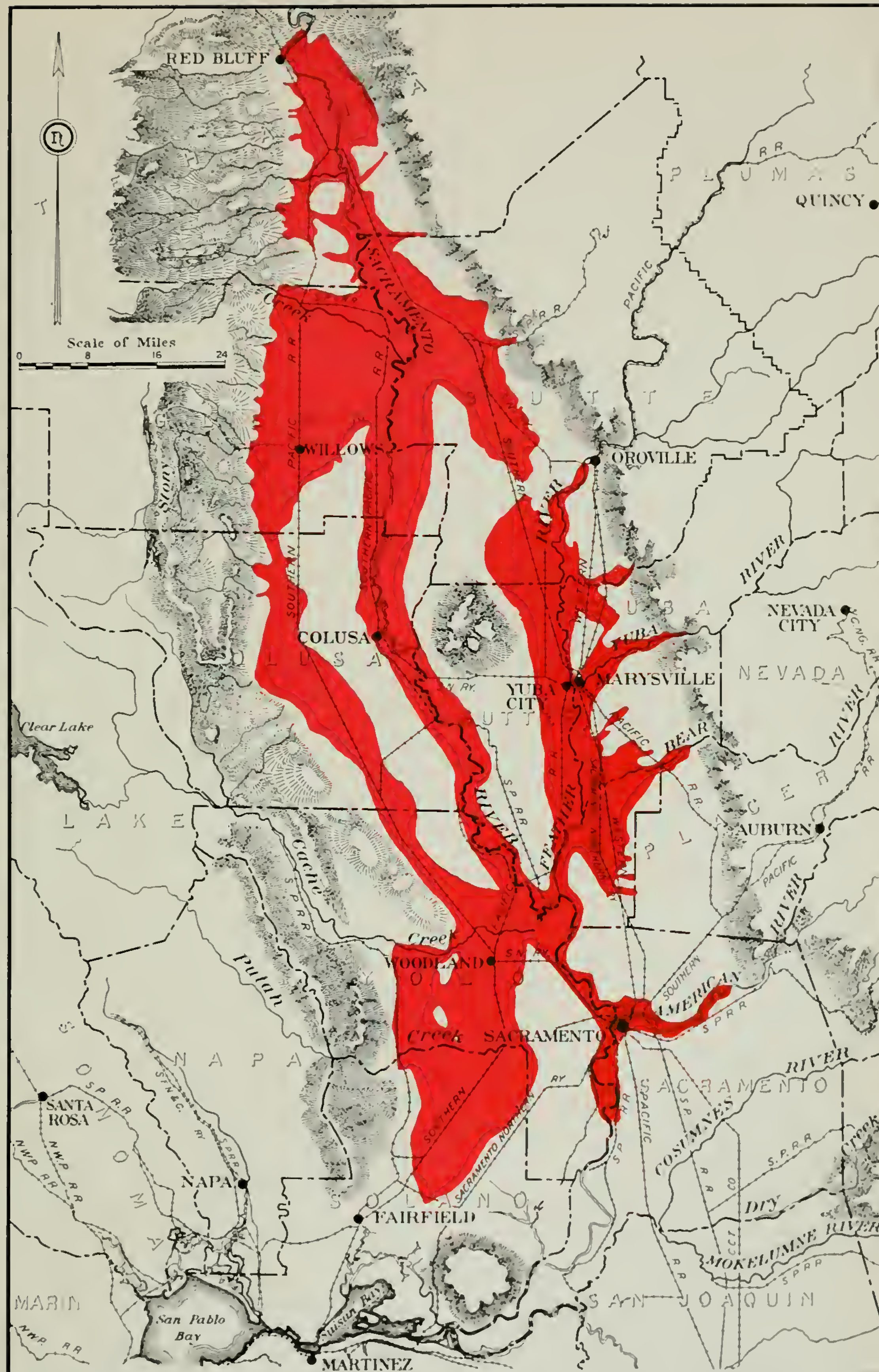
Descriptions and Water Storage Capacities of Specific Ground Water Storage Units.

(I) *Uplands Physiographic Unit.*—A study of the penetration records of wells drilled in the old alluvium of the uplands show the greater portion of the first 100 feet of the soil column to consist of fine, compact or cemented materials. The wells are usually drilled to greater depths and with two to four hundred feet of column sufficient thickness of loose water sand beds are penetrated to supply the wells with small quantities of water. The water so obtained is largely that derived originally through seepage from the surface streams which laid down the material but which has been held entrapped in the formation during the ages through which compaction and induration has taken place. It is yielded to wells at relatively low rates through comparatively slow drainage of communicating permeable members. The water yielded generally has a higher temperature and greater mineral content than surface water, due to its long contact with the containing material and lack of circulation therein. It is not subject to ready lateral replenishment because of the low transmissibility of the media. Hardpan is prevalent in the surface soil which causes the water applied to or falling upon the surface in quantity to run off rather than be absorbed. Therefore, little replenishment is had from the surface, and artificial recharge can not be accomplished.

The uplands therefore are not adapted to irrigation from ground water sources and surface water systems are to be considered their sole source of irrigation water. Local small ground water supplies, subject to annual replenishment, exist in the shallow recent alluvial veneer which overlies the older alluvium in isolated depressions and along minor stream trenches, but these have little economic importance in relation to the broad area making up the Uplands.

(II) *Modern Alluvium of the Low Plains and Alluvial Fans.*—The modern alluvium of the low plains and alluvial fans comprise ground water reservoirs which can be utilized and whose economic importance warrant detailed consideration in the general problem, particularly as to their location, extent and capacity, and the general method of charging and recharging that capacity. They consist generally of a highly absorptive mass of unconsolidated sands, gravels, and silt limited laterally and in depth by the older alluvium which is exposed on the surface uplands and is much less permeable, and towards the valley trough by the overflow basin areas and delta deposits. Outflow from these reservoir areas occurs, or in the past has occurred, through spring discharge into sloughs in the flood basins and delta region and return flow to the lower river channels. It is unlikely that measurable underground drainage takes place from these areas, but, with the charging of higher portions or to higher levels, drain channels through the basins can be used to collect and carry the outflow of ground water reservoirs to the Sacramento River and in this manner regulate, somewhat, the flow of that stream as well as provide pumped water supplies for the areas themselves.

Area 1 includes the flood plains of the east side major streams. In this area the American River has entrenched itself in the older alluvium and built up a flood plain deposit in this trench increasing in thickness



ABSORPTIVE AREAS IN THE SACRAMENTO VALLEY

downstream from 50 to 75 feet below the present surface of the river bottoms land. The storage capacity so created is limited to what has previously been referred to as an underflow conduit, extremely porous and readily charged through seepage from the surface stream. The Bear River has not entrenched itself so deeply in the older alluvium and, in times of flood flow, has spread out, dropping its sediment to form a shallow deposit of modern alluvium overlying the older alluvium. The logs of wells drilled in the area show the thickness of this deposit to be uneven, ranging between 20 to 40 feet, except near the present channel and west of the railroad, where it attains a thickness of 70 to 100 feet. The logs of wells drilled over the balance of Area 1 reveal similar conditions, except in the immediate Yuba River bottoms at Marysville, where the modern alluvium attains a thickness of 150 feet. Little of economic importance can be accomplished in the way of artificial recharge of ground water storage capacity in these restricted areas. Drainage would be to the flood basins and aggravate the problem of their reclamation. For these reasons, Area 1 is considered to have no ground water storage capacity.

Area 2 is an extensive body of modern stream deposits embracing the modern alluvial fans of Cache, Putah and many lesser creeks draining from the west into the Colusa and Yolo basins. The logs of wells drilled in the vicinity of Maxwell show the thickness of the deposit to range from 140 to 180 feet, at Williams 70 to 100 feet, at Arbuckle 60 to 80 feet, at Yolo about 100 feet, at Woodland 100 to 150 feet, and in excess of 100 feet on the immediate fan of Putah Creek. The wells drilled over the greater portion of the area have encountered thick beds of coarse gravels within 100 feet of ground surface and wells of large yield are common. Comparing the per cent of gravel and sand in the well column with well yields, it is estimated that the effective voids of the material are high and the drainage factor at least 15 per cent.

East of the railroad between Davis and Elmira, the modern alluvium consists of a shallow capping over extensive clay deposits, as the streams have built up their deltas above sea level over former tidal marshes. The surface area is reduced by eliminating that portion and the region between Cache Creek and Putah Creek lying above the 100-foot contour, as no logs of wells are available from which to determine the depth extent of the material overlying the older alluvium which outcrops in the latter region. With those limitations the surface area covers about 250,000 acres. Much of the area had a water table within ten feet of ground surface in the fall of 1929, and except for the pumping area around Dixon there has been little change in the ground water conditions since 1914.

Present seepage contributions from the tributary streams support the draft upon ground water. In order to create ground water storage in the area, the water table should be lowered by draft. A lowering of the water table to 25 feet below ground surface over the higher water table areas, and 65 feet below the higher lying lands, with an average water table lowering of 30 feet over the area, would provide 1,125,000 acre-feet of ground water storage capacity. More intense development of ground water supply than now practised in the area is warranted.

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Area 3 comprises the modern alluvial fan formed by the combined alluviation of Little Chico, Chico and Butte creeks, and minor streams. East of the Southern Pacific railroad, the modern alluvial cover over the older alluvium is relatively thin, varying from 20 to 60 feet, increasing with proximity to present surface channels. The important wells of that area do not depend upon the top water for their supply but penetrate to depths of 300 feet or more and obtain water from a porous volcanic formation exposed over the flank of the mountains from Oroville north.

The logs of wells drilled west of the railroad show 80 to 150 feet of modern alluvium. The formation consists of gravel lenses representing past stream channels imbedded in sands and silt clay laid down in the form of broad sheets at times of freshet overflow of banks. The watersheds drained by these streams contain rock high in lime and portions of the alluvium are reported cemented. The development of ground water from the recent alluvium has been limited and ground water storage capacity would depend upon the extent to which the water table will be drawn down through irrigation draft in the future. The present irrigation of lands from surface water diversion tends to maintain a fairly high water table over the area which drains towards Butte Basin.

The surface extent of the area underlain by sufficient thickness of recent alluvium to constitute a ground water reservoir is about 50,000 acres. Over this area, the water table could be drawn down to an average of 35 feet below ground surface. With an average limiting upper water table level of ten feet below ground surface, and a drainage factor of 12.5 per cent, a storage capacity of 156,000 acre-feet would be created.

Area 4 comprises an area of 185,000 acres made up largely of the alluvial fans of Stony and Willow creeks. The present channel of Stony Creek, a gravelly wash varying in width from one-eighth to one-half mile, is an example of the conditions that existed along countless channel locations at every level or stage in the upbuilding of its fan. Willow Creek system is responsible for a partial reworking of the Stony Creek sediments. The logs of wells drilled in the northerly portion of the area commonly show a large percentage of the top hundred feet of the column to be made up of clean, coarse gravel. The effective voids of the column will probably run as high as 18 to 20 per cent. The well log columns south of Willows show more clay and fine materials.

Ground water is being drawn upon at present for irrigation of lands south and east of Orland. The water table in the fall of 1929 was five feet below ground surface at the boundary of the area with the Colusa Basin, increasing in depth to 25 feet at the 175-foot contour of ground elevation and 35 feet at the 225-foot contour. With the highest water table level limited to an average of 15 feet below ground surface, with a maximum average lowering to 40 feet below ground level, and with a drainage factor of 18 per cent over 100,000 acres of the absorptive area and 12.5 per cent over 85,000 acres, there would be a storage capacity of about 716,000 acre-feet.

Area 5 comprises the alluvial fans superimposed on older alluvium at the northerly end of the valley. A study of the drillers' logs of wells located in this area indicates that the first channel of the Sacramento River subsequent to the Pleistocene crustal movements was located on the west side of the valley. The river took a course directly south of the mouth of Iron Canyon and entrenched itself in the uplifted northerly portion of the Pleistocene or older alluvium to depths through the western portion of the El Camino Irrigation District ranging from 230 feet below present ground surface at the northern boundary to about 350 feet at the southern boundary. This trench continues through Corning at depths of about 150 to 175 feet below present ground surface. Alluviation subsequently filled this trench with geologically modern deposits and the channel of the Sacramento River was forced easterly until Recent time through heavy alluviation from the western tributaries. The present erosive tendency is westward.

The result of this alluviation has been to provide a ground water storage area on the west side, in the form of a two to three-mile wide strip running from Redbank Creek south to Thomas Creek, and a more limited area in the vicinity of Corning. In addition, limited areas of the flood plains of the tributary streams provide narrow shallow storage basins. The ground water stored in the open gravel of the main trough is the most important and is utilized at present for irrigation and domestic supply in the El Camino Irrigation District (estimated pumping capacity 20,000 acre-feet per year), scattered areas between Red Bluff and Corning, and an extensive development (518 wells drilled) in the vicinity of Corning. The development has been progressive, receiving its greatest impetus since 1920. The total lowering of the water table since 1914 has been about ten feet.

The water table over the more northerly or El Camino Irrigation District area now stands on the average 45 feet below a ground surface area of about 17,500 acres. The character of the gravel, sand and clay media is such that the effective voids, in comparison with tested materials, should be as much as 15 per cent of the volume. The ground water storage capacity between present water table and 15 feet below ground surface, therefore, would be about 79,000 acre-feet. The ground water slopes toward the Sacramento River and would be discharged to the channel in times of low water. In the Corning area of about 5600 acres, the ground water storage capacity, with the same limiting water table levels as in the El Camino area and with a drainage factor of 15 per cent, would be approximately 25,000 acre-feet. As this capacity is confined by less pervious older alluvium, discharge to the river channel is limited and holdover of cyclic storage can be more readily effected.

The portion of Area 5 lying east of the Sacramento River, south of Salt Creek and north of Mill Creek is irrigated through surface water sources. No well logs are available, but the saturated condition of the area due to canal seepage and irrigation return indicates a relatively thin modern alluvial cover over the less permeable cemented old alluvium. The same conditions probably exist south of Pine Creek, the thickness of the modern alluvium being but 80 feet at Nord.

(III) *Modern Flood Plain Ridges of Sacramento and Feather Rivers.*—The third physiographic subdivision is capable of providing ground water storage capacity. North of a line drawn east and west through

Nord, the depth extent of the recent alluvial deposits along the Sacramento River is not great, being about 50 feet at Vina. Southerly of this line the thickness increases from 80 to 200 feet. The logs of wells drilled either side of the river exhibit beds of coarse sand, gravel and boulders in the first hundred feet below ground surface over a five-mile width making up the Sacramento River ridge. It is material closely resembling that now found in the stream bed, capable of transmitting water at relatively high rates. A similar condition exists along the Feather River ridge and Gridley Fan. These ridges occupy a surface area of about 410,000 acres beneath which ground water storage capacity can be created. It is estimated that 300,000 acres of this area has a drainage factor of 20 per cent and 110,000 acres a factor of 15 per cent. With an average 12-foot lowering of the ground water over this area, below the levels of 1929, a water storage capacity of 918,000 acre-feet would be created. The contour of the water table indicates that the continuous passage of water down the channels of the Sacramento and Feather rivers will provide replenishment if seepage therefrom is induced by lowering the water table beneath their channels.

(IV), (V) *Overflow or Flood Basins and Sacramento-San Joaquin Delta.*—The surface soils of the basin areas and delta region range from adobe to clay loam. Ground water is near the surface, but difficult to extract from the heavy fine material. Logs of wells drilled in the lower lands of the basin areas generally show similar clayey or silty clay material, in places cemented, to 50 feet or more below the ground surface. Along the borders of the basin areas, and to a limited extent elsewhere in the basins, are found sand strata interbedded with the dark clays to 200 feet below ground surface. These sand strata are continuous with the low plains and alluvial fans deposits and act as aquifers receiving ground water supplies laterally therefrom. On the whole, the flood basin areas and the delta region are to be excluded from consideration of ground water storage reservoirs.

