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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF ENGINEERING AND IRRIGATION

BULLETIN No. 4

WATER RESOURCES OF CALIFORNIA

A REPORT TO THE LEGISLATURE OF 1923

CALIFORNIA STATE PRINTING OFFICE
FRANK J. SMITH, Superintendent
SACRAMENTO, 1923

20273

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LETTER OF TRANSMITTAL.

January 1, 1923.

To the Members of the Legislature,
State of California,
Session of 1923.

The report on the "Water Resources of California," prepared by the Division of Engineering and Irrigation of this Department, is transmitted herewith. This report compiles the results of the state-wide investigation authorized by Chapter 889 of the Statutes of 1921. In placing this in your hands, I desire to mention the helpful services of the Consulting Board appointed pursuant to the provisions of the act and of the members of the civil engineering profession who have served on advisory committees and reviewed much of the work in preparing this report. They have freely given to the state valuable advice and assistance that have greatly aided these endeavors.

Respectfully submitted.

A. B. Fletcher

Director of Public Works.

LETTER FROM THE CONSULTING BOARD TO THE MEMBERS OF THE LEGISLATURE.

To the Honorable Members of the Legislature,

State of California,

Session of 1923.

The Consulting Board appointed under the provisions of chapter 889 of the Statutes of 1921, approves the report of the Division of Engineering and Irrigation of the State Department of Public Works, herewith submitted.

It is the judgment of the Board that the Division of Engineering and Irrigation should continue this work and that the required appropriation therefor should be made.

Respectfully submitted.

, *Chairman*

Members of Consulting Board.

ACKNOWLEDGMENT.

Much data have been contributed to this report by public and private offices without which the Department would have been wholly unable to produce this volume. The Department desires to publicly express its sincere appreciation to the parties who, through the furnishing of these data, have made it possible to increase the service to the public several-fold, in publishing this report.

FOREWORD.

The legislature of 1921 appropriated $200,000 for an investigation of California's water resources by the State Department of Public Works, Division of Engineering and Irrigation. Accordingly, an engineering investigation has been completed and a report transmitted to the legislature on January 1, 1923. The great mass of data collected and the complex analyses thereof made it advisable to present much of the information in separate volumes. Four of these are in print, entitled:

APPENDIX "A" "Flow in California Streams." Bulletin No. 5, State Department of Public Works.

APPENDIX "B" "Irrigation Requirements of California Lands." Bulletin No. 6, State Department of Public Works.

APPENDIX "C" "Utilization of the Water Resources of California." Bulletin No. 7, State Department of Public Works.

APPENDIX "D" "Relation of Settlement to Irrigation Development." Bulletin No. 8, State Department of Public Works.

Chapter 889 of the 1921 Statutes, which authorized this investigation, provided for the appointment by the Governor, of a Consulting Board to advise with the Department in their endeavors. The following were appointed by Governor Stephens:

J. C. FORKNER, Chairman
PETER COOK
JONATHAN S. DODGE
B. A. ETCHEVERRY
HARRY HAWGOOD
H. A. KLUEGEL
ROBERT B. MARSHALL
H. D. MCGLASHAN
O. B. TOUT
U. S. WEBB

Additional advice on the technical features of Appendix "A" to this report has been sought by the Department from:

C. E. GRUNSKY
LOUIS C. HILL
CHARLES D. MARX
H. D. MCGLASHAN

Also, further advice was sought on the technical features of Appendix "B" from:

A. N. BURCH
B. A. ETCHEVERRY
SAMUEL FORTIER
A. L. SONDEREGGER

The Department sought added advice on the technical features of Appendix "C" from:

A. J. CLEARY
G. A. ELLIOTT
F. C. HERRMANN
W. L. HUBER
A. KEMPKEY
WILLIAM MULHOLLAND

Appendix "D" was prepared by Dr. Elwood Mead, Professor of Rural Institutions of the University of California, and Chief of Division of Land Settlement of the State Department of Public Works, under cooperative arrangements with the University of California.

ORGANIZATION.

A. B. FLETCHER, *Director of Public Works*
W. F. McCLURE, *Chief of Division of Engineering and Irrigation*

The investigation of the water resources of the state and the preparation of the report thereon, was planned, directed and brought to completion by

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O. B. FIELD
FRANK P. FOOTE
GEORGE B. GLEASON
S. S. GORMAN
WILLIAM H. GORMAN
F. B. HILBY
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IRVIN INGERSON
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THOMAS LEWIS
J. A. LINDSAY
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W. J. MANETTA
T. C. MEAD
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R. I. MEYERHOLZ
E. H. MOORE
M. F. MOORE
W. B. MULLIN
T. R. NEISWANDER
T. NEUMAN
C. M. NEWTON
HARRY OLSEN
NOEL PIKE
NORMAN C. RAAB
B. A. REBER
GLENN ROOD
E. N. SAWTELLE
N. E. SPICKLEMIRE
R. C. STEVENSON
H. N. SULLIGER
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EARL D. STAFFORD
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G. H. WALTERS
A. V. WILSON

A. F. MCCONNELL, Editor of Report
J. J. HALEY, JR., Office Manager

CHAPTER 889 OF STATUTES OF 1921.

An act to provide for the investigation by the State of California of the possibilities of the storage, control and diversion of water for public use and public protection in the State of California, and making an appropriation for said purpose.

(Approved June 3, 1921.)

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

SECTION 1. It is hereby declared that the people of the State of California have a paramount interest in the use of all the waters of the State and the State of California shall determine what waters of the state, surface and underground, can be converted to public use, or controlled for public protection.

SEC. 2. The state engineering department is hereby authorized and instructed to make the investigation in this act provided for and for the purposes herein specified.

SEC. 3. It shall be the duty of the state engineering department to determine the maximum amount of water which can be delivered to the maximum area of land, the maximum control of flood waters, the maximum storage of waters, the effects of deforestation and all possibile and practicable uses for such waters in the State of California.