Summary of Underground Water Storage Capacities—The estimated underground water storage capacities available as set forth in the foregoing descriptions are summarized in the following table:

TABLE F-1

UNDERGROUND WATER STORAGE CAPACITY IN SACRAMENTO VALLEY

Physiographic unit	Surface area, in acres	Drainage factor, in per cent	Limiting water table levels, in feet below ground surface		Storage capacity, in acre-feet
			Upper average	Lower average	
II—Area 2	250,000	15	15	45	1,125,000
II—Area 3	50,000	12 5	10	35	156,000
II—Area 4	100,000	18	15	40	450,000
	85,000	12 5	15	40	266,000
II—Area 5	17,500	15	15	45	79,000
	5,600	15	15	45	25,000
III	300,000	20	10	22	720,000
	110,000	15	10	22	198,000
Totals	918,100				3,019,000

Hyde Forbes

APPENDIX G

DEPTHS TO GROUND WATER AT TYPICAL WELLS

IN

SACRAMENTO VALLEY

IN

FALLS OF 1929, 1930 AND 1931

TABLE OF CONTENTS

DEPTHS TO GROUND WATER AT TYPICAL WELLS IN SACRAMENTO VALLEY IN FALLS OF 1929, 1930 AND 1931

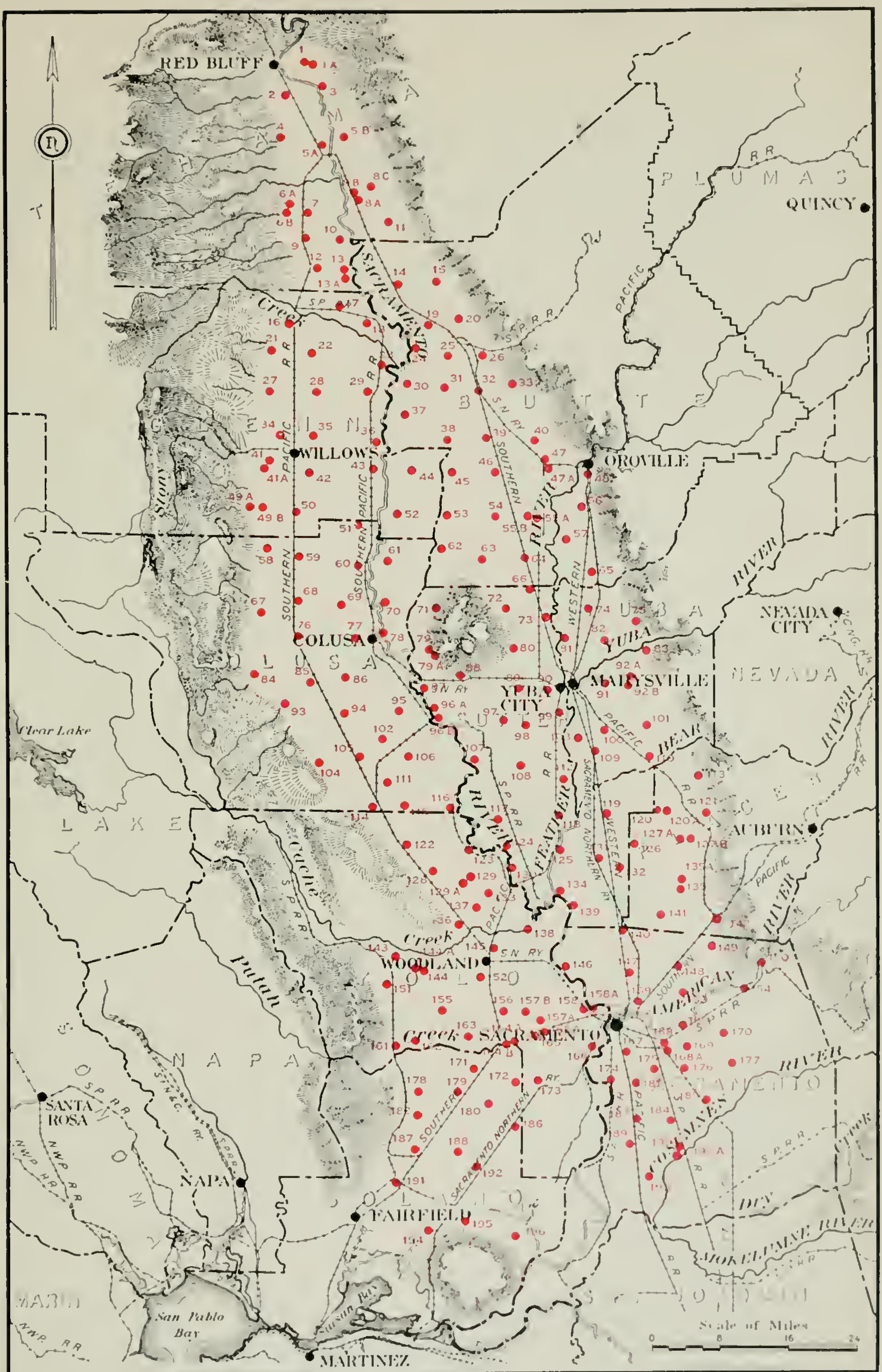
It was found during a survey of irrigated lands in the Sacramento Valley and adjacent foothills in 1929 that about 203,000 acres, or 28 per cent of all the lands irrigated in those areas in that year, were served by pumping from ground water. It is quite possible that with continued growth and development of irrigation in the Sacramento Valley, the use of ground water may become more extensive and therefore of more importance than at present. Because of this possibility, it was deemed advisable to begin a general but systematic collection and compilation of data on ground water conditions in the valley. The depths to ground water, therefore, were measured during the fall or early winter months of the years 1929, 1930 and 1931, in about 200 wells distributed over the valley floor. These wells are located at approximately five-mile intervals in both north and south and east and west directions. Their locations and numbers are shown on Plate G-I, "Locations of Measured Wells in Sacramento Valley." The depth from the ground surface to the water table at each well, in the fall of 1929, is shown on Plate F-II in Appendix F.

A description of the location of each well measured and the depths from the ground surface to the water tables in the falls of 1929, 1930 and 1931 are set forth in the following table:

TABLE G-1

DEPTHS TO GROUND WATER AT TYPICAL WELLS IN SACRAMENTO VALLEY—1929-1931

Well No.	Well location					Date of measurement	Depth to water from ground surface, in feet
	Quadrangle of United States Geological Survey	Township	Range	Section	Description		
1	Tehama	27 N.	3 W.	14	At intersection of south line of Sec. 14, with NW. line of Rio de Los Berrendos Grant. Owner, Geo. H. Hughes.	Nov. 29, 1929 Sept. 29, 1930 Dec. 29, 1930	19.0 22.6 25.5
1 A	Tehama	27 N.	3 W.	14	0.2 mile northeast of Highway 99 E. on north side of road along NW. line of Rio de Los Berrendos Grant. Owner, Geo. H. Hughes.	Dec. 3, 1931	29.8
2	Tehama	Rio la Barranca Colorado Grant			400 feet west of S.P. R.R. and 0.5 mile south of Red Bank Creek. Owner, J. J. Altube	Nov. 29, 1929 Sept. 29, 1930 Dec. 3, 1931	66.5 66.6 67.3
3	Tehama	Rio de Los Berrendos Grant			West side of State Highway, 0.4 mile south of Craig Creek, at Los Robles School. Owner, C. A. Davis.	Nov. 29, 1929 Sept. 29, 1930 Dec. 3, 1931	21.2 20.0 20.9
4	Tehama	26 N.	3 W.	32	In the SW. part of SE¼ of Sec.32, east of the county road. Owner, G. S. Reid	Dec. 2, 1929 Sept. 29, 1930 Dec. 3, 1931	29.4 29.9 31.5
5 A	Tehama	Saucos Rancho			East side of county road 0.7 mile south of Elder Creek and 0.5 mile east of S.P. R.R. Owner, W. J. Crane.	Nov. 29, 1929 Sept. 29, 1930 Dec. 3, 1931	22.7 21.0 21.5
5 B	Tehama	26 N.	2 W.	34	0.5 mile north of Mill Creek and 0.8 mile east of old Red Bluff-Molinos Road. Owner, A. H. Brockman.	Nov. 16, 1929 Sept. 29, 1930 Dec. 29, 1930 Dec. 4, 1931	28.5 10.3 32.0 21.5
6 A	Vina	24 N.	3 W.	16	0.1 mile south of N¼ corner of Sec. 16, west side of road	Dec. 2, 1929 Oct. 1, 1930 Dec. 3, 1931	34.0 36.8 36.0
6 B	Vina	24 N.	3 W.	16	0.2 mile west of center of Sec. 16, north side of road. Owner, E. M. Swalley	Dec. 2, 1929 Oct. 1, 1930 Dec. 3, 1931	36.5 39.0 39.5
7	Vina	24 N.	3 W.	14	North part of SW¼ of SE¼ of Sec. 14. Owner, G. C. Estes	Dec. 2, 1929 Oct. 1, 1930 Dec. 3, 1931	53.0 55.5 53.8



LOCATION OF MEASURED WELLS

IN

SACRAMENTO VALLEY

8A	Vina	24 N.	2 W.	[1]2	Near south line 0.3 mile east of SW. corner of Sec. 2. Owner, Geo. Vogelsang	Nov. 16, 1929 Sept. 29, 1930 Dec. 4, 1931	9.3 9.7 9.0
8 B	Vina	24 N.	2 W.	[1]2	Near south line 0.3 mile east of SW. corner Sec. 2. Owner, Geo. Vogelsang	Nov. 16, 1929 Sept. 29, 1930 Dec. 4, 1931	13.0 13.4 10.8
8 C	Vina	25 N.	1 W.	31	0.3 mile east of W¼ corner Sec. 31 on south side of road. Owner, Paul Parozzi	Nov. 16, 1929 Sept. 29, 1930 Dec. 4, 1931	40.5 40.7 42.0
9	Vina	24 N.	3 W.	35	0.3 mile north and 400 feet west of S¼ corner of Sec. 35. Owner, H. R. Eustis	Dec. 2, 1929 Dec. 29, 1930 Dec. 3, 1931	15.3 14.4 15.3
10	Vina	24 N.	2 W.	33	In SW¼ of SE¼ of Sec. 33, 300 feet south of crossroads at schoolhouse. Owner, Henry A. Martin	Dec. 2, 1929 Oct. 1, 1930 Dec. 3, 1931	30.0 30.1 30.7
11	Singer Creek	24 N.	1 W.	21	0.2 mile east and 0.3 mile north of SW. corner of Sec. 21. Owner, Stanford University	Nov. 16, 1929 Sept. 29, 1930 Dec. 4, 1931	41.4 41.4 42.5
12	Kirkwood	Capay Grant			2.0 miles south of north line and 0.1 mile east of west line of Capay Grant. Owner, J. Rath	Dec. 3, 1929 Oct. 1, 1930 Dec. 2, 1931	18.0 20.0 26.0
13	McIntosh Landing	Capay Grant			2.3 miles south of north line of Capay Grant, 1.0 mile west of Sacramento River. Owner, S. E. Bambauer	Dec. 3, 1929 Oct. 1, 1930	22.3 21.8
13 A	McIntosh Landing	Capay Grant			2.5 miles south of north line of Capay Grant and 1.0 mile west of Sacramento River. Owner, John P. Bambauer.	Dec. 3, 1929 Oct. 1, 1930 Dec. 2, 1931	32.0 31.8 32.5
14	Nord	23 N.	1 W.	34	In NW. corner of Sec. 34. Owner, J. A. Bennett	Dec. 3, 1929 Sept. 29, 1930 Dec. 4, 1931	12.3 14.0 14.0
15	Nord	23 N.	1 E.	29	Near east line of Sec. 29, 300 feet north of county road. Owner, Joe Girard	Nov. 29, 1929 Sept. 29, 1930 Dec. 4, 1931	34.2 32.3 39.1
16	Orland	22 N.	3 W.	21	On north side of county road, 0.6 mile west of E¼ corner. Owner, J. Benda	Dec. 6, 1929 Oct. 2, 1930 Dec. 29, 1930 Dec. 1, 1931	22.2 14.5 18.2 21.5

[1] Projected.

DEPTHS TO GROUND WATER AT TYPICAL WELLS IN SACRAMENTO VALLEY—1929-1931—Continued

Well No.	Well location					Date of measurement	Depth to water from ground surface, in feet
	Quadrangle of United States Geological Survey	Township	Range	Section	Description		
17	McIntosh Landing	Ca	pay Ran	cho	On north side of road on old Orland-Hamilton Road, 0.8 mile east of Capay Grant line	Dec. 3, 1929	19.3
						Oct. 1, 1930	12.2
						Dec. 29, 1930	14.0
						Dec. 1, 1931	18.0
18	Hamilton	Ca	pay Ran	cho	On north side Chico-Orland State Highway, 0.8 mile west of Glenn-Colusa Canal	Dec. 6, 1929	17.1
						Oct. 1, 1930	14.0
						Dec. 29, 1930	14.9
						Dec. 2, 1931	16.8
19	Chico Landing	Arroyo	Chico	Grant	0.2 mile south of S. P. R.R. on Chico-Orland Highway, 1.0 mile NW. of Sandy Gulch. Owner, J. M. Bird.	Dec. 5, 1929	15.5
						Oct. 4, 1930	15.3
						Dec. 4, 1931	16.5
20	Keefers	Arroyo	Chico	Grant	0.1 mile north of Sandy Gulch and 1.0 mile east of Shasta Road. Owner, G. Hemminger	Nov. 29, 1929	36.4
						Sept. 29, 1930	31.8
						Dec. 4, 1931	39.2
21	Orland	21 N.	3 W.	6	400 feet north and 100 feet west of the SE. corner of SW¼ of SE¼ of Sec. 6. Owner, Mrs. M. Doty Est.	Dec. 6, 1929	40.9
						Oct. 2, 1930	40.3
						Dec. 2, 1931	41.0
22	Orland	21 N.	3 W.	12	0.1 mile west of N¼ corner of Sec. 12. Owner, H. S. Howard	Dec. 4, 1929	30.9
						Oct. 2, 1930	27.3
						Dec. 29, 1930	27.3
						Dec. 2, 1931	28.0
23	Hamilton	Ca	pay Ranc	cho	2.5 miles south of St. John, 0.2 mile east of county road. Owner, G. N. McCampbell	Dec. 4, 1929	20.0
						Oct. 1, 1930	20.1
						Dec. 2, 1931	20.0
24	Chico Landing	Ran	cho de F Grant	arwell	0.2 mile southeast of the junction of Sacramento River and Chico Creek. Owner, J. D. Phelan	Dec. 5, 1929	18.9
						Oct. 4, 1930	18.8
						Dec. 4, 1931	19.0
25	Durham	21 N.	1 E.	10	On west side of Chico-Dayton Road, 0.4 mile south of north line Sec. 10. Owner, A. A. Richardson	Dec. 18, 1929	17.5
						Sept. 27, 1930	15.8
						Dec. 4, 1931	18.0

No.	Town	T.	R.	Sec.	Location	Date	Depth
26	Durham	21 N.	2 E.	8	Near center of Sec. 8. Owner, A. F. Lieurance	Nov. 20, 1929 Sept. 19, 1930 Dec. 4, 1931	13.5 13.5 14.0
27	Orland	21 N.	3 W.	31	0.2 mile southwest of center of Sec. 31. Owner, California Lands, Inc.	Dec. 6, 1929 Oct. 2, 1930 Dec. 2, 1931	20.8 16.7 22.5
28	Orland	21 N.	2 W.	31	On west line of Sec. 31, 0.4 mile south of NW. corner. Owner, David De Thier	Dec. 4, 1929 Oct. 2, 1930 Dec. 2, 1931	18.4 18.1 18.4
29	Hamilton	Jacinto Grant			1.0 mile west of Ord. Owner, I. L. Windell	Dec. 4, 1929 Oct. 1, 1930 Dec. 2, 1931	10.5 9.5 10.0
30	Chico Landing	Rancho de Farwell Grant			1.0 mile north of Parrot School on east side of road. Owner, E. T. Fell	Dec. 5, 1929 Oct. 4, 1930 Dec. 1, 1931	17.8 17.6 18.3
31	Durham	21 N.	1 E.	33	On center of east line of NE¼ of NE¼ of Sec. 33. Owner, W. K. Yocum	Nov. 21, 1929 Sept. 27, 1930 Dec. 5, 1931	15.5 15.9 16.3
32	Durham	21 N.	2 E.	31	100 feet east of S. P. R.R. about 1.0 mile south of Durham. Owner, Cooley Bros.	Nov. 20, 1929 Sept. 19, 1930 Dec. 5, 1931	13.0 12.7 14.5
33	Clear Creek	21 N.	2 E.	[1]26	East of Chico-Oroville Road, SE¼ of Sec. 26. Owner, Wm. Bradshaw	Nov. 18, 1929 Sept. 24, 1930 Dec. 5, 1931	25.3 26.5 27.8
34	Lyman	20 N.	3 W.	29	0.1 mile north and 0.3 mile west of SE. corner of Sec. 29	Dec. 6, 1929 Oct. 2, 1930 Nov. 30, 1931	17.6 18.1 18.9
35	Lyman	20 N.	3 W.	25	0.2 mile northwest of S¼ corner of Sec. 25. Owner, C. J. Wilderman	Dec. 4, 1929 Oct. 2, 1930 Dec. 2, 1931	18.4 18.5 18.0
36	Jacinto	Jacinto Grant			0.5 mile south of Sidd's Landing, 0.4 mile west of river road	Dec. 24, 1929 Oct. 1, 1930 Dec. 1, 1931	10.2 11.8 13.1
37	Newhard	Llano Seco Grant			1.0 mile south of headquarters of Llano Seco Ranch, 0.2 mile east of Perkins Lake. Owner, Llano Seco Ranch.	Dec. 5, 1929 Sept. 23, 1930 Dec. 1, 1931	15.1 15.1 15.5
38	Nelson	20 N.	1 E.	[1]33	300 feet south of NE. corner of Sec. 33	Nov. 21, 1929 Sept. 19, 1930 Dec. 1, 1931	6.3 4.5 4.8

[1] Projected.

DEPTHS TO GROUND WATER AT TYPICAL WELLS IN SACRAMENTO VALLEY—1929-1931—Continued

Well No.	Well location					Date of measurement	Depth to water from ground surface, in feet
	Quadrangle of United States Geological Survey	Township	Range	Section	Description		
39	Nelson	Esquon Grant			In town of Nelson, 1 block north of Nelson-Butte Creek Road, 1 block west of highway	Nov. 20, 1929 Sept. 19, 1930 Dec. 5, 1931	6.0 3.5 7.0
40	Dry Creek	20 N.	4 E.	32	0.1 mile southeast of NW. corner of Sec. 32. Owner, Anna Colm Est.	Nov. 20, 1929 Sept. 24, 1930 Dec. 5, 1931	10.5 10.9 14.5
41	Lyman	19 N.	3 W.	18	At NW. corner of NE¼ of NW¼ of Sec. 18. Owner, G. Fumassi	Nov. 7, 1929 Oct. 2, 1930 Nov. 29, 1931	24.5 27.5 24.8
41 A	Lyman	19 N.	3 W.	18	0.1 mile south of NW. corner of Sec. 18. Owner, Pete Ceccon	Dec. 6, 1929 Oct. 2, 1930	26.0 28.0
42	Logandale	19 N.	3 W.	23	On south side of road, 0.1 mile west of NE. corner of Sec. 23. Owner, Trenton Taylor	Dec. 24, 1929 Oct. 7, 1930 Nov. 30, 1931	8.2 8.7 9.5
43	Princeton	Larkins Children's Rancho Grant			1.5 mile south of Glenn and 0.4 mile west of county road. Owner, Annie F. Whyler	Dec. 4, 1929 Oct. 1, 1930 Dec. 1, 1931	13.9 12.0 14.0
44	Butte City	19 N.	1 W.	14	0.4 mile north and 0.4 mile west of SE. corner of Sec. 14. Owners, Paul Teihl and Jack Palagoni	Dec. 17, 1929 Oct. 1, 1930 Dec. 1, 1931	11.8 11.9 13.5
45	Laudlow	19 N.	1 E.	15	In SE. corner of SW¼ of Sec. 15. Owner, Jas. Robinson	Nov. 21, 1929 Sept. 19, 1930 Dec. 1, 1931	7.7 7.5 7.6
46	Laudlow	19 N.	2 E.	21	100 feet southwest of N¼ corner of Sec. 21. Owner, Frank E. Anderson	Nov. 18, 1929 Sept. 19, 1930 Dec. 5, 1931	3.0 3.5 3.9
47	Dry Creek	19 N.	4 E.	9	200 feet east of substation at Oroville Junction. Owner, Pacific Gas and Electric Co.	Nov. 21, 1929	47.0
47 A	Dry Creek	19 N.	4 E.	16	Center of Sec. 16	Dec. 16, 1931	34.8

48	Palermo	19 N.	4 E.	20	West side of S. P. R.R. near Wyandotte Olive Growers Association's packing house in the SE¼ of NW¼ of Sec. 20. Owner, Ophir Gold Dredging Company.	Nov. 21, 1929 Sept. 25, 1930 Dec. 16, 1931	41.3 37.8 44.2
49 A	Logan Creek	18 N.	4 W.	11	About 60 feet south of NW. corner of Sec. 11 at end of road	Dec. 7, 1929 Oct. 2, 1930 Nov. 29, 1931	13.3 15.7 19.0
49 B	Logan Creek	18 N.	4 W.	12	Near the N¼ corner of Sec. 12	Dec. 7, 1929 Oct. 2, 1930 Nov. 29, 1931	11.5 12.8 13.0
50	Logandale	18 N.	3 W.	[1]10	At about center of Sec. 10. Owner, Spaulding Ranch	Dec. 7, 1929 Oct. 2, 1930 Nov. 30, 1931	5.6 3.5 4.5
51	Princeton	Larkins Children's Rancho Grant			On south side of road, 2.4 miles west of Princeton. Owner, W. A. Luttrell	Dec. 18, 1929 Oct. 4, 1930 Nov. 30, 1931	6.0 5.4 8.3
52	Butte City	18 N.	1 W.	10	0.1 mile north of SW. corner of Sec. 10. Owner, C. J. Johnson	Dec. 24, 1929 Oct. 3, 1930 Dec. 1, 1931	10.8 11.5 10.5
53	Landlow	18 N.	1 E.	9	In SE¼ of SE¼ Sec. 9. Owner, Snider Brothers	Nov. 21, 1929 Oct. 3, 1930 Dec. 1, 1931	3.6 4.0 4.5
54	Landlow	18 N.	2 E.	16	Near SW. part of the NE¼ of Sec. 16. Owner, F. A. Ditzler	Nov. 21, 1929 Sept. 27, 1930 Dec. 1, 1931	6.7 5.4 7.8
55 A	Biggs	Fernandez Grant			South of East Biggs Road, west of S. N. R.R. Owner, Carrie Sixt	Nov. 18, 1929 Oct. 8, 1930 Dec. 16, 1931	18.5 17.1 19.6
55 B	Biggs	Fernandez Grant			0.4 mile east of S.N. R.R. north side of East Biggs Road. Owner, A. C. Hudson	Nov. 18, 1929 Oct. 8, 1930 Dec. 16, 1931	26.0 23.5 27.3
56	Palermo	18 N.	4 E.	7	On west side of road 0.2 mile south of NE. corner of Sec. 7. Owner, First National Bank of Chico	Nov. 20, 1929 Sept. 25, 1930 Dec. 14, 1931	6.5 6.0 16.0
57	Palermo	18 N.	3 E.	26	South of road in the SE¼ of SE¼ Sec. 26, 0.1 mile west of the east line of section. Owner, I. E. Passmore.	Nov. 20, 1929 Sept. 25, 1930 Dec. 14, 1931	16.0 14.9 16.8

[1]Projected.

DEPTHS TO GROUND WATER AT TYPICAL WELLS IN SACRAMENTO VALLEY—1929-1931—Continued

Well No.	Well location					Date of measurement	Depth to water from ground surface, in feet
	Quadrangle of United States Geological Survey	Township	Range	Section	Description		
58	Delevan	18 N.	3 W.	31	In SW. corner of Sec. 31	Dec. 7, 1929 Oct. 2, 1930 Nov. 29, 1931	4.6 5.8 6.5
59	Delevan	17 N.	3 W.	3	0.3 mile west of SE. corner of Sec. 3. Owner, Chester Robinson	Dec. 7, 1929 Oct. 7, 1930 Nov. 30, 1931	7.6 6.0 7.0
60	Compton Landing	Larkins Children's Rancho Grant			0.7 mile west of river road and 0.3 mile north of south line of Larkins Children's Rancho Grant. Owner, National Pacific Land Company.	Dec. 18, 1929 Oct. 4, 1930 Nov. 30, 1931	5.3 6.2 7.8
61	Sanborn Slough	17 N.	1 W.	8	On east line of Sec. 8, 0.3 mile south of NE. corner. Owner, Bank of America	Dec. 24, 1929 Oct. 3, 1930 Dec. 1, 1931	6.5 8.0 10.5
62	Pennington	18 N.	1 E.	33	0.1 mile north of SE. corner of SW¼ of SW¼ of Sec. 33. Owner, Tom King	Dec. 13, 1929 Oct. 6, 1930 Dec. 1, 1931	5.7 9.0 8.5
63	Pennington	17 N.	2 E.	8	In NW. corner of Sec. 8. Owners, R. J. and M. Nugent	Dec. 13, 1929 Oct. 6, 1930 Dec. 16, 1931	5.0 5.9 7.4
64	Gridley	17 N.	2 E.	12	100 feet south of NE. corner of Sec. 12. Owner, D. W. Gillett	Nov. 26, 1929 Sept. 27, 1930 Dec. 16, 1931	6.8 7.2 8.5
65	Honcut	17 N.	4 E.	16	In SW. corner of Sec. 16; west of Honcut and north of county road. Owner, S. N. D. Smullin	Nov. 27, 1929 Sept. 25, 1930 Dec. 14, 1931	23.5 22.2 24.5
66	Gridley	17 N.	3 E.	30	0.1 mile west of Boga Grant line and 300 feet south of county road. Owner, R. F. Johnson	Nov. 26, 1929 Sept. 27, 1930 Dec. 16, 1931	8.7 7.3 10.2
67	Sites	16 N.	4 W.	12	0.1 mile south of N¼ of Sec. 12. Owner, Frank Prine	Dec. 7, 1929 Oct. 2, 1930 Nov. 30, 1931	17.7 17.4 19.1

68	Delevan	17 N.	3 W.	34	0.3 mile west of SE. corner of Sec. 34 and 0.7 mile east of Maxwell. Owner, W. C. Baber	Dec. 7, 1929 Oct. 7, 1930 Nov. 30, 1931	7.6 5.3 8.0
69	Compton Landing	16 N.	2 W.	4	About the center of NE¼ of Sec. 4. Owner, Watts Brothers	Dec. 18, 1929 Oct. 4, 1930 Nov. 30, 1931	11.1 11.2 12.0
70	Sanborn Slough	16 N.	1 W.	5	In S½ of Sec. 5 near center of Sec., 300 feet east of road. Owner, J. W. Browning	Dec. 18, 1929 Oct. 3, 1930 Nov. 30, 1931	17.0 17.6 20.0
71	Sanborn Slough	16 N.	1 E.	5	50 feet west of north and south center line of Sec. 5, 0.2 mile north of county road. Owner, Winchester Gun Club.	Dec. 13, 1929 Oct. 6, 1930 Dec. 16, 1931	7.5 7.5 8.0
72	Gridley	16 N.	2 E.	3	In NW¼ of SE¼ of Sec. 3	Nov. 26, 1929 Oct. 21, 1930 Dec. 16, 1931	7.4 7.7 7.1
73	Gridley	Boga Grant			At Sunset Station on S. P. R.R. east side of highway. north side of county road. Owner, C. N. Sumner.	Nov. 23, 1929 Sept. 27, 1930 Dec. 16, 1931	8.3 7.8 8.8
74	Honcut	16 N.	4 E.	8	Near north line of Sec. 8, 100 feet west of S. P. R.R., south side of county road at Ramirez Station	Nov. 26, 1929 Sept. 25, 1930 Dec. 14, 1931	16.9 16.1 18.0
75	Browns Valley	16 N.	5 E.	18	In NE¼ of SE¼ of Sec. 18. Owner, Mrs. Geo. Graves	Nov. 27, 1929 Sept. 25, 1930 Dec. 14, 1931	24.4 24.0 25.3
76	Williams	16 N.	3 W.	27	At north line of Sec. 27, 0.3 mile east of S.P. R.R. Owner, Mills Orchard Company	Dec. 7, 1929 Oct. 2, 1930 Nov. 30, 1931	5.7 7.7 6.0
77	Powell Slough	16 N.	2 W.	26	In the NE. corner of Frac. Sec. 26, near Colus Grant line. Owner, A. E. Potter	Dec. 18, 1929 Oct. 4, 1930 Nov. 30, 1931	4.5 6.6 7.5
78	Meridian	16 N.	1 W.	20	0.2 mile northwest of center of Sec. 20. Owner, P. W. Berkey	Dec. 17, 1929 Oct. 3, 1930 Nov. 30, 1931	16.0 23.0 24.5
79	Meridian	16 N.	1 E.	31	0.1 mile west of E¼ corner of Sec. 31. Owner, Ware and O'Bannion	Nov. 27, 1929	20.5
79 A	Meridian	16 N.	1 E.	32	100 feet SE. of W¼ corner of Sec. 32. Owner, J. J. Carroll	Oct. 6, 1930 Dec. 16, 1931	28.4 29.8
80	Sutter	16 N.	2 E.	35	0.2 mile southeast of N¼ corner of Sec. 35. Owner, A. N. Brown	Nov. 26, 1929 Oct. 21, 1930 Dec. 16, 1931	12.0 11.5 13.0

DEPTHS TO GROUND WATER AT TYPICAL WELLS IN SACRAMENTO VALLEY—1929-1931—Continued

Well No.	Well location					Date of measurement	Depth to water from ground surface, in feet
	Quadrangle of United States Geological Survey	Township	Range	Section	Description		
81	Yuba City	Honcut Grant			0.4 mile southwest of junction of county roads. Owner, W. A. Beard	Nov. 26, 1929 Sept. 25, 1930 Dec. 16, 1931	15.9 15.6 16.7
82	Yuba City	16 N.	4 E.	27	In SW¼ of Sec. 27, 300 feet west of Marysville-Smartsville Road	Nov. 27, 1929 Sept. 25, 1930 Dec. 14, 1931	10.4 7.8 10.8
83	Browns Valley	16 N.	5 E.	33	On north side of main street of Hammonton, rear of rooming house opposite post office. Owner, Yuba Consolidated Gold Fields.	Nov. 23, 1929 Sept. 26, 1930 Dec. 14, 1931	27.0 25.4 26.2
84	Fairview	15 N.	4 W.	14	In SW. corner of NE¼ of SE¼ of Sec. 14. Owner, E. A. Brim	Dec. 7, 1929 Oct. 3, 1930 Nov. 24, 1931	13.9 16.3 17.5
85	Williams	15 N.	3 W.	24	300 feet north of W¼ corner of Sec. 24, and 1.0 mile south of Williams. Owner, Henry Wright	Dec. 24, 1929 Oct. 3, 1930 Nov. 24, 1931	5.7 8.0 10.5
86	Powell Slough	15 N.	2 W.	15	0.3 mile east and 300 feet north of SW. corner of Sec. 15. Owner, I. G. Zumwalt	Dec. 24, 1929 Oct. 3, 1930 Nov. 24, 1931	9.1 10.0 9.3
87	Meridian	15 N.	1 W.	25	0.2 mile south of NE. corner of Sec. 25. Owner, Mrs. E. Blackmer	Dec. 26, 1929 Oct. 7, 1930 Dec. 16, 1931	14.0 18.6 18.6
88	Marysville Buttes	15 N.	1 E.	14	In SE. part of NW¼ of Sec. 14. Owner, L. C. Stuhlman	Nov. 27, 1929 Oct. 6, 1930 Dec. 16, 1931	16.8 15.0 14.8
89	Sutter	15 N.	2 E.	24	In the SW¼ of SW¼ of Sec. 24. Owner, G. W. Knight	Nov. 27, 1929 Oct. 6, 1930 Dec. 15, 1931	13.0 12.0 13.0
90	Sutter	15 N.	3 E.	28	0.3 mile west of NE. corner of Sec. 28. Owner, H. D. Littlejohn	Nov. 27, 1929 Sept. 27, 1930 Dec. 15, 1931	25.3 28.3 29.3

91	Yuba City	15 N.	4 E.	22	In the NE. part of SW¼ of Sec. 22. Owner, Frank Mills	Nov. 22, 1929 Sept. 16, 1930 Dec. 14, 1931	24.9 24.5 26.5
92 A	Browns Valley	15 N.	5 E.	19	0.2 mile south of N¼ corner of Sec. 19. Owner, W. J. Sanford and Son	Nov. 22, 1929 Sept. 26, 1930 Dec. 14, 1931	24.3 24.1 26.2
92 B	Browns Valley	15 N.	5 E.	19	0.3 mile north of S¼ corner of Sec. 19. Owner, W. J. Sanford and Son	Nov. 22, 1929 Sept. 26, 1930 Dec. 14, 1931	25.3 25.0 26.0
93	Spring Valley	15 N.	3 W.	33	0.3 mile east of SW. corner of Sec. 33. Owner, Bank of Williams	Dec. 24, 1929 Oct. 3, 1930 Nov. 24, 1931	50.3 48.3 47.0
94	Arbuckle	14 N.	2 W.	3	300 feet north of SW. corner of Sec. 3. Owner, Jess Brown	Dec. 18, 1929 Oct. 3, 1930 Nov. 24, 1931	7.5 8.0 6.5
95	Grimes	14 N.	1 W.	3	In NE. corner of SW¼ of Sec. 3. Owner, Staap	Dec. 19, 1929 Oct. 3, 1930 Nov. 27, 1931	11.5 11.1 12.5
96 A	Grimes	14 N.	1 E.	5	In N½ of Sec. 5 east of county road, 0.4 mile south of north line. Owner, Birks Bros.	Dec. 24, 1929 Oct. 7, 1930 Nov. 27, 1931	14.4 15.1 16.0
96 B	Grimes	14 N.	1 E.	8	0.4 mile south and 0.2 mile west of NE. corner of Sec. 8. Owner, C. A. Foley	Dec. 26, 1929 Oct. 7, 1930 Nov. 27, 1931	10.0 7.7 13.0
97	Gilsizer Slough	14 N.	2 E.	10	On west side of road near center of Sec. 10	Nov. 27, 1929 Oct. 6, 1930 Dec. 12, 1931	9.8 9.0 9.0
98	Gilsizer Slough	14 N.	3 E.	18	NW. corner of Sec. 18. Owner, M. C. Vieira	Nov. 26, 1929 Oct. 6, 1930 Dec. 12, 1931	8.8 6.7 10.5
99	Gilsizer Slough	14 N.	3 E.	3	In center of S½ of Sec. 3. Owner, R. W. Klingsmith	Nov. 26, 1929 Sept. 27, 1930 Dec. 12, 1931	28.3 32.4 33.8
100	Ostrom	14 N.	4 E.	15	0.1 mile south of N¼ corner of Sec. 15. Owner, Hans Peterson	Nov. 22, 1929 Sept. 18, 1930 Dec. 11, 1931	17.4 16.9 17.4

[1] Projected.

DEPTHS TO GROUND WATER AT TYPICAL WELLS IN SACRAMENTO VALLEY—1929-1931—Continued

Well No.	Well location: Quadrangle of United States Geological Survey	Township	Range	Section	Description	Date of measurement	Depth to water from ground surface, in feet
101	Wheatland	14 N.	5 E.	16	In NE. corner of NW¼ of Sec. 16	Nov. 22, 1929 Sept. 18, 1930 Dec. 11, 1931	26.3 25.5 27.5
102	Grimes	14 N.	1 W.	20	0.1 mile north of south line of Sec. 20 and 0.1 mile west of county road. Owner, H. C. Spicer	Dec. 18, 1929 Oct. 3, 1930 Nov. 27, 1931	13.4 14.5 15.0
103	Ostrom	14 N.	4 E.	19	0.2 mile east of W. ¼ corner of Sec. 19. Owner, Barbar	Nov. 8, 1929 Sept. 26, 1930 Dec. 11, 1931	12.0 12.7 12.6
104	Spring Valley	13 N.	2 W.	6	75 feet east of west line and 0.3 mile south of NW. corner of Sec. 6. Owner, J. Turnbull	Dec. 18, 1929 Oct. 3, 1930 Nov. 24, 1931	81.0 79.9 85.5
105	Arbuckle	14 N.	2 W.	35	In town of Arbuckle, 100 feet east of railroad station. Owner, H. L. Strickler	Jan. 2, 1930 Oct. 3, 1930 Nov. 24, 1931	60.0 60.7 62.0
106	Grimes	14 N.	1 W.	35	At SW. corner of SE¼ of Sec. 35	Jan. 2, 1930 Oct. 3, 1930 Nov. 27, 1931	3.5 4.3 4.0
107	Tisdale Weir	13 N.	1 E.	1	On east and west center line of Sec. 1, on the east side of road on east side of Sacramento River. Owner, Mrs. R. Coulter.	Dec. 26, 1929 Oct. 7, 1930 Nov. 27, 1931	9.4 18.5 17.8
108	Gilsizer Slough	13 N.	2 E.	1	0.1 mile south of center of E½ of Sec. 1. Owner, Jackson Diggs	Nov. 26, 1929 Oct. 7, 1930 Dec. 12, 1931	12.7 13.3 13.0
109	Ostrom	14 N.	4 E.	29	60 feet north of SE. corner of Sec. 29 on east side of road	Nov. 8, 1929 Sept. 26, 1930 Dec. 11, 1931	10.5 10.4 11.0
110	Wheatland	Johnson	Rancho	Grant	Northwest of the NE. corner of town of Wheatland. Owner, C. H. Dam	Nov. 22, 1929 Sept. 19, 1930 Dec. 11, 1931	22.2 23.6 23.3