SEC. 4. It shall be the duty of the state engineering department to determine a comprehensive plan for the accomplishment of the maximum conservation, control, storage, distribution and application of all the waters of the state, and to estimate the cost of constructing dams, canals, reservoirs or other works necessary in carrying out this plan, and to report the result of such investigations with recommendations not later than the legislative session of 1923.

SEC. 5. In carrying out the provisions of this act the state engineering department is hereby authorized to examine any and all data, estimates and proposals in furtherance of the above purpose, according to its judgment of their engineering worth, and to cooperate with any department, bureau, office, service, or division of the United States, or of the state or counties, or with any municipality, irrigation, reclamation, conservation, drainage, flood control, levee, or other district agency for irrigation, reclamation, drainage, or flood control purposes, or for the development of hydro-electric power; or with any interested association, company or individual; *provided, further*, that the engineering department is hereby expressly authorized to accept, receive and use any funds or moneys contributed to it by any person, irrigation district, reclamation district, water and conservation district or any political subdivision of the State of California for the purpose of cooperating in the work aforesaid and carrying out the purposes of this act.

SEC. 6. With the approval of the governor, the state engineering department is hereby authorized to employ such assistance as in its judgment it may require and to incur such expense as may be necessary to carry out the purposes of this act. The governor is further authorized to appoint a consulting board, composed of citizens of special and technical qualifications, to serve in an advisory capacity, and without pay, in making the above investigation.

SEC. 7. There is hereby appropriated out of any money in the state treasury, not otherwise appropriated, the sum of two hundred thousand dollars, and made immediately available for any of the purposes of this act.

SEC. 8. This act shall not in any way be construed so as to deprive persons, corporations, or districts of vested rights.

SEC. 9. Any section or portion of a section of any act, statute or law of the State of California in conflict with the provisions of this act is hereby repealed.

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CHAPTER I.

RECOMMENDATIONS TO THE LEGISLATURE OF 1923.

One-third of the aggregate value of all of California's products are those raised on the farm, and one-fourth of all its manufactories are concerned in milling, canning or preserving, cleaning, or otherwise preparing food stuffs for the market. In a state whose wealth is taken from the soil in such large portions, agriculture and the problems attendant to its expansion, press for consideration. The accelerated expansion of agricultural production in California has been attained through the more intensive cultivation of its fertile soils. Irrigating about one-third of all the lands farmed, this state now yields an average crop value that is almost three times larger for each acre cultivated,[1] than the average production on an acre of tilled land in any of the three states that exceed California in total annual production on their farmed lands. The abundant soil-moisture obtained through the supplementary supplies, has enabled the responsive soils of California to produce many fold under irrigation and is placing this state in a foremost position among the states of a nation of farms.

Even more than in the past, will the future be concerned in the extension of irrigation to additional areas and the perfection of the supply for those lands now watered, because the agricultural lands of this state are now yielding to capacity under the conditions of dry farming. It is therefore essential that state activities should be guided by thoughts for the orderly and economical development of its water resources, so that all the needs of civilization for water may be supplied while the predominant use for agriculture may expand to the full limit of its wealth-producing powers. In this report, the Department of Public Works and its consultants have endeavored to compile and present information on the water resources of California that will enable your honorable body to guide the state's destiny with confidence and wisdom.

The data amassed, the comparisons, the computations and the deductions involved in preparing this report, are so voluminous that they are printed in four separate volumes. Appendix "A," "Flow in California Streams," in seventy-six pages of text, two hundred and forty-four pages of tables, and in one hundred and eighty-five maps and diagrams, describes the location, the volume, the source, and the variability of occurrence of the state's waters, and the capacities of storage works required for their utilization. Appendix "B," "Irrigation Requirements of California Lands," in seventy-six pages of text, one hundred and fifteen pages of tables and seven maps and diagrams, gives a digest of all information obtainable on the past use of water for irrigation, and presents an analysis of the future requirements of all

[1]The California State Department of Agriculture estimates the average value of farm products per acre for the four ranking states in 1922, was, in order of their total production: Texas, $27.50; Iowa, $21; Illinois, $20; and California, $59.50.

of California's arable lands. Appendix "C," "Utilization of the Water Resources of California," presents a general preliminary plan for obtaining the maximum use from the state's waters and the control of floods. Appendix "D," "Relation of Settlement to Irrigation Development," discusses colonization problems of irrigation projects. All this information, basic for a full conception of the potential value of the state's water resources, its greatest possession, is briefly summarized in the chapters of this report.

A general preliminary plan for achieving the greatest service from these waters, is presented as requested by the legislative enactment providing for these investigations. This plan outlines a scheme of coordinated development whereby a maximum accomplishment may ultimately be obtained whose physical works for storing water would cost but slightly more than half as much as similar attainment under an uncoordinated plan. The canals for transporting this water to the regions of use are, many of them, very long and obtain water from several sources, pass through numerous communities, and could be made possible only through organization of large sections of the state. Without such canals much of the state's waters will go unused. Only then, through united endeavors, almost statewide in extent, can the maximum service be obtained from the state's waters.

The reservoirs involved in the maximum development of the state's waters are some 260 in number. These and twice as many more were examined by field parties in these investigations, and a selection made of a third of all the possible sites reported on. Time did not allow, neither did the preliminary investigation warrant, a detailed examination of dam sites. Before it is finally known that the selected sites are feasible, borings and exploration trenches must be made. The canals outlined on the map of the comprehensive plan, largely pass through territory of which adequate maps do not exist. Many surveys must be made before it may be ascertained that these canals are feasible and that they are in the most economical location. *It is therefore recommended to your honorable body that funds be appropriated to pursue the study of the comprehensive plan in greater detail than has been possible for this report.*

It is also desired to call to your attention the value of records of the waters flowing in California streams. Because of the sporadic way in which the waters pass down the stream channels, reliable estimates of future expectancies can only be made from uninterrupted records of many years' duration. The inventory of the state's waters presented in this report has been based on an estimated fifty-year mean flow. This was accomplished by expanding records of measured run-off through comparison with precipitation records and, on many streams, the entire estimate of run-off was obtained by comparison. It is urgent that provision be made for the continuance of stream gaging records at least as extensive as in the past, and some increase be made in appropriations for this work if possible. The construction of all the great hydraulic works on which the future wealth of this state depends, must be designed in accord with these records of stream flow. It is important that they be continuous and on all the streams.