111	Hershey	13 N.	1 W.	16	0.3 mile west and 0.1 mile north of SW. corner of Sec. 16. Owner, N. Griffin	Dec. 18, 1929 Oct. 7, 1930 Nov. 24, 1931	18.2 18.5 19.5
112	Nicolaus	13 N.	3 E.	14	0.1 mile south of north line of Sec. 14 near New Helvetia Grant line. Owner, Johnson and Solomonson.	Nov. 26, 1929 Sept. 27, 1930 Dec. 12, 1931	15.4 15.6 15.4
113	Lincoln	13 N.	6 E.	9	0.2 mile east and 400 feet north of SW. corner of Sec. 9	Nov. 11, 1929 Sept. 18, 1930 Dec. 11, 1931	42.2 40.2 42.5
114	Harrington	13 N.	1 W.	31	At south line 0.4 mile west of SE. corner of Sec. 31. Owner, Hershey Est.	Jan. 2, 1930 Oct. 7, 1930 Nov. 24, 1931	117.7 119.1 121.5
115	Hershey	13 N.	1 W.	35	0.4 mile north and 0.3 mile east of SW. corner of Sec. 35. Owner, M. T. Emmert	Dec. 18, 1929 Oct. 7, 1930 Nov. 27, 1931	34.5 34.5 35.0
116	Kirkville	13 N.	1 E.	[1]34	0.2 mile north of Colusa-Yolo County line, 0.3 mile west of county road	Jan. 2, 1930 Oct. 7, 1930 Nov. 27, 1931	14.9 10.7 13.0
117	Marcuse	12 N.	2 E.	4	In SE. corner of NE¼ of Sec. 4. Owner, Sutter Basin Co.	Dec. 26, 1929 Oct. 7, 1930 Nov. 25, 1931	3.9 11.0 5.0
118	Nicolaus	12 N.	3 E.	3	0.1 mile south and 0.3 mile east of E. ¼ corner of Sec. 3. Owner, Geo. Pollock	Nov. 7, 1929 Sept. 27, 1930 Dec. 12, 1931	7.7 6.1 6.2
119	Nicolaus	13 N.	4 E.	33	300 feet north and 100 feet west of SE. corner of Sec. 33. Owner, Dooley Brothers	Nov. 8, 1929 Sept. 8, 1930 Dec. 30, 1930 Dec. 10, 1931	21.0 20.1 20.4 21.1
120	Sheridan	13 N.	5 E.	34	In SE. corner of Sec. 34 near concrete lined reservoir. Owner, Harold Brown	Nov. 23, 1929 Sept. 25, 1930	21.3 20.4
120 A	Sheridan	13 N.	5 E.	35	0.3 mile east and 0.3 mile north of SW. corner of Sec. 35. Owner, Harold Brown	Dec. 11, 1931	16.3
121	Lincoln	13 N.	6 E.	34	0.2 mile east of SW. corner Sec. 34. Owner, Allen Jones	Nov. 9, 1929 Sept. 10, 1930 Dec. 11, 1931	8.0 10.2 8.9
122	Zamora	12 N.	1 W.	23	0.3 mile west of SE. corner of Sec. 23. Owner, A. Huhs	Jan. 2, 1930 Oct. 7, 1930 Nov. 24, 1931	15.3 18.3 17.0

[1] Projected.

DEPTHS TO GROUND WATER AT TYPICAL WELLS IN SACRAMENTO VALLEY—1929-1931—Continued

Well No.	Well location					Date of measurement	Depth to water from ground surface, in feet
	Quadrangle of United States Geological Survey	Township	Range	Section	Description		
123	Ronda	12 N.	1 E.	[1]25	Near east line of Sec. 25, 0.1 mile south of Sacramento River. Owner, River Farms Co.	Jan. 2, 1930 Oct. 7, 1930 Nov. 27, 1931	15.7 18.5 19.5
124	Knights Landing	12 N.	2 E.	[1]26	At NW. corner of NE¼ of Sec. 26. Owner, Nick Hile	Dec. 26, 1929 Oct. 7, 1930 Nov. 25, 1931	5.5 5.9 6.0
125	Vernon	12 N.	3 E.	[1]22	0.1 mile north of south line of Sec. 22, 0.2 mile north of Lee School. Owner, Mrs. Wessing	Nov. 7, 1929 Sept. 27, 1930 Dec. 15, 1931	10.8 11.5 11.8
126	Pleasant Grove	12 N.	5 E.	19	0.1 mile north of SE. corner of Sec. 19. Owner, Pacific Investment Co.	Nov. 23, 1929 Sept. 26, 1930 Dec. 11, 1931	17.0 16.3 18.1
127 A	Lincoln	12 N.	6 E.	19	0.3 mile south and 0.1 mile west of NE. corner of Sec. 19. Owner, Mrs. David McCartney	Nov. 9, 1929 Sept. 18, 1930 Dec. 11, 1931	10.0 9.8 9.4
127 B	Lincoln	12 N.	6 E.	19	Near east line, 0.3 mile south of NE. corner of Sec. 19. Owner, Mrs. David McCartney	Nov. 9, 1929 Sept. 18, 1930 Dec. 11, 1931	15.3 15.3 15.4
128	Zamora	11 N.	1 E.	8	Near center of NE¼ of Sec. 8. Owner, E. A. Clausen	Jan. 2, 1930 Oct. 7, 1930 Nov. 24, 1931	15.7 17.7 25.0
129	Ronda	11 N.	1 E.	12	0.7 mile north of SE. corner of Sec. 12, west side of road	Jan. 2, 1929 Oct. 7, 1930	9.9 10.7
129 A	Ronda	11 N.	1 E.	12	0.1 mile north of S. ¼ corner of Sec. 12. Owner, W. E. Curtis	Nov. 27, 1931	9.0
130	Knights Landing	11 N.	2 E.	[1]2	On east side of paved road, 1.8 miles north of bridge at Knights Landing. Owner, Frank L. Spencer.	Dec. 26, 1929 Oct. 7, 1930 Nov. 25, 1931	12.8 15.6 16.5
131	Vernon	12 N.	4 E.	33	300 feet east of Catlett Station, Sacramento Northern R.R. Owner, C. Yuhre	Nov. 8, 1929 Sept. 25, 1930 Dec. 10, 1931	15.4 16.0 16.4

132	Pleasant Grove	11 N.	4 E.	1	In NW. corner of S½ of Sec. 1. Owner, G. H. Trevathan	Nov. 8, 1929 Sept. 26, 1930 Dec. 10, 1931	13.3 12.8 14.4
133	Ronda	11 N.	2 E.	21	In SE. corner of NW¼ of Sec. 21. Owner, Alameda Sugar Company	Jan. 2, 1930 Oct. 7, 1930 Nov. 27, 1931	20.5 43.3 26.4
134	Vernon	11 N.	3 E.	22	In SE. corner of frac. Section 22, in center of Vernon. Owner, Mrs. M. Owsley	Nov. 7, 1929 Sept. 27, 1930 Dec. 15, 1931	22.3 22.3 22.3
135	Roseville	11 N.	6 E.	18	Near south line, 0.3 mile east of SW. corner of Sec. 18. Owner, Pringle Brothers	Nov. 9, 1929 Sept. 18, 1930	30.0 29.3
135 A	Roseville	11 N.	6 E.	18	Near well No. 135	Dec. 11, 1931	31.4
136	Yolo	10 N.	1 E.	2	200 feet east of S. ¼ corner of Sec. 2. Owner, J. E. Jackson	Dec. 28, 1929 Oct. 10, 1930 Nov. 24, 1931	22.2 22.8 32.5
137	Ronda	11 N.	2 E.	31	0.1 mile south of north line of Sec. 31 on the east side of Cache Creek Slough. Owner, Dick Bros.	Dec. 29, 1929 Oct. 10, 1930 Nov. 27, 1931	28.2 32.7 36.5
138	Grays Bend	10 N.	3 E.	[1]7	Near center of Sec. 7. Owner, Sorosis Fruit Company	Dec. 28, 1929 Oct. 10, 1930 Nov. 25, 1931	12.4 14.4 15.2
139	Vernon	11 N.	3 E.	25	0.1 mile north of south line of Sec. 25, 100 feet east of river levee. Owner, A. Linggi	Nov. 7, 1929 Sept. 27, 1930 Dec. 15, 1931	17.0 17.3 17.5
140	Arcade	10 N.	5 E.	7	0.1 mile east and 0.4 mile north of SW. corner of Sec. 7. Owner, Abraham Zine	Nov. 8, 1929 Sept. 26, 1930 Dec. 10, 1931	20.5 20.1 21.4
141	Pleasant Grove	11 N.	5 E.	34	0.2 mile west and 400 feet north of SE. corner of Sec. 34	Nov. 9, 1929 Sept. 18, 1930 Dec. 10, 1931	38.3 38.5 39.0
142	Antelope	10 N.	6 E.	12	0.2 mile east of NW. corner of Sec. 12. Owner, Scott Martin	Nov. 9, 1929 Sept. 18, 1930 Dec. 10, 1931	38.5 33.6 33.0
143	Jacobs Corner	10 N.	1 W.	27	0.2 mile east of SW. corner of Guesisosi Grant. Owner, Seth Sovereign	Dec. 20, 1929 Oct. 10, 1930 Nov. 20, 1931	9.5 9.3 14.5

[1] Projected.

DEPTHS TO GROUND WATER AT TYPICAL WELLS IN SACRAMENTO VALLEY—1929-1931—Continued

Well No.	Well location					Date of measurement	Depth to water from ground surface, in feet
	Quadrangle of United States Geological Survey	Township	Range	Section	Description		
144	Jacobs Corner	10 N.	1 E.	31	In NE. corner of frac. Sec. 31. Owner, V. J. Bartels	Dec. 20, 1929	14.6
144 A	Jacobs Corner	10 N.	1 E.	31	0.3 mile west and 0.1 mile north of NE. corner of frac. Sec. 31. Owner, V. J. Bartels	Oct. 10, 1930 Nov. 23, 1931	16.8 18.5
145	Yolo	10 N.	2 E.	21	In NW. part of SW¼ of Sec. 21. Owner, H. C. Dennison & Co.	Dec. 20, 1929 Oct. 10, 1930 Nov. 25, 1931	12.0 13.5 17.0
146	Elkhorn Weir	9 N.	3 E.	2	Lot 17, Elkhorn Subdivision. Owner, Susie Cahill	Nov. 7, 1929 Sept. 26, 1930 Dec. 15, 1931	22.0 16.9 17.4
147	Arcade	9 N.	5 E.	7	In NW. part of NE¼ of Sec. 7, 300 feet east of W. P. R.R. Owner, John Decker	Nov. 8, 1929 Sept. 26, 1930 Dec. 15, 1931	18.3 20.0 20.0
148	Antelope	Del Paso Grant			0.5 mile southeast of Walerga Station, S. P. R.R. Owner, John B. Leitch	Nov. 23, 1929 Dec. 15, 1931	55.2 55.8
149	Antelope	10 N.	6 E.	26	400 feet southeast of N. ¼ corner of Sec. 26. Owner, E. Blodgett	Nov. 2, 1929 Sept. 18, 1930 Dec. 10, 1931	80.0 79.8 82.0
150	Folsom	Rio de los Americanos Grant			In town of Folsom, 200 feet northwest of Catholic Church. Owner, Mrs. F. Marshall	Nov. 4, 1929 Oct. 21, 1930 Dec. 10, 1931	34.5 34.3 35.5
151	Jacobs Corner	9 N.	1 W.	16	0.1 mile southwest of NE. corner of W½ of Sec. 16. Owner, Mrs. W. L. Bourland	Dec. 20, 1929 Oct. 10, 1930 Nov. 20, 1931	16.1 12.5 20.4
152	Yolo	9 N.	2 E.	5	In SW. corner of Sec. 5. Owner, A. W. Fox	Dec. 20, 1929 Oct. 11, 1930 Nov. 20, 1931	15.9 15.7 21.5
153	Mills	Del Paso Grant			3.2 miles east and 0.2 mile north of Del Paso Country Club House. Owner, J. A. Shumate	Nov. 2, 1929 Sept. 18, 1930 Dec. 15, 1931	62.0 60.0 61.5

154	Folsom	Rio do	los Americanos Grant		At packing plant, Nimbus Station; Placerville branch of S. P. R.R. Owner, Libby, McNeil and Libby.	Nov. 4, 1929 Oct. 21, 1930 Dec. 10, 1931	32.5 32.4 35.7
155	Merritt	9 N.	1 E.	28	0.3 milo west of SE. corner of Sec. 28	Dec. 20, 1929 Oct. 10, 1930 Nov. 20, 1931	14.6 13.7 14.0
156	Swingle	9 N.	2 E.	27	0.3 mile north of SE. corner of Sec. 27	Dec. 20, 1929 Oct. 10, 1930 Nov. 19, 1931	8.0 10.1 10.5
157 A	Swingle	9 N.	3 E.	33	0.1 mile north of SW. corner of Sec. 33	Jan. 3, 1930 Oct. 10, 1930 Nov. 18, 1931	7.0 7.5 9.0
157 B	Swingle	9 N.	3 E.	30	0.4 mile east of SW. corner of Sec. 30	Jan. 3, 1930 Oct. 10, 1930 Nov. 18, 1931	7.0 7.6 8.5
158	Lovdal	9 N.	4 E.	[1]29	1.0 mile south of Leeman and 0.5 mile southwest of Sacramento River. Owner, W. E. M. Beardslee.	Jan. 3, 1930 Oct. 24, 1930	9.5 12.0
158 A	Lovdal	9 N.	4 E.	[1]29	Near well No. 158	Nov. 19, 1931	17.5
159	Brighton	9 N.	5 E.	[1]29	300 feet west of junction of Del Paso Blvd. and El Camino Ave. Owner, W. O. Erwin	Nov. 2, 1929 Sept. 26, 1930 Dec. 15, 1931	20.5 21.0 23.0
160	Mills	8 N.	6 E.	5	0.3 mile north and 0.6 mile east of SE. corner of Sec. 5. Owner, E. S. Bartell	Nov. 1, 1929 Oct. 21, 1930 Dec. 9, 1931	22.2 22.2 22.4
161	Winters	8 N.	1 W.	22	About center of N½ of NW¼ of frac. Sec. 22. Owner, A. S. Bard	Dec. 20, 1929 Oct. 10, 1930 Nov. 20, 1931	36.0 35.5 43.0
162	Winters	8 N.	1 W.	13	In SW. corner of NE¼ of frac. Sec. 13, north of Los Putos Grant line. Owner, L. W. Joerger	Dec. 20, 1929 Oct. 10, 1930 Nov. 20, 1931	27.7 26.2 30.5
163	Merritt	8 N.	1 E.	12	0.1 mile west of SE. corner of Sec. 12. Owners, Geo. Mellott and Fred Lowe	Dec. 20, 1929 Oct. 11, 1930 Nov. 20, 1931	21.3 24.8 28.3
164 A	Swingle	8 N.	2 E.	13	0.1 mile east of center of N½ of Sec. 13. Owner, Cary Montgomery	Jan. 3, 1930 Oct. 10, 1930 Nov. 19, 1931	15.5 22.4 22.0

[1] Projected.

DEPTHS TO GROUND WATER AT TYPICAL WELLS IN SACRAMENTO VALLEY—1929-1931—Continued

Well No.	Well location					Date of measurement	Depth to water from ground surface, in feet
	Quadrangle of United States Geological Survey	Township	Range	Section	Description		
164 B	Swingle	8 N.	2 E.	13	In center of N½ of Sec. 13	Jan. 3, 1930 Oct. 10, 1930 Nov. 19, 1931	14.0 19.7 21.0
165	Swingle	8 N.	3 E.	9	0.3 mile south of NW. corner of Sec. 9	Jan. 3, 1930	6.8
165 A	Swingle	8 N.	3 E.	9	0.3 mile east and 0.1 mile south of NW. corner of Sec. 9	Jan. 3, 1930 Oct. 10, 1930 Nov. 19, 1931	7.5 9.6 9.0
166	Lovdal	8 N.	4 E.	16	4 miles from M St. Bridge on S. N. R.R. near Jefferson Station. Owner, B. Mente	Jan. 3, 1930 Oct. 24, 1930 Nov. 19, 1931	5.8 6.0 6.2
167	Brighton	8 N.	5 E.	30	200 feet southwest of NE. corner of Sec. 30. Owner, O. E. Coughlin	Nov. 1, 1929 Oct. 24, 1930 Dec. 10, 1931	28.0 27.3 27.9
168	Brighton	8 N.	5 E.	13	0.2 mile north of SW. corner of Sec. 13. Owners, Earl and Byron Davis	Nov. 4, 1929	61.0
168 A	Brighton	8 N.	5 E.	24	0.2 mile east and 100 feet south of NW. corner of Sec. 24. Owners, Earl and Byron Davis	Oct. 22, 1930 Dec. 9, 1931	39.3 41.0
169	Mills	8 N.	6 E.	20	200 feet north of Walsh Station (crossroads). Owner, P. A. Johnson	Nov. 4, 1929 Oct. 22, 1930 Dec. 9, 1931	38.5 40.5 40.7
170	Mills	8 N.	7 E.	18	0.1 mile southeast of NW. corner of Sec. 18. Owner, Natomas Company	Nov. 4, 1929 Oct. 21, 1930 Dec. 9, 1931	74.0 74.5 73.8
171	Dixon	8 N.	2 E.	32	In NW. corner of S½ of Sec. 32. Owner, Robert Collier	Dec. 21, 1929 Oct. 11, 1930 Nov. 19, 1931	30.3 32.3 34.0
172	Saxon	7 N.	2 E.	12	In the NE. part of NW¼ of Sec. 12. Owner, Maxwell Brothers	Dec. 20, 1929 Oct. 10, 1930 Nov. 19, 1931	12.2 11.1 11.8

173	Saxon	7 N.	3 E.	4	0.1 mile northeast of SW. corner of Sec. 4. Owner, Mrs. L. Childers	Jan. 3, 1929 Oct. 10, 1930 Nov. 19, 1931	16.0 16.4 19.0
174	Babel Slough	7 N.	4 E.	11	Near center of Sec. 11 on north side of Sacramento River. Owner, L. G. Klotz	Jan. 3, 1930 Oct. 24, 1930 Dec. 7, 1931	11.8 14.0 14.7
175	Florin	7 N.	5 E.	2	0.1 mile southeast of NW. corner of Sec. 2. Owner, Jas. Rutter Est.	Nov. 5, 1929 Oct. 22, 1930 Dec. 7, 1931	34.0 33.8 34.0
176	Elk Grove	7 N.	6 E.	5	In NE. corner of W½ of Sec. 5. Owner, T. Lewis Est.	Nov. 5, 1929 Oct. 22, 1930 Dec. 7, 1931	41.0 42.4 43.0
177	Buffalo Creek	8 N.	7 E.	32	0.4 mile south of NW. corner of Sec. 32	Nov. 5, 1929 Oct. 22, 1930 Dec. 9, 1931	47.5 48.4 48.5
178	Wolfskill	7 N.	1 E.	18	0.2 mile south of NW. corner of Sec. 18. Owner, Stolp Brothers	Dec. 21, 1929 Oct. 11, 1930 Nov. 20, 1931	34.6 37.4 36.5
179	Dixon	7 N.	1 E.	14	At about center of NE¼ of Sec. 14. Owner, Carl Schmeiser	Dec. 21, 1929 Oct. 11, 1930 Nov. 20, 1931	44.0 46.3 51.0
180	Dixon	7 N.	2 E.	21	At about center of W½ of Sec. 21. Owner, Asa Peake Est.	Dec. 21, 1929 Oct. 11, 1930 Nov. 19, 1931	25.0 24.7 25.6
181	Florin	7 N.	5 E.	8	0.1 mile south of E. and W. center line of Sec. 8, 150 feet east of Lower Stockton Road. Owner, Fred Seymour.	Nov. 14, 1929 Oct. 24, 1930 Dec. 7, 1931	21.4 21.7 23.4
182	Wolfskill	7 N.	1 E.	30	In SW. corner of Sec. 30. Owner, Geo. Gardner	Dec. 20, 1929 Oct. 11, 1930 Nov. 20, 1931	30.8 31.9 33.0
183	Florin	7 N.	5 E.	32	400 feet south of E. and W. center line of Sec. 32, 150 feet west of Lower Stockton Road. Owner, J. Elliott Co.	Nov. 11, 1929 Oct. 23, 1930 Dec. 7, 1931	21.9 22.9 24.1
184	Elk Grove	7 N.	6 E.	31	200 feet north of SW. corner of Sec. 31. Owner, Musz Brothers	Nov. 5, 1929 Oct. 22, 1930 Dec. 7, 1931	37.0 38.1 38.5

[1] Projected.

DEPTHS TO GROUND WATER AT TYPICAL WELLS IN SACRAMENTO VALLEY—1929-1931—Continued

Well No.	Well location					Date of measurement	Depth to water from ground surface, in feet
	Quadrangle of United States Geological Survey	Township	Range	Section	Description		
185	Elk Grove	7 N.	6 E.	22	0.2 mile west of SE. corner of Sec. 22. Owner, A. G. Daley	Nov. 5, 1929 Oct. 22, 1930 Dec. 7, 1931	39.5 39.6 41.5
186	Saxon	6 N.	2 E.	1	0.4 mile west of NE. corner of Sec. 1	Dec. 27, 1929 Oct. 10, 1930 Nov. 19, 1931	8.7 6.4 9.8
187	Elmira	6 N.	1 W.	13	In SE. corner of Sec. 13	Dec. 20, 1929 Oct. 11, 1930 Nov. 23, 1931	20.3 22.0 24.0
188	Main Prairie	6 N.	1 E.	23	In NE. corner of Sec. 23	Dec. 15, 1929 Oct. 10, 1930 Nov. 23, 1931	11.5 13.2 13.5
189	Bruceville	6 N.	5 E.	17	0.1 mile south of center of Sec. 17, west of Lower Stockton Road. Owner, Ed Kloss	Nov. 14, 1929 Oct. 23, 1930 Dec. 7, 1931	19.5 20.8 21.8
190	Galt	6 N.	6 E.	[1]20	0.2 mile southeast of NW. corner of Sec. 20. Owner, A. Padovan.	Nov. 12, 1929 Oct. 22, 1930	21.8 22.1
190 A	Galt	6 N.	6 E.	20	75 feet south of McConnell Station on S.P. R.R. between State Highway and railroad	Dec. 9, 1931	22.0
191	Elmira	5 N.	1 W.	11	In NW. part of Sec. 11, 100 feet west of railroad, 0.1 mile south of N. line of Section. Owner, J. H. McDonald.	Dec. 27, 1929 Oct. 11, 1930 Nov. 23, 1931	11.4 13.4 16.5
192	Maine Prairie	6 N.	2 E.	29	0.2 mile north of SW. corner of Sec. 29. Owner, Mrs. Jas. McNeill	Dec. 27, 1929 Oct. 10, 1930 Nov. 23, 1931	9.2 10.5 11.3
193	Bruceville	5 N.	5 E.	3	In the SE. corner of NW¼ of Sec. 3. Owner, Emil Obrist	Nov. 14, 1929 Dec. 30, 1930 Dec. 7, 1931	18.1 18.3 18.8

194	Denverton	4 N.	1 E.	5	In center of NW¼ of Sec. 5, 0.3 mile east of Denverton. Owner, C. M. Engell	Dec. 27, 1929	8.4
						Oct. 11, 1930	12.5
						Nov. 23, 1931	23.5
195	Birds Landing	5 N.	1 E.	36	0.1 mile southwest of NE. corner of Sec. 36	Dec. 27, 1929	15.2
						Oct. 10, 1930	16.1
						Nov. 23, 1931	16.0
196	Rio Vista	4 N.	2 E.	1	About 0.3 mile north of SE. corner of Sec. 1. Owner, E. E. and M. I. Church	Dec. 27, 1929	6.5
						Oct. 10, 1930	6.7
						Nov. 23, 1931	8.7

[1] Projected.

APPENDIX H

ADEQUACY OF INITIAL AND ULTIMATE MAJOR UNITS OF STATE WATER PLAN IN SACRAMENTO RIVER BASIN IN THE YEARS 1929, 1930 AND 1931

TABLE OF CONTENTS

ADEQUACY OF INITIAL AND ULTIMATE MAJOR UNITS OF STATE WATER PLAN IN SACRAMENTO RIVER BASIN IN THE YEARS 1929, 1930 AND 1931

The water supply studies pertaining to the State Water Plan in the Sacramento River Basin, and contained in the body of this report, are based on the estimated and measured surface run-offs which have occurred during the 40-year period extending from October 1, 1889, to October 1, 1929. This period is one of wide variability in run-off. It includes not only years of plenteous run-off but also ones of paucity in supply. For example, in the flood years of 1907 and 1909, the seasonal run-offs from the drainage basin are estimated at 41,691,000 acre-feet and 38,737,000 acre-feet, respectively, more than one and one-half times the estimated mean annual run-off for the 40-year period. In 1889–1890, the seasonal run-off is estimated at 63,563,000 acre-feet, two and one-half times the average for the period. On the other hand, during the 40-year period, there were years and consecutive years during which the run-off was far below the average. The season of lowest run-off for the period is 1923-1924 with a run-off of 6,623,000 acre-feet. It is believed from a study of precipitation records that that season is the one of lowest run-off since 1871, and probably since 1850. It should be mentioned, also, that the smallest combined run-off for periods up to five consecutive seasons, from 1871 to 1929, probably occurred during this 40-year period.

At the initiation of the State investigations in the latter part of 1929, this 40-year period was selected after careful consideration as the one on which to base the water supply analyses. Therefore, the sizes of the reservoirs of the State Water Plan in both the Sacramento and San Joaquin river basins were proportioned and the yields therefrom in regulated water and in hydroelectric power were estimated on the volumes and characteristics of the available flows during that period.

The adequacy of the major units proposed both for the initial and ultimate developments was tested by monthly analyses throughout the 40-year period. It was found that the 11-year period 1918–1929 was the critical one of lowest run-off and actually determined the sizes and adequacy of the units. It was ascertained by these tests that the units of the State Water Plan in the Sacramento River Basin in conjunction with those proposed in the San Joaquin River Basin would have accomplished the objectives of the initial and ultimate developments of the State Water Plan. The results of these tests and the accomplishments of the plan are set forth in Chapters X and XI of this bulletin.

Since the completion of the studies which were based on available water supplies for the 40-year period 1889–1929, and on which the major units of the State Water Plan for initial and ultimate development were proportioned, two seasons of low run-off have occurred, namely 1929–1930 and 1930–1931. Therefore, it was deemed desirable to test further the adequacy of the plans proposed for initial and ultimate development in the Sacramento River Basin by the inclusion of these years in the water supply analyses and, if either plan were found inadequate, to point out wherein, if possible, a modification of it could be made which would assure dependable supplies of water to all areas served by the plans. This has been done and the results of the analyses and investigations are given in this appendix.

There also is given herein an analysis for the Sacramento River Basin, the San Joaquin River Basin, and the combined basins, of the probability of occurrence of seasonal run-offs of various magnitudes. This is presented for the purpose of indicating the probable frequency with which the low seasonal run-offs of the past few years might be expected to occur in the future and, therefore, of indicating further the adequacy of the plans.

Water Supply.

The water supplies—full natural, and ultimate and present net run-offs—from the Sacramento River Basin streams for the seasons 1929–1930 and 1930–1931 were estimated by the methods described in Chapter II. The full natural and ultimate net run-offs at the dam sites for the major reservoir units of the State Water Plan in the basin, and the present net run-offs at those on the larger streams, were estimated by the methods described in Chapters II and IX.

Indices of Seasonal Wetness.—In order to estimate the run-offs from some of the unmeasured streams, and also to obtain a comparison of the precipitation in the seasons of 1929–1930 and 1930–1931 with that in other seasons and with the mean, indices of seasonal wetness were computed for the precipitation divisions lying wholly or partially in the Sacramento River Basin. In calculating the values of these indices, the mean precipitation for each station or division was taken as that for the 50-year period 1871–1921. The indices for each division for the seasons 1929–1930 and 1930–1931 are shown in Table H-1 which is an extension of Table 3 in Chapter II.

TABLE H-1

INDICES OF SEASONAL WETNESS FOR SACRAMENTO RIVER BASIN

Season	Index of wetness in division						
	A	B	F	G	H	J	M
1929-30	70	79	88	85	81	71	83
1930-31	49	58	61	55	57	57	59

Full Natural Run-offs.—The seasonal full natural run-offs from the mountain and foothill drainage basins of the major streams and minor streams, or groups of minor streams, of the Sacramento River Basin, for the seasons 1929–1930 and 1930–1931, are shown in Table H-2 which is an extension of Table 5 in Chapter II. This table also includes the 40-, 20-, 10- and 5-year means given in Table 5. Mean seasonal run-offs also are shown in the table for the 42-year period 1889–1931, the 22-year period 1909–1931, the 12-year period 1919–1931, and the 7-year period 1924–1931.

TABLE H-2

SEASONAL FULL NATURAL RUN-OFFS OF SACRAMENTO RIVER BASIN STREAMS

Run-off in acre-feet

Stream or stream group	Drainage area, in square miles	Mean for 40-year period 1889–1929	Mean for 20-year period 1909–1929	Mean for 10-year period 1919–1929	Mean for 5-year period 1924–1929	1929–1930	1930–1931	Mean for 42-year period 1889–1931	Mean for 22-year period 1909–1931	Mean for 12-year period 1919–1931	Mean for 7-year period 1924–1931
MAJOR STREAMS—											
Sacramento River at Kennett dam site[1]	6,649	6,149,000	5,379,000	4,745,000	5,060,000	4,390,000	2,614,000	6,023,000	5,208,000	4,538,000	4,615,000
Sacramento River at Red Bluff	9,258	9,354,000	7,898,000	6,775,000	7,351,000	6,094,000	3,322,000	9,133,000	7,608,000	6,430,000	6,596,000
Feather River at Oroville	3,627	5,201,000	4,271,000	3,594,000	3,652,000	3,907,000	1,470,000	5,081,000	4,127,000	3,443,000	3,377,000
Yuba River near Smartsville	1,200	2,653,000	2,240,000	2,083,000	2,143,000	1,815,000	645,000	2,585,000	2,148,000	1,941,000	1,882,000
Bear River at Van Trent	262	402,000	328,000	298,000	298,000	205,000	67,300	389,000	311,000	271,000	252,000
American River at Fairoaks	1,919	3,069,000	2,624,000	2,267,000	2,285,000	1,656,000	715,000	2,979,000	2,493,000	2,087,000	1,970,000
Stony Creek at mouth of canyon	710	514,000	379,000	316,000	386,000	248,000	90,200	498,000	360,000	292, 00	324,000
Cache Creek at Capay dam site	996	762,000	595,000	531,000	634,000	569,000	97,300	742,000	571,000	498,000	548,000
Putah Creek at Winters	655	442,000	332,000	273,000	324,000	325,000	34,200	430,000	318,000	257,000	283,000
Totals	18,627	22,397,000	18,667,000	16,137,000	17,073,000	14,819,000	6,441,000	21,837,000	17,936,000	15,219,000	15,232,000
MINOR STREAMS[2]—											
Mill Creek Group	971	1,131,000	903,000	809,000	872,000	920,000	390,000	1,108,000	880,000	783,000	810,000
Butte Creek Group	251	464,000	357,000	332,000	337,000	385,000	165,000	455,000	350,000	323,000	319,000
Honcut Creek Group	314	194,000	144,000	125,000	138,000	142,000	63,600	189,000	140,000	121,000	128,000
Dry Creek	79	48,600	38,800	35,600	37,100	35,500	16,900	47,500	37,700	34,000	34,000
Coon Creek Group	210	34,700	25,500	23,300	23,300	12,300	5,600	33,500	24,000	20,900	19,200
Red Bank Creek Group	109	79,400	68,700	67,500	79,300	55,800	25,500	77,600	66,200	63,000	68,300
Elder Creek Group	414	352,000	302,000	305,000	368,000	176,000	57,900	341,000	285,000	274,000	296,000
Willow Creek Group	394	100,000	86,900	85,300	99,600	67,200	34,000	97,600	83,600	79,500	85,600
Totals	2,742	2,403,700	1,925,900	1,782,700	1,954,300	1,793,800	758,500	2,349,200	1,866,500	1,698,400	1,760,100
Grand totals	21,369	24,800,700	20,592,900	17,919,700	19,027,300	16,612,800	7,199,500	24,186,200	19,802,500	16,917,400	16,992,100

[1] The amounts shown for the drainage area and run-offs for the Sacramento River at Kennett dam site are not used in obtaining the totals since these amounts are included in those for the Sacramento River at Red Bluff.

[2] See Table 5 in Chapter II for streams included in each group.

The seasonal full natural run-offs at the dam sites for the major reservoir units of the State Water Plan in the Sacramento River Basin, for the seasons 1929–1930 and 1930–1931, are shown in Table H-3.

Ultimate Net Run-offs.—The ultimate net run-offs for the seasons 1929–1930 and 1930–1931 at the dam sites for the major reservoir units of the State Water Plan in the Sacramento River Basin are also shown in Table H-3. These ultimate net run-offs are those that could have been expected under conditions of ultimate impairment by diversions and storage for ultimate irrigation developments and the present power developments, upstream from each dam site.

Present Net Run-offs.—The present net run-offs for the seasons 1929–1930 and 1930–1931 at the dam sites for the major reservoir units at which the construction of power plants is proposed in the State Water Plan for the Sacramento River Basin are also shown in Table H-3. These present net run-offs are those that could have been expected under conditions of present impairment by diversions and storage for present irrigation developments and the present power developments, upstream from each dam site.

TABLE H-3

SEASONAL RUN-OFFS AT DAM SITES FOR MAJOR RESERVOIRS

Stream	1929-30			1930-31		
	Full natural run-off, in acre-feet	Present net run-off, in acre-feet	Ultimate net run-off, in acre-feet	Full natural run-off, in acre-feet	Present net run-off, in acre-feet	Ultimate net run-off, in acre-feet
Sacramento River at Red Bluff	6,094,000	5,815,000	5,391,000	3,322,000	3,177,000	3,111,000
Sacramento River at Kennett dam site	4,390,000	4,206,000	3,999,000	2,614,000	2,551,000	2,582,000
Feather River at Oroville	3,907,000	3,588,000	3,940,000	1,470,000	1,492,000	1,572,000
Yuba River at Narrows dam site	1,757,000	1,436,000	1,228,000	628,000	463,000	255,000
Bear River at Camp Far West dam site	205,000	------------	154,000	67,300	------------	53,700
American River at Folsom dam site	1,644,000	1,653,000	1,513,000	711,000	721,000	581,000
North Fork of American River at Auburn dam site	1,004,000	992,000	841,000	429,000	425,000	267,000
South Fork of American River at Coloma dam site	574,000	562,000	512,000	262,000	250,000	200,000
Stony Creek at Millsite dam site	208,000	------------	125,000	75,700	------------	46,800
Cache Creek at Capay dam site	569,000	------------	133,000	97,300	------------	5,300
Putah Creek at Monticello dam site	308,000	------------	270,000	32,500	------------	23,100
Trinity River at Fairview dam site	815,000	------------	711,000	402,000	------------	335,000

Adequacy of Kennett Reservoir As an Initial Unit.