Lastly, the desirability of stimulating the rate of rural settlement in California has been pointed out in this report. This subject is placed before you as one worthy of your attention.

CHAPTER II.

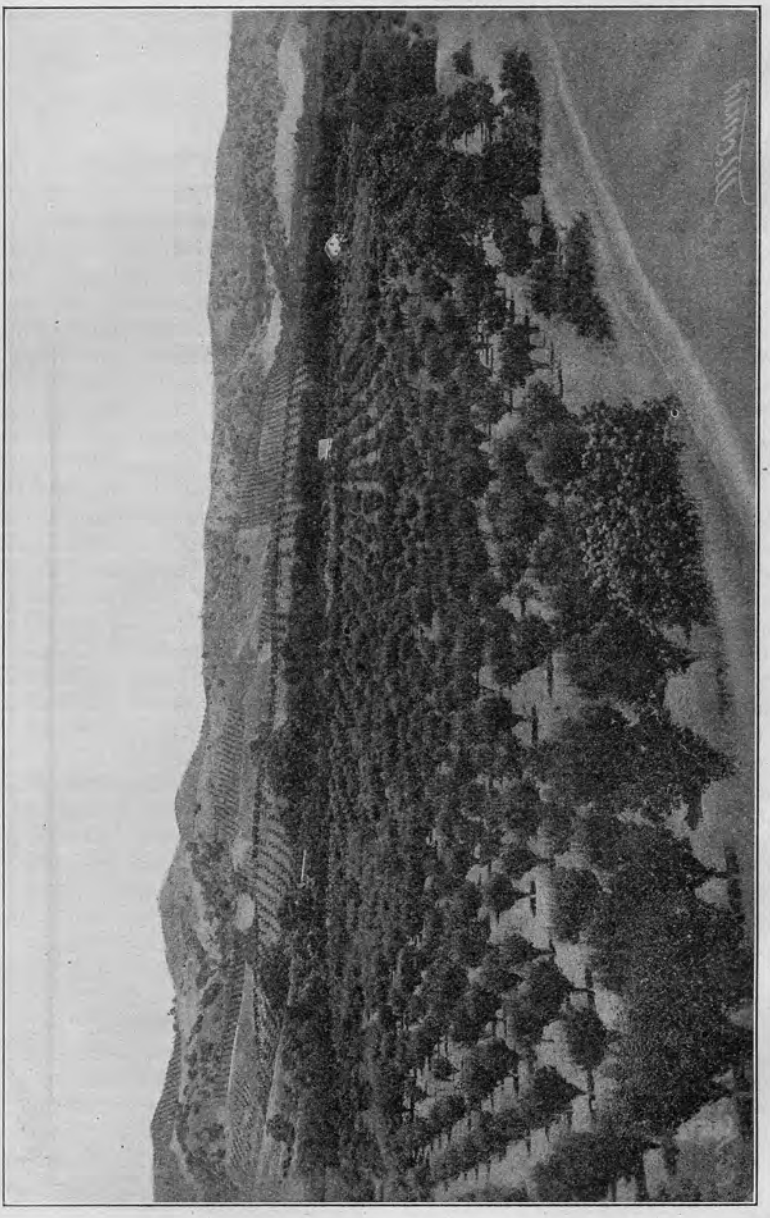
CALIFORNIA.

California, second in area, but first among the states of the Union in value of natural resources, lies between the Great Basin of the North American continent and the Pacific Ocean. Confined on the north by Oregon and on the south by Mexico, it constitutes three-fifths of the western boundary of the United States. The six hundred and fifty miles of its meridional length extends to over nine hundred miles of seashore as the coast line pursues a diagonal and more tortuous course in delineating the headlands and coastal indentations of the Pacific littoral.

Within the two hundred miles of California's average width, there are 23,000,000 acres of agricultural lands disposed in parcels of various sizes and separated by mountains that occupy much of the intervening space. These agricultural areas are the flat and rolling lands of the state that have soils, disposed in appreciable areas of regular surface conformation, suitable for the production of harvestable crops. The grains, fruits, berries, grapes, vegetables and other farm produce for which California is famed, are grown on these lands. They are located on the valley floors, in the foothills and on the plateaus of the state. Included in the agricultural areas, are lands at present deficient in natural moisture, but more or less conveniently situated for the ultimate acquisition of an accessory water supply. Slightly over one-half of these agricultural areas were farmed in 1920.

The non-agricultural regions of California, the mountains, are, for the most part, precipitous, rocky or soilless. Occupying three-fifths the area of the state, these upland regions are spacious collectors of precipitation that fill the stream channels with water, without which much of the state's arable lands could never reveal their powers of production because of deficient soil-moisture. Although they are mostly non-tillable, nevertheless the mountainous regions have supplied the alluvial earth through glacial action, weathering or erosion, that their streams have conveyed to lower levels and deposited there to become the fertile, productive soils of the agricultural areas.

California's mountains are so disposed that their greater part is comprised within two ranges. These diverge in their southerly course at Mount Shasta within forty miles of the Oregon line, and leave between their bases, the long flat valley that averages a quarter the breadth of the state and half its length. Girdling this valley in their southward course, these two mountain chains proceed in long sweeping curves to a convergence at Tehachapi Pass, three-quarters the way down the state from the north boundary. The encircling line of crests of these two ranges enclose within a rock wall, two-thirds of California's agricultural lands. This wall is cleft to valley-floor level in but one



AGRICULTURAL LANDS IN FOOTHILL REGION.

place. Through this cutting, the interior drainage issues, flowing westwardly to mingle with the waters of the Pacific Ocean.

The mountains to the east of this Great Central Valley, the Sierra Nevada Range, extend for two-thirds the length of the state between Mount Shasta on the north and Tehachapi Pass on the south and their crests are the highest of California's mountains. Serrated and precipitous, their altitudes increase from north to south and culminate in Mount Whitney, 14,500 feet high, the highest peak in the United States excluding Alaska. Between the two extremities of this range, many peaks rise to heights greater than 8000 feet above the sea and eleven peaks pierce the clouds to more than 14,000 feet. In the northerly quarter of this range is Lassen, the culminating peak of its vicinity, 10,580 feet high and North America's only active volcano.

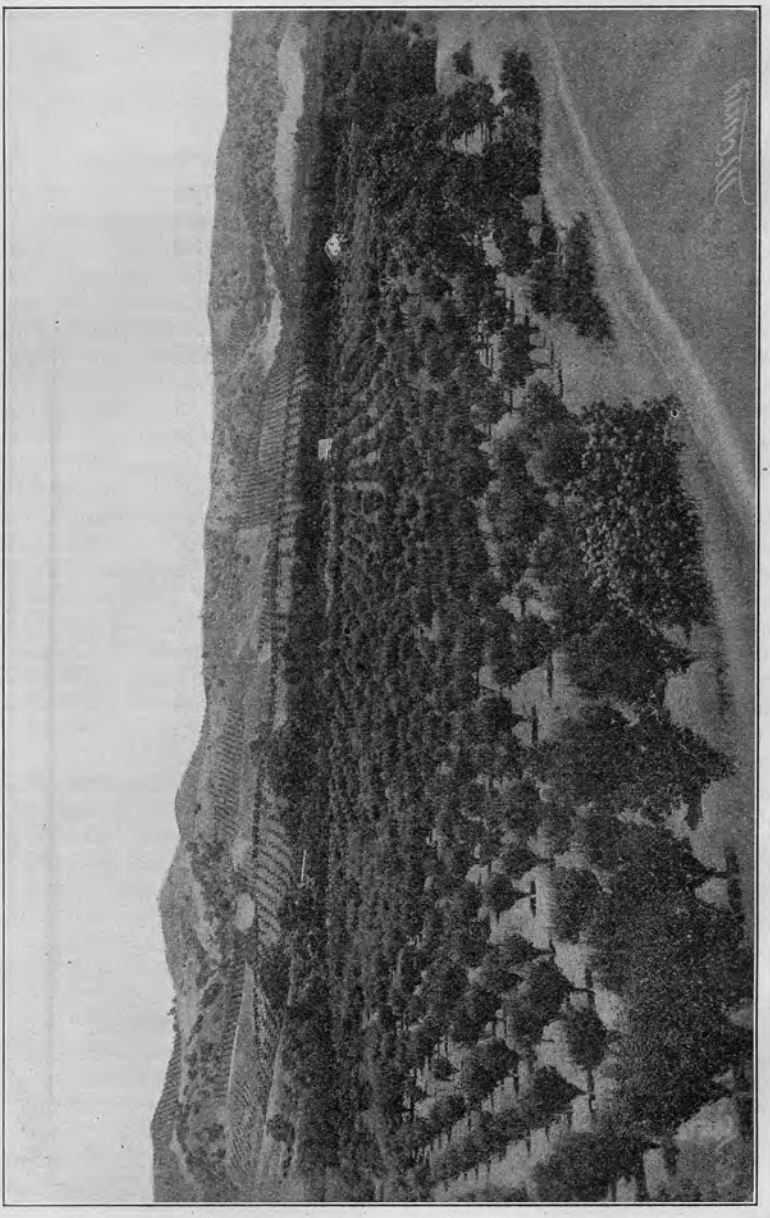
The westerly of the two mountain chains encircling the Great Central Valley, the Coast Range, after separating at Mount Shasta from the mass of mountains in the northern part of the state, parallels the margin of the Pacific Ocean and takes a somewhat narrower path in its southerly course, than does the Sierra Nevada Range. The Coast Mountains do not attain the elevations of the Sierra Nevadas, neither are they so diverse of surface or massive in structure. Their highest peaks are less than 9000 feet in elevation and those above 5000 feet are but few in number.

Southward from the convergence of these two ranges at Tehachapi Pass and on to the Mexican Border, California's mountains continue as a single chain. Their crests are less continuous and their main axis is less easily discernible than from the Pass northward. A few dominating peaks rise to heights of more than 10,000 feet, but their general altitude is intermediate in elevation between those of the Coast Range and Sierra Nevada Mountains.

This mountain range divides two very diverse regions. To the west, the Pacific slope, the agricultural lands of which extend from the ocean's margin well up to the mountain flanks, is an intensively developed and highly productive area of moderate climate fluctuation; while to the east lies an undeveloped expanse, almost rainless, with climatic extremes, and largely unproductive through lack of an accessory water supply. However, there are extensive productive areas in Imperial, Palo Verde and Coachella valleys which have acquired irrigation supplies and are realizing on the great fertility of their arid soils. In this expanse of flat lands and mountains is Salton Sink, an inland sea, the surface of which is more than 250 feet below ocean level.

On the Pacific slope of this dividing range in the southern quarter of the state, in its broad valleys and adjacent to the seashore, is spread the bulk of California's agricultural lands that lie west of the state's mountains, in all, one-sixth of their total area. These lands are located mostly along the streams near their ocean outlets. Northward from Santa Barbara Channel they are scattered rather meagerly along the Pacific margin, for their continuity is interrupted by extensive stretches of precipitous shore line that rises abruptly from the water's edge.

To the east of Southern California's dividing range south of the Tehachapi Pass, one-tenth of the state's arable lands lie between their crests and the state's eastern border. Northerly from these lands and along the eastern border of the state, another tenth of the agricultural



AGRICULTURAL LANDS IN FOOTHILL REGION.

lands are located in scattered parcels in the elevated valleys and plateaus east of the crests of California's mountains. These are mostly situated at elevations of from 4000 to 5000 feet or more above sea level.