In Chapter XI, four methods of operation of the initial Kennett reservoir unit of the State Water Plan are described and the accomplishments of the unit in conjunction with other units of the initial plan are given for each method. The studies on which the accomplishments for the immediate initial development (Method II) and complete initial development (Method III) were based, covered the ten years 1919 to 1928, inclusive. However, power outputs for these methods of operation were estimated for the 40-year period 1890–1929, inclusive. In testing the adequacy of the Kennett reservoir through the years 1929, 1930 and 1931, studies were made for Methods II and III. The methods of operation and accomplishments are as follows:

Immediate Initial Development—Method II.—With operation under this method, space would have been reserved in the reservoir during the flood season for flood control, and stored water would have been released in such manner as to supplement the flows from unregulated streams in the Sacramento River Basin or those regulated by present developments, from return irrigation waters in the Sacramento Valley, and from inflows to the Sacramento-San Joaquin Delta from the San Joaquin River Basin under conditions with the immediate initial development* of the State Water Plan in that basin in operation, to make supplies available for irrigation, navigation, salinity control and the generation of power. The following would have been accomplished:

1. The space reserved in the reservoir each season for flood control would have prevented flood flows from exceeding 125,000 second-feet at Red Bluff.
2. A navigable depth of five to six feet would have been maintained in the Sacramento River from the city of Sacramento to Chico Landing, with a substantial increase in depths from the latter point to Red Bluff.
3. Irrigation demands on the Sacramento River above Sacramento would have been supplied, without deficiency, up to 6000 second-feet maximum draft in July. A full irrigation supply would have been furnished in all years to all lands along the Sacramento River above the delta. There would have been about 700,000 acre-feet more water available, distributed in accordance with the irrigation demand, for these lands in 1931.
4. A supply of 1,083,000 acre-feet per season, without deficiency, would have been furnished the Sacramento-San Joaquin Delta for its present requirements.
5. A fresh water flow of not less than 3,300 second-feet would have been maintained past Antioch into Suisun Bay, controlling salinity to the lower end of the Sacramento-San Joaquin Delta.
6. A water supply of 44,000 acre-feet per year, without deficiency, would have been made available in the delta for the developed industrial and agricultural areas along the south shore of Suisun Bay in Contra Costa County.
7. The average annual output in hydroelectric energy, generated incidental to other uses, in the 42-year period 1890–1932, would have been 1,572,400,000 kilowatt hours.

By comparing the foregoing accomplishments with those set forth for Method II, in Chapter XI, it may be seen that they are identical except in the matter of power output of the unit. In this particular the inclusion of the power outputs for the three years 1929, 1930 and 1931 would have reduced the average annual output from 1,591,800,000 kilowatt hours for the 40-year period 1890–1930 to 1,572,400,000 kilowatt hours for the 42-year period 1890–1932, or 1.3 per cent. The other objectives sought to be accomplished by the Kennett reservoir in the immediate initial development would have been fully met during the years 1929, 1930 and 1931. The accomplishments are summarized in Table II-6 in which a comparison of performance in the years 1919–1928, inclusive, and 1919–1931, inclusive, also is made.

* Friant reservoir, San Joaquin River-Kern County canal, Madera canal, and Magunden-Edison pumping system constructed.

TABLE H-4

ANNUAL SURPLUS OF WATER IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH KENNETT RESERVOIR OPERATED AS AN INITIAL UNIT UNDER METHOD II

1919-1932

Year	Net flow into delta, in acre-feet[1]			Drafts from net flow into delta, in acre-feet				Surplus water above all drafts, in acre-feet	Total run-off into Suisun Bay, in acre-feet
	From Sacramento Valley	From San Joaquin Valley	Total from both valleys	Total gross allowance for delta	Salinity control to lower end of delta	Industrial and irrigation use in developed areas along south side of Suisun Bay	Total		
1919	16,295,000	2,769,000	19,064,000	1,083,000	2,389,000	44,000	3,516,000	15,548,000	17,937,000
1920	12,665,000	2,312,000	14,977,000	1,083,000	2,395,000	44,000	3,522,000	11,455,000	13,850,000
1921	21,998,000	4,440,000	26,438,000	1,083,000	2,389,000	44,000	3,516,000	22,922,000	25,311,000
1922	19,727,000	6,997,000	26,724,000	1,083,000	2,389,000	44,000	3,516,000	23,208,000	25,597,000
1923	12,346,000	4,116,000	16,462,000	1,083,000	2,389,000	44,000	3,516,000	12,946,000	15,335,000
1924	6,439,000	1,108,000	7,547,000	1,083,000	2,395,000	44,000	3,522,000	4,025,000	6,420,000
1925	15,952,000	3,432,000	19,384,000	1,083,000	2,389,000	44,000	3,516,000	15,868,000	18,257,000
1926	15,229,000	2,190,000	17,419,000	1,083,000	2,389,000	44,000	3,516,000	13,903,000	16,292,000
1927	24,903,000	4,688,000	29,591,000	1,083,000	2,389,000	44,000	3,516,000	26,075,000	28,464,000
1928	17,071,000	3,295,000	20,366,000	1,083,000	2,395,000	44,000	3,522,000	16,844,000	19,239,000
1929	9,835,000	1,497,000	11,332,000	1,083,000	2,389,000	44,000	3,516,000	7,816,000	10,205,000
1930	12,267,000	1,638,000	13,905,000	1,083,000	2,389,000	44,000	3,516,000	10,389,000	12,778,000
1931	7,272,000	553,000	7,825,000	1,083,000	2,389,000	44,000	3,516,000	4,309,000	6,698,000
Averages	14,769,000	3,003,000	17,772,000	1,083,000	2,390,000	44,000	3,517,000	14,255,000	16,645,000

[1] Includes regulated water from Kennett, Friant and existing reservoirs, unregulated run-off and return waters.

Table H-4 shows for each year from 1919 to 1931, inclusive, with Kennett reservoir operated under Method II, the net amounts of water reaching the Sacramento-San Joaquin Delta annually, the amount drawn from this supply for all purposes in the delta, the amount of water which would have flowed past Antioch into Suisun Bay for salinity control, the amount of water available for irrigation and industrial use in the San Francisco Bay Basin, the surplus water which would have reached the delta in addition to that for the foregoing uses, and the total amount of water which would have flowed into Suisun Bay, including that for salinity control.

It may be seen by comparing corresponding items in Table H-4 with those in Table 148 in Chapter XI that the values for net flows from the Sacramento Valley into the delta, for the surplus water above all drafts and for the total flows into Suisun Bay are slightly different. These differences are due entirely to changes in the amounts of water released from the Kennett reservoir in order to obtain a more favorable power output.

Table H-5 shows the distribution of the surpluses and flows into Suisun Bay, by months, in the years of maximum and minimum run-off, and the average for the whole period. This table is comparable with Table 149, in Chapter XI, which gives corresponding data for the ten-year period 1919 to 1928, inclusive.

TABLE H-5

MONTHLY DISTRIBUTION OF SURPLUS WATER IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH KENNETT RESERVOIR OPERATED AS AN INITIAL UNIT UNDER METHOD II

1919-1932

Month	Year of maximum total run-off into delta, 1927		Year of minimum total run-off into delta, 1924		Average for period 1919–1932	
	Surplus water above all drafts, in acre-feet	Run-off into Suisun Bay, in acre-feet	Surplus water above all drafts, in acre-feet	Run-off into Suisun Bay, in acre-feet	Surplus water above all drafts, in acre-feet	Run-off into Suisun Bay, in acre-feet
January	2,711,000	2,914,000	526,000	729,000	1,573,000	1,776,000
February	7,513,000	7,697,000	958,000	1,148,000	2,699,000	2,884,000
March	3,883,000	4,086,000	494,000	697,000	2,461,000	2,664,000
April	4,066,000	4,262,000	410,000	606,000	2,136,000	2,332,000
May	2,904,000	3,107,000	64,000	267,000	1,854,000	2,057,000
June	1,853,000	2,049,000	10,000	206,000	906,000	1,102,000
July	239,000	442,000	0	203,000	164,000	367,000
August	118,000	321,000	0	203,000	74,000	277,000
September	177,000	373,000	38,000	234,000	138,000	334,000
October	348,000	551,000	196,000	399,000	307,000	510,000
November	1,097,000	1,293,000	568,000	764,000	716,000	912,000
December	1,166,000	1,369,000	761,000	964,000	1,227,000	1,430,000
Totals	26,075,000	28,464,000	4,025,000	6,420,000	14,255,000	16,645,000

Complete Initial Development—Method III.—With operation under this method, space would have been reserved in the reservoir during the flood season for flood control, and stored water would have been released in such manner as to supplement the flows from unregulated streams in the Sacramento River Basin or those regulated by present developments, from return irrigation waters in the Sacramento Valley, and from inflows to the Sacramento-San Joaquin Delta from the San Joaquin River Basin under conditions with the complete initial development* of the State Water Plan in that basin in operation, to make supplies available for irrigation, navigation, salinity control and the generation of power. The following would have been accomplished:

Items 1, 3, 4, 5 and 6 same as under Method II.

2. A navigable depth of five to six feet would have been maintained in the Sacramento River from the city of Sacramento to Chico Landing, with a substantial increase in depth from the latter point to Red Bluff, except in 1931. In that year there would have been a maximum monthly deficiency of 30 per cent with a decrease in navigable depths of a lesser percentage.
7. An irrigation supply of 896,000 acre-feet annually, without deficiency in any year except 1931, would have been made available in the Sacramento-San Joaquin Delta** to supply the "crop lands"† now being served from the San Joaquin River about the mouth of the Merced River. The deficiency in 1931 would have been 35 per cent of the full irrigation supply through the months May to September, inclusive. The deficiency in the annual supply would have been 25 per cent. Even with this deficiency the "crop lands" would have received 200,000 acre-feet, or 43 per cent, more water than would have been available to them under present conditions of supply.
8. The average annual output in hydroelectric energy, generated incidental to other uses, in the 42-year period 1890–1932, would have been 1,558,600,000 kilowatt hours.

By comparing the foregoing accomplishments with those set forth for Method III in Chapter XI, it may be seen that they are identical except in the items of irrigation supply for the "crop lands" in the San Joaquin Valley, the maintenance of navigation on the Sacramento River, and the power output of the unit. In these particulars, the inclusion of the three years 1929, 1930 and 1931 would have somewhat reduced the accomplishments. The average annual energy output would have been reduced from 1,581,100,000 kilowatt hours for the 40-year period 1890 to 1929, inclusive, to 1,558,600,000 kilowatt hours for the 42-year period 1890 to 1931, inclusive, or about 1.4 per cent. The supply to the "crop lands" would have had bearable deficiencies of 35 per cent from May to September, inclusive, in 1931 and of 25 per cent for the year. There would also have been a maximum monthly deficiency in the flow required for navigation in the Sacramento River of 30 per cent, with a decrease in navigable depths of a lesser percentage. The other objectives sought to be accomplished by the Kennett reservoir unit in the complete initial development would have been fully met, however, in the years 1919 to 1931, inclusive. The accomplishments are summarized in Table H-6 in which a comparison of performance in the years 1919 to 1928, inclusive, and 1919 to 1931, inclusive, also is shown.

* Friant reservoir, San Joaquin River-Kern County canal, Madera canal, Magunden-Edison pumping system, San Joaquin River pumping system, and Sacramento-San Joaquin cross channel constructed.

** See footnote (1) to Table H-7.

† See footnote (2) to Table H-7.

TABLE H-6

SUMMARY COMPARISON OF PERFORMANCE OF KENNETT RESERVOIR OPERATED AS AN INITIAL UNIT OF STATE WATER PLAN IN CRITICAL PERIODS 1919-1929 AND 1919-1932 OF FORTY-TWO YEAR PERIOD 1890-1932

Item	Accomplishments			
	Immediate initial development		Complete initial development	
	1919-1929	1919-1932	1919-1929	1919-1932
1. Floods controlled to 125,000 second-feet flow at Red Bluff	No exceedence	No exceedence	No exceedence	No exceedence
2. A navigable depth of five to six feet maintained in the Sacramento River from Sacramento to Chico Landing with a substantial increase in depths from the latter point to Red Bluff.	Fully maintained in all years	Fully maintained in all years	Fully maintained in all years	Fully maintained in all years except 1931. In 1931, there would have been a maximum monthly deficiency of 30 per cent, with a decrease in navigable depths of a lesser percentage.
3. Irrigation demands on the Sacramento River above Sacramento supplied up to 6,000 second-feet maximum draft in July.	Full supply in all years	Full supply in all years	Full supply in all years	Full supply in all years
4. A supply of 1,083,000 acre-feet per season furnished the Sacramento-San Joaquin Delta for its present requirements.	Full supply in all years	Full supply in all years	Full supply in all years	Full supply in all years
5. A fresh water flow of 3,300 second-feet maintained past Antioch into Suisun Bay to control salinity to the lower end of the Sacramento-San Joaquin Delta.	Full supply in all years	Full supply in all years	Full supply in all years	Full supply in all years
6. A water supply of 44,000 acre-feet annually made available in the delta for the developed industrial and agricultural areas along the south shore of Suisun Bay in Contra Costa County.	Full supply in all years	Full supply in all years	Full supply in all years	Full supply in all years
7. An irrigation supply of 896,000 acre-feet annually made available in the delta for a supply for the "crop lands [3]" now being served from the San Joaquin River above the mouth of the Merced River.	----------	----------	Full supply in all years	Full supply in all years except 1931. Deficiency in 1931 of 35 per cent from May to September, inclusive, and 25 per cent for year.
8. An average annual hydroelectric energy output in kilowatt hours from the Kennett reservoir unit, of	[1]1,591,800,000	[2]1,572,400,000	[1]1,581,100,000	[2]1,558,600,000

[1] Mean for 40-year period 1890-1929, inclusive.
[2] Mean for 42-year period 1890-1931, inclusive.
[3] See footnotes (1) and (2) to Table II-7.

TABLE H-7

ANNUAL SURPLUS OF WATER IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH KENNETT RESERVOIR OPERATED AS AN INITIAL UNIT UNDER METHOD III

1919–1932

Year	Net flow into delta, in acre-feet[1]			Drafts from net flow into delta, in acre-feet					Surplus water above all drafts, in acre-feet	Total run-off into Suisun Bay, in acre-feet
	From Sacramento Valley	From San Joaquin Valley	Total from both valleys	Total gross allowance for delta	Salinity control to lower end of delta	Irrigation supply for "crop lands" in San Joaquin Valley having rights to water to be diverted at Friant[2]	Industrial and irrigation use in developed areas along south side of Suisun Bay	Total		
1919	16,337,000	2,769,000	19,106,000	1,083,000	2,389,000	896,000	44,000	4,412,000	14,694,000	17,083,000
1920	12,642,000	2,312,000	14,954,000	1,083,000	2,395,000	896,000	44,000	4,418,000	10,536,000	12,931,000
1921	21,999,000	4,440,000	26,439,000	1,083,000	2,389,000	896,000	44,000	4,412,000	22,027,000	24,416,000
1922	19,728,000	6,997,000	26,725,000	1,083,000	2,389,000	896,000	44,000	4,412,000	22,313,000	24,702,000
1923	12,306,000	4,116,000	16,422,000	1,083,000	2,389,000	896,000	44,000	4,412,000	12,010,000	14,399,000
1924	7,031,000	1,108,000	8,139,000	1,083,000	2,395,000	896,000	44,000	4,418,000	3,721,000	6,116,000
1925	15,407,000	3,432,000	18,839,000	1,083,000	2,389,000	896,000	44,000	4,412,000	14,427,000	16,816,000
1926	15,231,000	2,190,000	17,421,000	1,083,000	2,389,000	896,000	44,000	4,412,000	13,009,000	15,398,000
1927	24,904,000	4,688,000	29,592,000	1,083,000	2,389,000	896,000	44,000	4,412,000	25,180,000	27,569,000
1928	17,126,000	3,295,000	20,421,000	1,083,000	2,395,000	896,000	44,000	4,418,000	16,003,000	18,398,000
1929	9,823,000	1,497,000	11,320,000	1,083,000	2,389,000	896,000	44,000	4,412,000	6,908,000	9,297,000
1930	12,315,000	1,684,000	13,999,000	1,083,000	2,389,000	896,000	44,000	4,412,000	9,587,000	11,974,000
1931	7,043,000	616,000	7,659,000	1,083,000	2,389,000	668,000	44,000	4,184,000	3,475,000	5,864,000
Averages	14,761,000	3,011,000	17,772,000	1,083,000	2,390,000	879,000	44,000	4,396,000	13,376,000	15,766,000

[1] Includes regulated water from Kennett, Friant and existing reservoirs, unregulated run-off and return waters. The amounts shown for the San Joaquin Valley include such portions of these waters intercepted by the San Joaquin River pumping system before reaching the delta as could be used in supplying "crop land" rights in this valley, obviating the pumping of that portion of this supply from the delta.

[2] "Crop lands" are those areas suitable for growing crops which are now served or probably will be served in the near future by diversion from the San Joaquin River above the mouth of the Merced River under existing rights.

Table H-7 shows the same items for the operation of the Kennett reservoir unit under Method III as are shown in Table H-4 for the operation under Method II, except that in this case the amount of water made available for an irrigation supply for lands in the San Joaquin Valley is also shown.

By comparing Table H-7 with Table 150 in Chapter XI, it may be noted that there are no changes in any of the items, including the surplus water above all drafts from the Sacramento-San Joaquin Delta and the total run-off into Suisun Bay, in any of the years from 1919 to 1928, inclusive. In addition, however, Table H-7 includes data for the years 1929, 1930 and 1931.

Table H-8 shows the distribution of the surpluses and flows into Suisun Bay, by months, in the years of maximum and minimum run-off and the average for the whole period 1919 to 1931, inclusive. This table is comparable with Table 151, in Chapter XI, which gives corresponding data for the ten-year period 1919 to 1928, inclusive.

TABLE H-8

MONTHLY DISTRIBUTION OF SURPLUS WATER IN SACRAMENTO-SAN JOAQUIN DELTA AND FLOW INTO SUISUN BAY WITH KENNETT RESERVOIR OPERATED AS AN INITIAL UNIT UNDER METHOD III

1919-1932

Month	Year of maximum total run-off into delta, 1927		Year of minimum total run-off into delta, 1931		Average for period 1919–1932	
	Surplus water above all drafts, in acre-feet	Run-off into Suisun Bay, in acre-feet	Surplus water above all drafts, in acre-feet	Run-off into Suisun Bay, in acre-feet	Surplus water above all drafts, in acre-feet	Run-off into Suisun Bay, in acre-feet
January	2,701,000	2,904,000	605,000	808,000	1,538,000	1,741,000
February	7,486,000	7,670,000	490,000	674,000	2,642,000	2,827,000
March	3,831,000	4,034,000	620,000	823,000	2,394,000	2,597,000
April	3,951,000	4,147,000	214,000	410,000	2,003,000	2,199,000
May	2,745,000	2,948,000	0	203,000	1,711,000	1,914,000
June	1,690,000	1,886,000	0	196,000	767,000	963,000
July	97,000	300,000	0	203,000	72,000	275,000
August	10,000	213,000	0	203,000	3,000	206,000
September	100,000	296,000	0	196,000	74,000	270,000
October	320,000	523,000	40,000	243,000	283,000	486,000
November	1,047,000	1,243,000	229,000	425,000	680,000	876,000
December	1,202,000	1,405,000	1,277,000	1,480,000	1,209,000	1,412,000
Totals	25,180,000	27,569,000	3,475,000	5,864,000	13,376,000	15,766,000

Adequacy of Major Units of State Water Plan for Great Central Valley—Ultimate Development.