The extreme range in altitude of California's variegated surface is from two hundred and seventy-five feet below sea level in Death Valley, to fourteen thousand five hundred feet above, attaining this elevation at Mount Whitney, but seventy-five miles distant from the lowest depression. The greater part of the flat lands, or about one-fifth of the total area of the state, lies between the elevation of the ocean's edge and five hundred feet above. These flat lands comprise the gently sloping ocean littoral, an extensive mountain-girdled valley known as the Sacramento-San Joaquin, and the almost rainless area in the southeastern corner of the state. These regions, 33,000 square miles in extent, include the bulk of California's agricultural area.

Higher in elevation than these flat lands, are the slopes lying between the plain-like areas and the base of the mountains. These are the rolling foothills and the more elevated valleys, lands that are transitional between the plains and the highland regions. Located between 500 and 2500 feet above sea level, they comprise about one-third the area of the state. One-quarter of all the agricultural land lies in this transitional region, and only the scattered parcels in high mountain valleys and that on the plateau in northeastern California, lie above it.

Higher than 2500 feet in elevation lie the mountains proper. For a large part they are a rugged and precipitous region of steep acclivities, of rocky extrusions and serrated ridges, and of deep canyons and rock-walled gorges, that comprise nearly half the area of the state, but interspersed at intervals throughout this highland region are mountain valleys and meadows, attractive in their richness and scenic beauty. The mountain and foothill regions, together, are over triple the area of the agricultural lands. In receiving greater precipitation, the mountain regions shed large volumes of water into the streams and rivers and are the source of nearly all of the state's waters.

CHAPTER III.

CLIMATE.

The California year is distinctive from that in most other states of the Union, in having but two well-defined seasons, summer and winter. This occurs because the transitional periods, spring and autumn, are brief and devoid of special features other than that they are intermediate between the more clearly defined seasons of summer and winter. The summer, or growing period, is long, warm and without heavy rains; the winter is the dormant period, or interval of retarded growth in the annual cycle of plant life, and normally is short, cool, and at times stormy. The greater portion of the waters precipitated upon the lands of California fall during this season of winter.

The covert of encircling mountains and the proximity of an ocean that borders the state with nine hundred miles of coast line, so modifies California's climate that only moderate seasonal fluctuations of temperature occur over most of its area. Any great extremes of heat and cold that do transpire are confined principally to the high mountain or arid areas. On the low lands generally, the mean monthly temperatures show departures from the average for the entire year, markedly less than similarly compared heat measurements for the adjoining states or those located eastward and included in the same latitude.

California is exempt from hurricanes and tornadoes, and though the mountainous regions experience days of intense cold, blizzards are unknown over the valley areas. Favored of nature through immunity from devastating tempest, rigorous cold, and enervating heat, California's climate is heralded the world over.

The outstanding features of the state's climatic regime are the rains of winter and the sunshine of summer. During the winter months, the state is swept by moisture-laden winds that traverse large areas in their journey from one locality to another; while in the summer or dry season, similar winds may blow, but they are rainless and serve only to modify the mounting temperatures that ensue from continuous sunshine. This distinct division of the year into a short season of intermittent drenching rains and a longer season of warmth and sunshine, determines that, more and more, in the years to come, this peculiarity of climate will influence the activities of man in this state. As greater numbers of people elect to live within its borders, water will be needed in increasing amounts for every activity, and all of California's waters originate in the precipitation concentrated in a few months of the year.

Of greatest economic importance therefore, among the climatic phenomena, are the moisture-carrying winds that visit the state at annually recurrent intervals. In blowing over the land areas, these winds precipitate varying amounts of water along the way as they are cooled, and deflected or diverted by local topography. The shelter of knolls, of hills or mountains, or of ridges or spurs, may lessen the amounts reaching leeward areas, while increased quantities may fall on more

Absolute and average frost-free period.

Mean monthly temperature in degrees F.

Number and U.S. Weather Bureau Station.

Mean monthly precipitation in inches.

JANUARY

FEBRUARY

MARCH

APRIL

MAY

JUNE

JULY

AUGUST

SEPTEMBER

OCTOBER

NOVEMBER

DECEMBER

1. AZUSA
2. ESCONDIDO
3. IMPERIAL
4. MOJAVE
5. BISHOP
6. OAKDALE
7. FRESNO
8. COALINGA
9. SANTA MARIA
10. GONZALES
11. SAN JOSE
12. RIO VISTA
13. MARYSVILLE
14. AUBURN
15. SANTA ROSA
16. ALTURAS

32 40 50 60 70 80 90

Critical Temperature

Note: "Critical Temperature" is the mean monthly temperature below which there is little active plant growth.

Authority: B. A. Etcheverry.

1 2 3 4 5 6 7

FROST-FREE PERIOD

TEMPERATURE

PRECIPITATION

ILLUSTRATIVE CLIMATOLOGY OF AGRICULTURAL LANDS

STATE DEPARTMENT OF PUBLIC WORKS
DIVISION OF ENGINEERING AND IRRIGATION
CALIFORNIA WATER RESOURCES INVESTIGATION
CHAPTER 889 1921 STATUTES

Plate I

CHAPTER 855 1951 STATUTES

CALIFORNIA WATER RESOURCES INVESTIGATION

DIVISION OF ENGINEERING AND IRRIGATION

STATE DEPARTMENT OF PUBLIC WORKS

ILLUSTRATIVE CLIMATOLOGY OF AGRICULTURAL LANDS

Plate 17

PRECIPITATION

TEMPERATURE

FROST-FREE PERIOD

1. LATHROP
2. ESCONDIDO
3. IMPERIAL
4. MOLAVE
5. BISHOP
6. OAKDALE
7. FRESNO
8. COALINGA
9. SANTA MARIA
10. GONZALES
11. SAN JOSE
12. RIO VISTA
13. MARYSVILLE
14. AUBURN
15. SANTA ROSA
16. ALTURAS

JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

Mean monthly precipitation in inches.

Mean monthly temperature in degrees F.

Absolute and average frost-free period.

U. S. Weather Bureau Station number and name

Normal Temperature

Monthly Temperature is that active Authority

Critical Temperature

Note: Bar graph shows mean monthly temperature, at the urest

exposed locations. The greater cooling of the air upon moving up slopes and arriving at higher elevations, usually inceases the precipitation in the mountainous regions over that on lower lands.

The annual quantity of moisture released from the atmosphere to fall upon the several parts of the state, is as variant as the rugged topography.[1] In general, precipitation increases in depth from south to north, being least in the southeastern corner of California where it is nearly zero, and greatest in the North Pacific region contiguous to the Oregon line where the mean annual rainfall attains a depth of one hundred inches or more. The mountains generally receive more than the valleys between them. The greater portion of the flat lands have a mean depth of precipitation of less than twenty inches annually and one-third of their area has less than ten inches. Depths of more than twenty inches are mostly confined to the mountainous regions which on their more elevated portions receive from thirty-five to one hundred inches, or more. In the highest mountain regions, precipitation occurs largely as snow; on those of lesser altitude both snow and rain fall, but the mantle of snow on the earth is of short duration; while the areas lying closer to the ocean's level, seldom experience a fall of snow but receive all precipitation as rain. The mild climate of this lower portion of the state extends, therefore, to nearly all its flat-lands, to the gently sloping ocean littoral, to the extensive mountain-girdled valley containing three-fifths of all the agricultural lands, and to the rolling foothills and detrital-filled valleys transitional to the highland regions—in all about one-half the area of the state.

To depict the features of rain, temperature and frost in California's agricultural areas, Plate I has been prepared, "Illustrative Climatology on Agricultural Lands." For convenience, the tillable lands of the state have been segregated into sixteen divisions or sections, the boundaries of which are shown on Plate III, "Map of Agricultural Areas and Duty of Water Sections." A station of the United States Weather Bureau has been selected in each one of these sections to illustrate its climatic features, and the mean precipitation and temperature for each month of the year, together with the frost-free periods for each one of these stations is graphically delineated on Plate I.

The top section of this plate shows, by means of colored columns drawn upwardly from a common base line, the mean monthly precipitation that has occurred at the Weather Bureau Station that is named at the foot of the bar. At the extremity of each equally-spaced cross-line on the sheet, at the left margin, are numerals which express values of mean monthly precipitation in inches of depth. The colored columns in intercepting these cross-drawn lines, indicate by their height, the amount of mean monthly precipitation.

On the middle section of the Plate I, the mean temperatures that have prevailed during each month of the year at the stations named above them, are represented by similarly colored columns that also project upward from a common base line. These show the values of mean monthly temperatures by their intercepts on cross-drawn lines that are numbered with temperature values at the left margin.

[1] See Isohyetose Map of California contained in Appendix "B" to this report, for complete delineation of precipitation over the state.

The lower section of the plate, designated "Frost Free Period," has transverse bars which progress partially across the paper. In so doing, their length exemplifies time. The space between the left and right hand margins represents the full twelve months of the year. Vertical lines divide this space into equal units of time and the monthly intervals are accentuated by heavier drawn lines. Spreading across the sheet and crossing these vertical lines, the sections of the bars in solid color show the duration of the period at each of the sixteen Weather Bureau stations, within which frost has never occurred. Extensions of the bars, hatched with colored shading lines, show by the distance between their extreme ends, the average duration of the frost-free period for the years of record. The bars are similarly colored to the columns of temperature and precipitation and are named at the left margin opposite their ends.

Plate I illustrates in a pictorial way, the climatic characteristics that prevail over California's agricultural lands. The precipitation section of this graph shows that almost without exception, the rainfall in amounts to be of much value to agriculture, is confined to the months of November, December, January, February and March; while the temperature section shows that the period favorable to the growth of plants and vegetation, is from March to November, inclusive. Except for March and November, the rains in California occur during the time of the year in which most plants are dormant and for seven warm months of the long growing season, the rains on the agricultural lands are light. Thus for a period during each twelve months, California is favored with precipitation-releasing winds, and once a year at coinciding times, the mountain ranges are clothed in snow, foothill eminences and slopes are drenched with rain, and valleys and plains are wetted by the same spacious storms; while through the remainder of the annual cycle, sunshine and warmth are dominant and precipitation is small in amount.

CHAPTER IV.

THE STATE'S WATERS.

The moisture-bearing winds that traverse California during the winter season precipitate three hundred billion tons of water annually upon the surface of the state. Most of this falls as rain or snow upon the mountain areas. This precipitation: as rain, strikes the surface of their slopes, off which portions run toward lower elevations; as snow, it mantles the earth's surface or collects in wind-blown drifts to await warmer temperature for conversion to liquid water, that may likewise pursue a downhill course toward the ocean.

These moving waters, ever journeying to lower elevations, concentrate in the ravines and gullies toward which the surfaces slope. They follow the steepest gradients and the most deeply cut depressions and, continually enhanced in volume by like accumulations, restlessly pursue their downward course until finally they become engulfed in the earth's vast reservoir of waters—the ocean. Falling on the drainage areas as precipitation, concentrating on the land surface as run-off, coursing down the water-channels as stream flow, these waters reach the ocean as drainage; and so by returning to the storehouse of waters from which they were first vaporized and carried to the mountainous area by the moisture-bearing winds, they complete a circuit of travel.

The same storms that drench the uplands or clothe them in snow, precipitate lesser amounts on the lower flat lands, and this almost entirely as rain. Lacking the surface inclination to put the water in motion, the earth coverings of these lowland areas largely absorb the rains falling upon them or, detained in pools or puddles or in the saturated top soil, they are later evaporated back to the atmosphere. Only during extremely heavy downpours of infrequent occurrence do the flat lands contribute run-off to the stream channels.