The major units for the ultimate development of the Great Central Valley also have been tested for their adequacy in meeting the objectives and water requirements as laid down for the State Water Plan, through the years 1929, 1930 and 1931. In Chapter X, the ultimate plan has been analyzed for three methods of operation, designated as I, II and III, for the years 1918–1928, inclusive. These methods differ primarily in the amount of water which is made available in the Sacramento-San Joaquin Delta for utilization in the San Joaquin River Basin or elsewhere. This amount increases from Method I to II and there is a further increase under Method III. The methods are fully described in Chapter X, to which reference is made. In the analysis for this appendix, Method II only is used as it represents the most logical basis of analysis.

In making this adequacy test extended through 1929, 1930 and 1931, the same methods were employed as were used and described in Chapter X for the period 1918–1928, inclusive. The same methods were employed in estimating the available water supplies. The physical units, both surface storage and conveyance, were identical in type, size and location. The areas to be served, the water requirements for those areas and for other purposes remained unchanged. In making the study through the years 1918 to 1931, inclusive, however, some use was made of ground water in 1924 and 1931 in the areas along the east side of the lower San Joaquin Valley which under the State Water Plan will receive a supply wholly or largely from local sources. Also, an additional draft was made on the available ground water storage in the Upper San Joaquin Valley. The analysis in all studies was made on a month by month basis.

The water supply available for storage and regulation in the major reservoir units was obtained by deducting from the full natural runoffs of the streams entering the Great Central Valley, the net use of 2,283,000 acre-feet per season, or as much thereof as could have been obtained, for an irrigation supply for 1,439,000 acres of lands, being the net irrigable mountain valley and foothill lands lying at elevations too high to be irrigated by gravity from the major reservoir units, thus providing for the ultimate needs of these areas. Also, a supply of 448,000 acre-feet per year, or as much thereof as would have been available, was deducted from the Tuolumne River water for a supply for the city of San Francisco, and 224,000 acre-feet per year, except in 1931 when this supply would have been decreased by required releases for prior rights, was furnished the San Francisco Bay Basin from Pardee reservoir on the Mokelumne River.

In the operation of the plan, space was reserved, during the flood seasons, in the reservoirs listed in Table 139 in Chapter X, for controlling flood flows. The table also furnishes data on the amounts of space so reserved and the sizes of the flows to which floods on each stream would be controlled.

The performance of the State Water Plan in the fourteen-year period 1918–1931, inclusive, operated under Method II, and with the conditions just hereinbefore stated, is set forth in Table H-9. In order that the performance in this period may be compared with that during the eleven-year period 1918–1928, inclusive, for which the adequacy test was previously made and for which the results are given in Chapter X, the accomplishments during this latter period also are set forth in Table H-9. The accomplishments for the period 1918–1928, inclusive, as given in the table, differ slightly, however, from those set forth in Chapter X, because it was assumed that deficiencies in surface supplies in 1924 in the areas along the east side of the San Joaquin Valley would have been made up by drawing upon ground water. Ground water is now utilized to some extent in those areas.

TABLE H-9

SUMMARY COMPARISON OF PERFORMANCE OF STATE WATER PLAN FOR GREAT CENTRAL VALLEY OPERATED UNDER METHOD II—ULTIMATE DEVELOPMENT—IN CRITICAL PERIODS 1918-1929 AND 1918-1932 OF FORTY-TWO-YEAR PERIOD 1890-1932

Item	Accomplishments in period	
	1918-1929	1918-1932
1. A supply of 9,033,000 acre-feet per season, gross allowance, available in the principal streams, for the irrigation of the net area of 2,640,000 acres of irrigable lands of all classes on the Sacramento Valley floor.	Full supply in all years	Full supply in all years except 1931. Deficiencies in that year—seasonal, 32 per cent; maximum in any area, 35 per cent.
2. A supply of 1,200,000 acre-feet per season for the irrigation of all the net area of 392,000 acres of irrigable lands, and for unavoidable losses, in the Sacramento-San Joaquin Delta.	Full supply in all years	Full supply in all years except 1931. Deficiencies in that year—seasonal and maximum monthly, 32 per cent.
3. A fresh water flow of 3300 second-feet past Antioch into Suisun Bay for the control of salinity to the lower end of the delta.	Full supply in all years	Full supply in all years except 1931. Deficiencies in that year—seasonal, 19 per cent; maximum monthly, 32 per cent.
4. A supply of 5,342,000 acre-feet per season, gross allowance, for the irrigation of the net area of 1,810,000 acres of irrigable lands of all classes in the lower San Joaquin Valley, including 134,000 acres of foothills on the eastern side of the valley below the major reservoir units.	Full supply in all years except 1924. Seasonal deficiency of 35 per cent in supply of 896,000 acre-feet for "crop lands[1]" in 1924.	Full supply in all years except 1924 and 1931. Deficiency in 1924 same as shown in preceding column. Deficiencies in 1931—seasonal, 26 per cent; maximum in any area, 35 per cent.
5. A supply of 4,700,000 acre-feet per season for the irrigation of a net area of 2,350,000 acres of class 1 and 2 lands on the eastern and southern slopes of the Upper San Joaquin Valley.	Full supply in all years	Full supply in all years except 1931. Deficiency in that year of 50 per cent in supply for an area of 23,000 acres dependent upon Tule River.
6. A supply of 1,570,000 acre-feet per season for the irrigation of the net irrigable area of 785,000 acres of class 1 and 2 lands lying on the western slope of the Upper San Joaquin Valley.	Full supplies in all years except 1924. Seasonal deficiency of 35 per cent in that year.	Full supply in all years except 1924 and 1931. Seasonal deficiencies in those years, 35 per cent.
7. A water supply and channel depth in the San Joaquin River sufficient to provide a navigable depth of six feet as far upstream as Salt Slough, nine miles above the Merced River.	Fully maintained in all years	Fully maintained in all years.
8. A supply of 403,000 acre-feet per year, in the Sacramento-San Joaquin Delta, for use in the San Francisco Bay Basin. Of this, 80,000 acre-feet are allotted to industrial use and 323,000 acre-feet to irrigation.	Full supply in all years except 1924. Annual deficiency of 35 per cent in 1924 in the irrigation supply.	Full supply in all years except 1924 and 1931. Deficiency in 1924 same as shown in preceding column. Maximum monthly deficiency in 1931—32 per cent in both industrial and irrigation supplies. Annual deficiency in industrial supply, 19 per cent, and in irrigation supply, 30 per cent.

[1] "Crop lands" are those areas suitable for growing crops which are now served or probably will be served in the near future by diversions from the San Joaquin River above the mouth of the Merced River under existing rights.

It may be noted from the accomplishments set forth in Table H-9 for the period 1918–1931, inclusive, that there would have been some deficiencies in 1924 and 1931. It should be noted, however, that in only one relatively small area would the deficiency have exceeded 35 per cent in any month and that in most instances the seasonal or yearly supply would have been much less than 35 per cent deficient. Occasional deficiencies of such magnitude in water supplies are not serious and can be endured.

However, if it should be desirable to have perfect supplies in years of deficient precipitation, or ones with only small and infrequent shortages, the necessary additional water supplies could be obtained in several ways. These supplies could be obtained by increasing the storage capacity in the Sacramento River Basin, by the use of ground water in that basin, by the importation of water from the upper Klamath and Eel rivers, or by a combination of any or all of these methods.

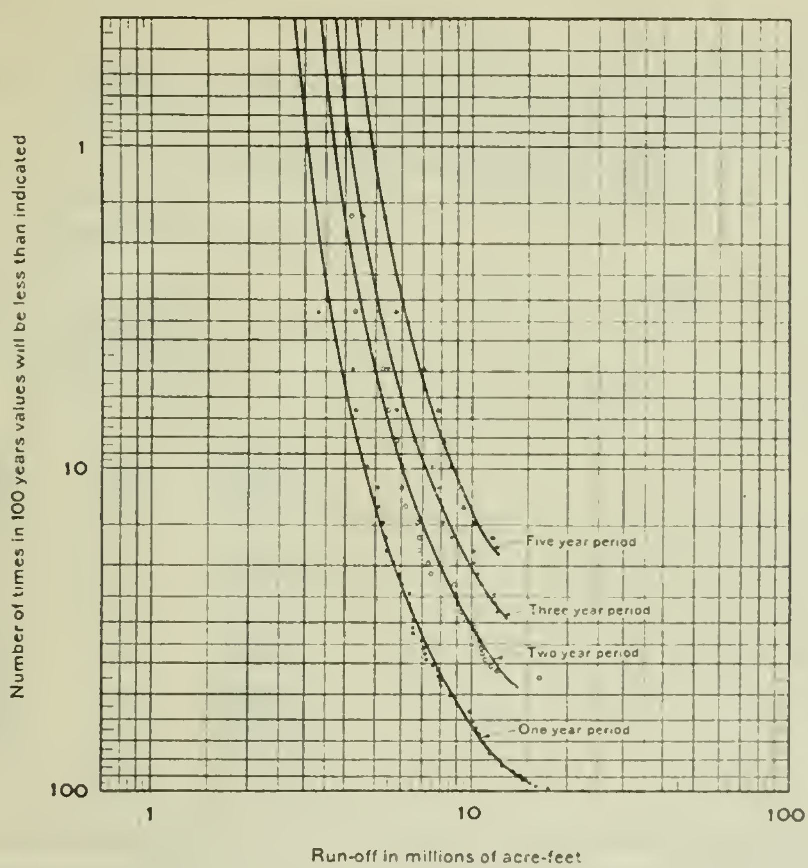
Probable Frequency of Occurrence of Seasons and Consecutive Seasons of Subnormal Run-off.

The adequacy of the units for the initial and ultimate developments of the State Water Plan for the Great Central Valley has been tested through the periods of lowest run-off of record. For the period of 1889–1929, it is found that the units proposed would have furnished adequate and dependable supplies for all purposes and to all areas in accord with the objectives which it was sought to attain in laying down the requirements for the plan. It is found also that the units would have been adequate through the years of subsequent subnormal run-off 1930 and 1931 to furnish a dependable supply although it would have been deficient in some instances about 35 per cent. Such a deficiency occurring only once in the period of analysis is not serious and it is doubtful if it would be economic to provide a perfect supply in a year which would occur so infrequently.

However, it is important to determine as accurately as practicable, the probable frequency of occurrence of seasons and consecutive seasons of low run-off because it is such periods which determine the magnitude and dependability of the water supplies for any particular project. In the Sacramento River Basin, it has been determined that a surplus of water exists over and above the ultimate water requirements. This determination has been based on the records of run-off and precipitation which have occurred since 1889. In order that some idea may be obtained of the magnitude and probable frequency of occurrence of low run-offs from the Sacramento River Basin, and also the San Joaquin River Basin, a study was made utilizing all available information on run-off and precipitation in the two basins. The study was divided into two parts. The first part pertains to the upper Sacramento River on which the Kennett reservoir, the initial unit in the Sacramento River Basin, is located, and the second to the entire Great Central Valley.

Upper Sacramento River Basin.—The upper Sacramento River Basin as herein designated is that portion of the basin lying above the United States Geological Survey gaging station at Red Bluff. Although the Kennett reservoir is located about fifty miles upstream from that point, with 2600 square miles of the entire 9258 square miles of drainage lying downstream from the Kennett dam, nevertheless, the Kennett reservoir has been assumed to be operated so far as practicable to supplement the flows passing Red Bluff. In other words, the unregulated flows originating below Kennett dam have been used in the studies and undoubtedly would be utilized in practice to the fullest practicable extent in the operation of the Kennett reservoir. Therefore, in the analyses of the frequency of occurrence of seasonal run-offs tributary to the Kennett reservoir, those of the Sacramento River at Red Bluff have been used as applying to that reservoir.

PLATE H-I



PROBABLE FREQUENCIES
OF MEAN SEASONAL RUN-OFFS
FROM
UPPER SACRAMENTO RIVER BASIN ABOVE RED BLUFF

The data used in the analyses comprise the seasonal run-offs from October 1, 1871, to October 1, 1932, or a period of 61 years. The values used are full natural run-offs unimpaired by upstream diversion. From 1894 to 1932, the values are based on actual measurements. Prior to 1894, the values have been estimated from developed precipitation–run-off curves using precipitation records in the basin and run-off records at Red Bluff. The reestimated values are given for 1889 to 1894 in this report and for 1871 to 1889 in Table 46, Bulletin No. 5, "Flow in California Streams," Division of Engineering and Irrigation, State Department of Public Works.

Analyses were made to estimate the probable frequency of occurrence of single seasons, and also two, three and five consecutive seasons, of low run-off. In making the analysis for the single season, or one-year periods, the seasonal values of run-off were arranged and numbered in order of increasing magnitude. The number assigned to any particular seasonal run-off value gave the frequency with which seasonal run-offs equal to or less than that particular value had occurred during the period analyzed. These numbers were then converted to values representing frequencies in 100 years. Each frequency value represented the number of times in 100 years which

TABLE H-10

FREQUENCIES OF OCCURRENCE OF SEASONAL RUN-OFFS OF PERIOD 1919-1931 FROM UPPER SACRAMENTO RIVER BASIN ABOVE RED BLUFF

Based on Seasonal Run-offs for 61-Year Period 1871-1932
Mean Seasonal Run-off, 9,230,000 acre-feet

Period (Season October 1st through September 30th)	Mean seasonal run-off for period		Average frequency of occurrence (from curves on Plate H-1)
	In acre-feet	In per cent of mean seasonal run-off for period 1871-1932	
One-year periods—			
1919-1920	4,220,000	46	Once in 14 years
1923-1924	3,290,000	36	Once in 59 years
1928-1929	4,400,000	48	Once in 12 years
1930-1931	3,320,000	36	Once in 53 years
Two-year periods—			
1922-1924	4,320,000	47	Once in 40 years
1929-1931	4,700,000	51	Once in 27 years
Three-year periods—			
1917-1920	5,830,000	63	Once in 19 years
1921-1924	5,100,000	55	Once in 33 years
1928-1931	4,600,000	50	Once in 55 years
Five-year periods—			
1915-1920	7,060,000	76	Once in 18 years
1919-1924	6,200,000	67	Once in 31 years
1921-1926	5,810,000	63	Once in 40 years
1926-1931	6,480,000	70	Once in 25 years

the seasonal run-off would be equal to or less than the corresponding seasonal run-off. These values of seasonal run-offs were plotted on logarithmic scale paper in accord with their respective frequencies. A smooth curve interpreting the trend of the data was drawn and extended to a frequency of 0.4 in 100 years. Analyses of the mean seasonal run-offs for consecutive two, three and five-season periods were made in a similar manner. These analyses delineated on Plate H-I, "Probable Frequencies of Mean Seasonal Run-offs from Upper Sacramento River Basin above Red Bluff," are an empirical interpretation of all the available data and are believed to be indicative, at least, of the frequency of occurrence of mean seasonal run-offs of various magnitudes during single seasons and consecutive two, three and five-season periods.

Table H-10 shows the average frequencies with which the low run-offs of several recent seasons, and periods of consecutive seasons, are likely to occur.

It may be noted that a seasonal run-off less than 3,320,000 acre-feet for the season 1930–1931 would be expected to occur once in 53 years and that for the season 1923–1924, once in 59 years. For the Kennett reservoir, capacity 2,940,000 acre-feet, the critical period is the three seasons 1928–1931. It may be seen that the mean seasonal run-off for that period is 4,600,000 acre-feet and that it would be expected to occur once in 55 years.

Great Central Valley.—Analyses similar to those for the upper Sacramento River Basin above Red Bluff were made for the entire Sacramento River Basin, for the San Joaquin River Basin and for the combined basins to estimate the probable frequencies of occurrence of seasonal run-offs of varying magnitudes. As in the case of the upper Sacramento River, the values used in the analyses are the full natural run-offs. For these analyses, the run-offs from mountainous areas of the major streams only were used. Those for the minor streams and unmeasured areas were not included. They represent less than 10 per cent of the total run-off from the basins. Graphs similar to those for the upper Sacramento River Basin were prepared and are presented herewith as Plate H-II, "Probable Frequencies of Mean Seasonal Run-offs from Major Streams of Sacramento and San Joaquin River Basins."

Values of frequency of occurrence of mean seasonal run-offs during several recent seasons and periods of two, three and five consecutive seasons have been taken from the developed curves on Plate H-II and are tabulated in Table H-11. These values are presented for the Sacramento River Basin alone, for the San Joaquin River Basin alone and for the combined basins.

An inspection of the figures in the table reveals that the run-off may be expected to be less than that of the season 1923–1924, the season of lowest run-off, once in 130 years for the Sacramento River Basin, once in 128 years for the San Joaquin River Basin and once in 147 years for the combined basins. The corresponding figures for the smallest mean seasonal run-off for two consecutive seasons are once in 26 years for the Sacramento River Basin in 1922–1924, once in 43 years for the San Joaquin River Basin in 1929–1931, and once in 33 years for the combined basins, also in 1929–1931. Similarly, the corresponding figures for the three run-off seasons 1928–1931, the driest three consecutive seasons during the period 1918–1931, are once in 62 years for the Sacramento River Basin, once in 62 years for San Joaquin River Basin and once in 77 years for the combined basins.