California's water-producing area is the mountains. Influenced by the topography, elevation, and exposure of the divers localities, the storms traversing the state deposit varying quantities of water on their diverse surfaces. In each area, however, only a portion of the waters cast from the clouds ever reach the stream channels; the rest is dissipated through evaporation. This division of the waters starts immediately with their precipitation from the rain clouds and continues throughout the entire water movement. Moisture is evaporated from the falling particles of rain or snow, from the gathering waters on their catchment areas, from the snow fields, from wetted soil areas, and from the flowing streams. Water is also vaporized from the vegetation that grows on the mountain slopes. Much of the moisture that wets the earth's surface is absorbed by the root systems of vegetation, so that where trees, bushes and undergrowth are dense, large volumes of water are vaporized through transpiration from plant-surfaces. So evaporation is persistently in progress, and, effectively and without respite, reduces the volumes of water precipitated upon the earth's sur-

A STREAM IN THE SIERRA NEVADA MOUNTAINS.

face. The fraction of these waters finally becoming stream flow in each season may be less than one-fourth or more than three-fourths of the total precipitation, according to the amounts falling, the contingencies of the season's weather, and the circumstances of topography and geology on the catchment areas.

Except as it falls upon frozen or nonabsorbent surfaces, precipitation upon striking the earth must first moisten its top-covering, and it is only after this has become saturated that waters gather on the surface to journey down the slopes of the catchment areas. While collecting in puddles and pools or moving down the slopes in streamlets, some of this run-off trickles into seams and cracks of the mountain's rocky structure, while other quantities are absorbed by pervious soil-coverings. This moisture advances by the attractions of gravity and capillarity and, filling the pores and interstices of the earth's crust, penetrates to great depths. Although usually only a small portion of the total, these percolating waters are especially valuable to man in their reappearance at lower elevations as perennial springs to moisten meadow lands or to increase the waning summer flow of brooks and streams. These tardy waters, in penetrating the subsurface regions and pursuing a dilatory underground course, wet the beds of the stream channels the year round and furnish nearly all of the dry season stream flow, and are the principal waters available when the great volume of winter run-off has subsided. Their total amount, however, is small, for three-fourths of the run-off from California's mountains concentrates in the stream channels, hurries down the water courses and passes by the low-lying agricultural lands within forty-five days after its precipitation upon the earth's surface.

Following precipitation so closely, the state's waters appear in the stream channels in fluctuating flows having a striking similarity to the periodic occurrence of precipitation. Plate II, "Characteristics of Run-off from California Mountains," presents the hydrographs of five streams, each typical of a separate section of the state. These hydrographs show the run-off, month by month, for the greatest year and for the least, as well as the mean monthly flow of all the years of record. For convenience of comparison, the monthly run-off is plotted in per cent of the annual mean. These hydrographs show how the bulk of California's waters run off their mountain catchment areas during the winter months, and how only meager quantities flow in the streams during the middle and late summer. The great variation between the run-off of the maximum and minimum years shows the wide limits between which seasonal run-off fluctuates, and how, in the smallest season, the usual scanty summer flow is much reduced and this much earlier in the season than in other years.

This investigation has studied the features of flow in all the streams of the state,[1] the amounts of their waters, and their variability of production. All discoverable data have been assembled and analyzed and, although actual measurements of flow are available but for a limited number of years on the major streams, through comparison of these data, quantities have been ascertained for every stream. For these purposes the minor streams were arranged in groups and these groups, together with the major streams, total one hundred and forty in number. The location of each one of these streams or groups of

[1] See Appendix "A," "Flow in California Streams."

minor streams is shown on the map of California, Plate IV, "Preliminary Comprehensive Plan for Maximum Development of California's Water Resources." Each basin bears a number on this map which refers to a table at the top of the sheet. This table gives the name of the stream draining the basin or the main stream in the group of small basins.

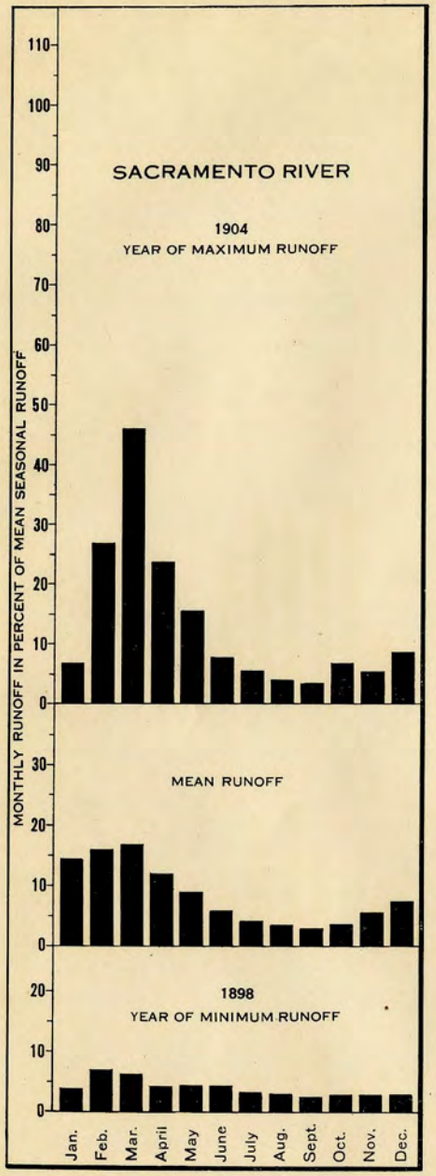
An audit of all these waters is presented in Table I, "Water Resources of California," in which is a complete inventory of the state's waters. In listing the flow at the head of the main body of agricultural land on each stream, the waters in this table are practically all that are available, both surface and underground, for use on the flat lands of the state for the subterranean waters of the flat lands largely receive their supply by percolation from the stream channels crossing them or from percolation of diverted waters poured out upon their land surfaces.