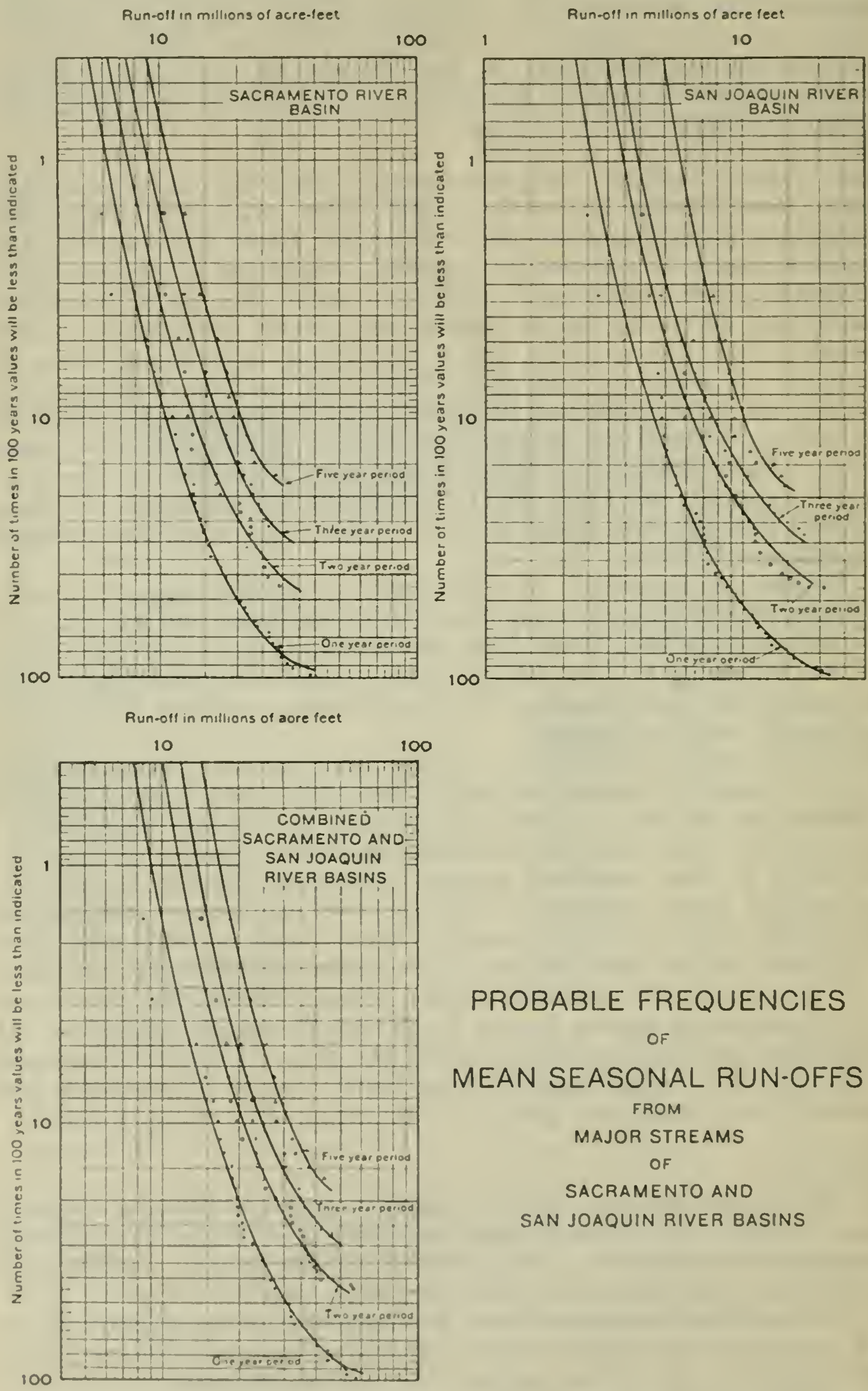
Summary.

The studies made to test the adequacy of the initial and ultimate major units of the State Water Plan and to estimate the probable frequency of occurrence of single and consecutive seasons of subnormal run-off such as those used in these tests, show that:

1. The objectives sought to be accomplished by the Kennett reservoir unit in the immediate initial development would have been fully met throughout the 42-year period 1890 to 1931, inclusive.

2. The objectives sought to be accomplished by the Kennett reservoir unit in the complete initial development would have been fully

PLATE H-II



PROBABLE FREQUENCIES

OF

MEAN SEASONAL RUN-OFFS

FROM

MAJOR STREAMS

OF

SACRAMENTO AND

SAN JOAQUIN RIVER BASINS

TABLE H-11

FREQUENCIES OF OCCURRENCE OF SEASONAL RUN-OFFS OF PERIOD 1918-1931 IN GREAT CENTRAL VALLEY OF CALIFORNIA

Based on seasonal run-offs of major streams for 61-year period 1871-1932

Period (Season October 1st through September 30th)	Sacramento River Basin — Mean seasonal run-off, 1871-1932, 21,570,000 acre-feet			San Joaquin River Basin — Mean seasonal run-off, 1871-1932, 10,880,000 acre-feet			Combined Sacramento and San Joaquin River Basins — Mean seasonal run-off, 1871-1932, 32,450,000 acre-feet		
	Mean seasonal run-off for period		Average frequency of occurrence (from curves on Plate H-II)	Mean seasonal run-off for period		Average frequency of occurrence (from curves on Plate H-II)	Mean seasonal run-off for period		Average frequency of occurrence (from curves on Plate H-II)
	In acre-feet	In per cent of mean seasonal run-off for period 1871-1932		In acre-feet	In per cent of mean seasonal run-off for period 1871-1932		In acre-feet	In per cent of mean seasonal run-off for period 1871-1932	
One-year periods—									
1919-1920	9,540,000	44	Once in 14 years	7,340,000	67	Once in 3 years	16,880,000	52	Once in 8 years
1923-1924	5,960,000	28	Once in 130 years	2,500,000	23	Once in 128 years	8,460,000	26	Once in 147 years
1928-1929	8,870,000	41	Once in 18 years	4,840,000	44	Once in 8 years	13,710,000	42	Once in 16 years
1930-1931	6,440,000	30	Once in 85 years	2,740,000	25	Once in 75 years	9,180,000	28	Once in 96 years
Two-year periods—									
1918-1920	13,320,000	62	Once in 10 years	7,280,000	67	Once in 8 years	20,600,000	63	Once in 10 years
1922-1924	10,300,000	48	Once in 26 years	5,990,000	55	Once in 12 years	16,280,000	50	Once in 21 years
1927-1929	13,680,000	63	Once in 10 years	5,960,000	55	Once in 12 years	19,640,000	61	Once in 12 years
1928-1930	11,840,000	55	Once in 16 years	5,160,000	47	Once in 18 years	17,000,000	52	Once in 18 years
1929-1931	10,630,000	49	Once in 23 years	4,120,000	38	Once in 43 years	14,750,000	45	Once in 33 years
Three-year periods									
1917-1920	12,760,000	59	Once in 25 years	7,440,000	68	Once in 11 years	20,200,000	62	Once in 18 years
1923-1926	12,450,000	58	Once in 27 years	5,800,000	53	Once in 20 years	18,250,000	56	Once in 26 years
1928-1931	10,040,000	47	Once in 62 years	4,360,000	40	Once in 62 years	14,400,000	44	Once in 77 years
Five-year periods—									
1916-1921	16,760,000	78	Once in 19 years	8,820,000	81	Once in 16 years	25,580,000	79	Once in 18 years
1921-1926	14,280,000	66	Once in 32 years	7,980,000	73	Once in 22 years	22,260,000	69	Once in 29 years
1922-1927	15,720,000	73	Once in 23 years	7,680,000	71	Once in 26 years	23,400,000	72	Once in 24 years
1926-1931	15,050,000	70	Once in 27 years	6,330,000	58	Once in 61 years	21,380,000	66	Once in 33 years

met throughout the 42-year period 1890 to 1931, inclusive, except in 1931. In that year there would have been bearable deficiencies in the irrigation supply for the "crop lands" in the San Joaquin Valley and in the flows and depths for navigation on the Sacramento River above the city of Sacramento. The electric energy outputs in the years 1930 and 1931 would have caused a decrease of about 1.4 per cent in the average annual output for the 42-year period 1890–1931, inclusive, from what it would have been for the 40-year period 1890–1929, inclusive. There would have been a full supply for all other uses.

3. The objectives sought to be accomplished by the major units of the State Water Plan for the Great Central Valley under conditions of ultimate development would have been fully met throughout the 42-year period 1890 to 1931, inclusive, except in 1924 and 1931. The unbearable deficiencies in supply where they would have existed in limited areas in the lower San Joaquin Valley in 1924 and 1931 could have been reduced to bearable amounts by the utilization of available ground water in those areas.

4. Low seasonal run-off such as those which occurred in the seasons 1923–1924 and 1930–1931, and in the three consecutive seasons 1928 to 1931, in the upper Sacramento River watershed, and which were used in the tests of the adequacy of the Kennett reservoir unit in the initial developments, may be expected to occur with average frequencies of once in 50 to 60 years.

5. Low seasonal run-offs such as those which occurred in the seasons 1923–1924 and 1930–1931, and in the three consecutive seasons 1928 to 1931, in the Great Central Valley, and which were used in the tests of the adequacy of the State Water Plan for this valley, may be expected to occur with the following average frequencies:

Period	*Sacramento River Basin*	*San Joaquin River Basin*	*Combined Sacramento and San Joaquin River Basins*
1923–1924	Once in 130 years	Once in 128 years	Once in 147 years
1930–1931	Once in 85 years	Once in 75 years	Once in 96 years
1928–1931	Once in 62 years	Once in 62 years	Once in 77 years

PUBLICATIONS

DIVISION OF WATER RESOURCES

PUBLICATIONS OF THE

DIVISION OF WATER RESOURCES

DEPARTMENT OF PUBLIC WORKS

STATE OF CALIFORNIA

When the Department of Publ'c Works was created in July, 1921, the State Water Commission was succeeded by the Division of Water Rights, and the Department of Engineering was succeeded by the Division of Engineering and Irrigation in all duties except those pertaining to State Architect. Both the Division of Water Rights and the Division of Engineering and Irrigation functioned until August, 1929, when they were consolidated to form the Division of Water Resources.

STATE WATER COMMISSION

First Report, State Water Commission, March 24 to November 1, 1912.
Second Report, State Water Commission, November 1, 1912 to April 1, 1914.
*Biennial Report, State Water Commission, March 1, 1915, to December 1, 1916.
Biennial Report, State Water Commission, December 1, 1916, to September 1, 1918.
Biennial Report, State Water Commission, September 1, 1918, to September 1, 1920.

DIVISION OF WATER RIGHTS

*Bulletin No. 1—Hydrographic Investigation of San Joaquin River, 1920–1923.
*Bulletin No. 2—Kings River Investigation, Water Master's Reports, 1918–1923.
*Bulletin No. 3—Proceedings First Sacramento-San Joaquin River Problems Conference, 1924.
*Bulletin No. 4—Proceedings Second Sacramento-San Joaquin River Problems Conference, and Water Supervisor's Report, 1924.
*Bulletin No. 5—San Gabriel Investigation—Basic Data, 1923–1926.
Bulletin No. 6—San Gabriel Investigation—Basic Data, 1926–1928.
Bulletin No. 7—San Gabriel Investigation—Analysis and Conclusions, 1929.
*Biennial Report, Division of Water Rights, 1920–1922.
*Biennial Report, Division of Water Rights, 1922–1924.
Biennial Report, Division of Water Rights, 1924–1926.
Biennial Report, Division of Water Rights, 1926–1928.

DEPARTMENT OF ENGINEERING

*Bulletin No. 1—Cooperative Irrigation Investigations in California, 1912–1914.
*Bulletin No. 2—Irrigation Districts in California, 1887–1915.
Bulletin No. 3—Investigations of Economic Duty of Water for Alfalfa in Sacramento Valley, California, 1915.
*Bulletin No. 4—Preliminary Report on Conservation and Control of Flood Waters in Coachella Valley, California, 1917.
*Bulletin No. 5—Report on the Utilization of Mojave River for Irrigation in Victor Valley, California, 1918.
*Bulletin No. 6—California Irrigation District Laws, 1919 (now obsolete).
Bulletin No. 7—Use of water from Kings River, California, 1918.
*Bulletin No. 8—Flood Problems of the Calaveras River, 1919.
Bulletin No. 9—Water Resources of Kern River and Adjacent Streams and Their Utilization, 1920.
*Biennial Report, Department of Engineering, 1907–1908.
*Biennial Report, Department of Engineering, 1908–1910.
*Biennial Report, Department of Engineering, 1910–1912.
*Biennial Report, Department of Engineering, 1912–1914.
*Biennial Report, Department of Engineering, 1914–1916.
*Biennial Report, Department of Engineering, 1916–1918.
*Biennial Report, Department of Engineering, 1918–1920.

* Reports and Bulletins out of print. These may be borrowed by your local library from the California State Library at Sacramento, California.

DIVISION OF WATER RESOURCES

Including Reports of the Former Division of Engineering and Irrigation

*Bulletin No. 1—California Irrigation District Laws, 1921 (now obsolete).
*Bulletin No. 2—Formation of Irrigation Districts, Issuance of Bonds, etc., 1922
Bulletin No. 3—Water Resources of Tulare County and Their Utilization, 1922
Bulletin No. 4—Water Resources of California, 1923.
Bulletin No. 5—Flow in California Streams, 1923.
Bulletin No. 6—Irrigation Requirements of California Lands, 1923.
*Bulletin No. 7—California Irrigation District Laws, 1923 (now obsolete).
*Bulletin No. 8—Cost of Water to Irrigators in California, 1925.
Bulletin No. 9—Supplemental Report on Water Resources of California, 1925.
*Bulletin No. 10—California Irrigation District Laws, 1925 (now obsolete).
Bulletin No. 11—Ground Water Resources of Southern San Joaquin Valley, 1927.
Bulletin No. 12—Summary Report on the Water Resources of California and a Coordinated Plan for Their Development, 1927.
Bulletin No. 13—The Development of the Upper Sacramento River, containing U. S R. S. Cooperative Report on Iron Canyon Project, 1927.
Bulletin No. 14—The Control of Floods by Reservoirs, 1928.
*Bulletin No. 18—California Irrigation District Laws, 1927 (now obsolete).
*Bulletin No. 18—California Irrigation District Laws, 1929 Revision (now obsolete).
Bulletin No. 18-B—California Irrigation District Laws, 1931, Revision.
Bulletin No. 19—Santa Ana Investigation, Flood Control and Conservation (with packet of maps), 1928.
Bulletin No. 20—Kennett Reservoir Development, an Analysis of Methods and Extent of Financing by Electric Power Revenue, 1929.
Bulletin No. 21—Irrigation Districts in California, 1929.
Bulletin No. 21-A—Report on Irrigation Districts in California for the Year 1929, 1930.
Bulletin No. 21-B—Report on Irrigation Districts in California for the year 1930, 1931.
Bulletin No. 22—Report on Salt Water Barrier (two volumes), 1929.
Bulletin No. 23—Report of Sacramento-San Joaquin Water Supervisor, 1924–1928.
Bulletin No. 24—A Proposed Major Development on American River, 1929.
Bulletin No. 25—Report to Legislature of 1931 on State Water Plan, 1930.
Bulletin No. 26—Sacramento River Basin, 1931.
Bulletin No. 27—Variation and Control of Salinity in Sacramento-San Joaquin Delta and Upper San Francisco Bay, 1931.
Bulletin No. 28—Economic Aspects of a Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers, 1931.
Bulletin No. 28-A—Industrial Survey of Upper San Francisco Bay Area, 1930.
Bulletin No. 31—Santa Ana River Basin, 1930.
Bulletin No. 32—South Coastal Basin, a Cooperative Symposium, 1930.
Bulletin No. 33—Rainfall Penetration and Consumptive Use of Water in Santa Ana River Valley and Coastal Plain, 1930.
Bulletin No. 34—Permissible Annual Charges for Irrigation Water in Upper San Joaquin Valley, 1930.
Bulletin No. 35—Permissible Economic Rate of Irrigation Development in California, 1930.
*Bulletin No. 36—Cost of Irrigation Water in California, 1930.
Bulletin No. 37—Financial and General Data Pertaining to Irrigation, Reclamation and Other Public Districts in California, 1930.
Bulletin No. 38—Report of Kings River Water Master for the Period 1918–1930.
Bulletin No. 39—South Coastal Basin Investigation, Records of Ground Water Levels at Wells, 1932.
Biennial Report, Division of Engineering and Irrigation, 1920–1922.
Biennial Report, Division of Engineering and Irrigation, 1922–1924.
Biennial Report, Division of Engineering and Irrigation, 1924–1926.
Biennial Report, Division of Engineering and Irrigation, 1926–1928.

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* Reports and Bulletins out of print. These may be borrowed by your local library from the California State Library at Sacramento, California.

PAMPHLETS

Act Governing Supervision of Dams in California, with Revised Rules and Regulations, 1932.

Water Commission Act with Amendments Thereto, 1931.

Rules, Regulations and Information Pertaining to Appropriation of Water in California, 1930.

Rules and Regulations Governing the Determination of Rights to Use of Water in Accordance with the Water Commission Act, 1925.

Tables of Discharge for Parshall Measuring Flumes, 1928.

General Plans, Specifications and Bills of Material for Six and Nine Inch Parshall Measuring Flumes, 1930.

COOPERATIVE AND MISCELLANEOUS REPORTS

*Report of the Conservation Commission of California, 1912.

*Irrigation Resources of California and Their Utilization (Bul. 254, Office of Exp. U. S. D. A.) 1913.

*Report, State Water Problems Conference, November 25, 1916.

*Report on Pit River Basin, April, 1915.

*Report on Lower Pit River Project, July, 1915.

*Report on Iron Canyon Project, 1914.

*Report on Iron Canyon Project, California, May, 1920.

*Sacramento Flood Control Project (Revised Plans), 1925.

Report of Commission Appointed to Investigate Causes Leading to the Failure of St. Francis Dam, 1928.

Report of the California Joint Federal-State Water Resources Commission. 1930.

Conclusions and Recommendations of the Report of the California Irrigation and Reclamation Financing and Refinancing Commission. 1930.

*Report of California Water Resources Commission to the Governor of California on State Water Plan, 1932.

*Booklet of Information on California and the State Water Plan Prepared for United States House of Representatives' Subcommittee on Appropriations, 1931.

*Bulletin on Great Central Valley Project of State Water Plan of California Prepared for United States Senate Committee on Irrigation and Reclamation, 1932.

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