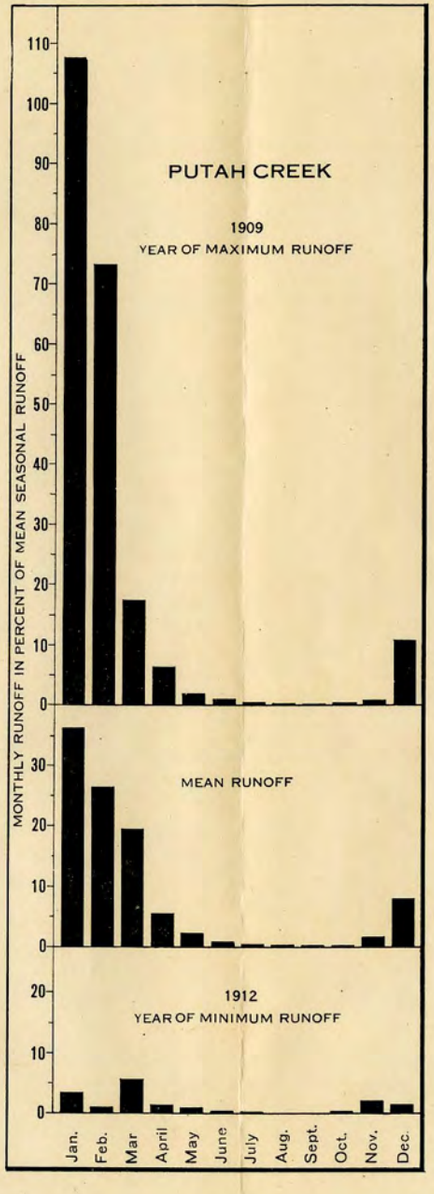
The first two columns of Table I contain the names of the streams or groups of minor streams and their reference numbers. Through these reference numbers, information that is too voluminous to incorporate in this summary tabulation may be conveniently traced in the diagrams and tables of Appendix "A" to this report. Spread out in forty columns to the right of these first two panels are values which characterize the amounts of water in each stream and its variability of flow.

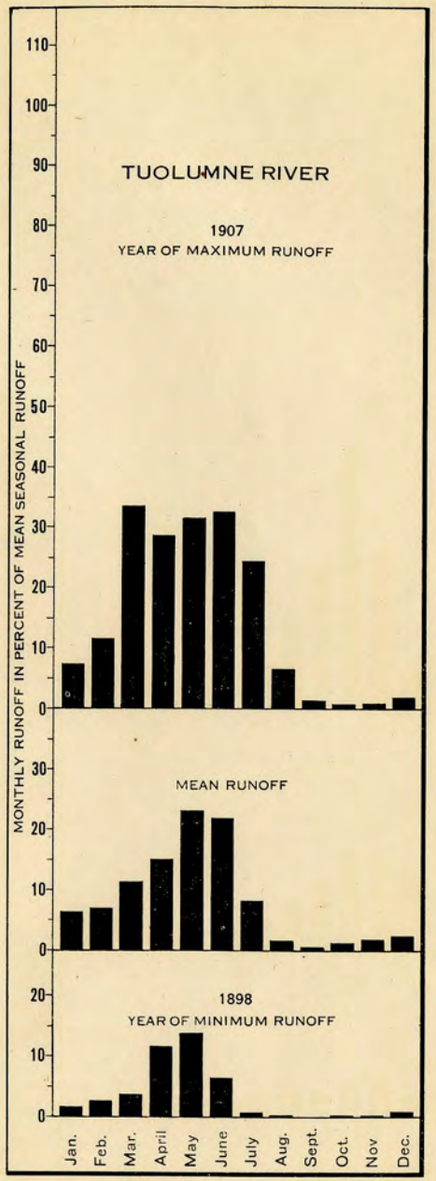
Of these columns, the third contains the areas of the drainage basins, while in the fourth to the twelfth are values of their run-off expressed in a variety of units. Included among these entries are the quantities of water running off their collecting areas in an average season, and in the seasons of greatest and least run-off. These quantities affixed to each stream definitely locate all the state's waters. The mean seasonal quantities express the average amounts in which they may be expected to appear and constitute a statement of practically all existing waters, while the values for the extreme seasons show the limits between which the flow of successive seasons may vary.

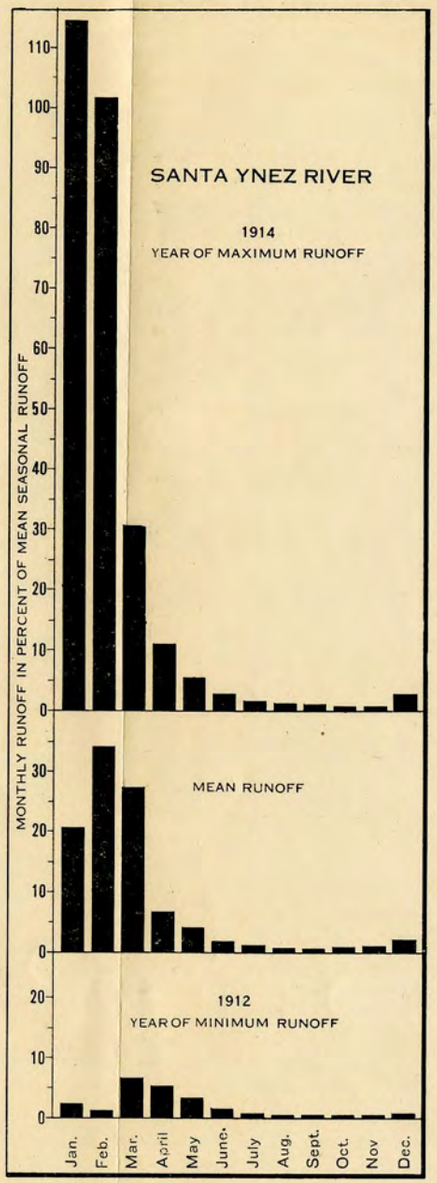
While the average annual water production of all these streams is 72,500,000 acre-feet, this invoice of California's waters shows that the combined maximum yield is two and three-quarters times this amount, and that the combination of all streams for the least seasons is but three-eighths as much as the average annual amount. The total run-off in successive seasons, then, fluctuates between limits, one seven times the other, and the value of any one season lies at random between them.

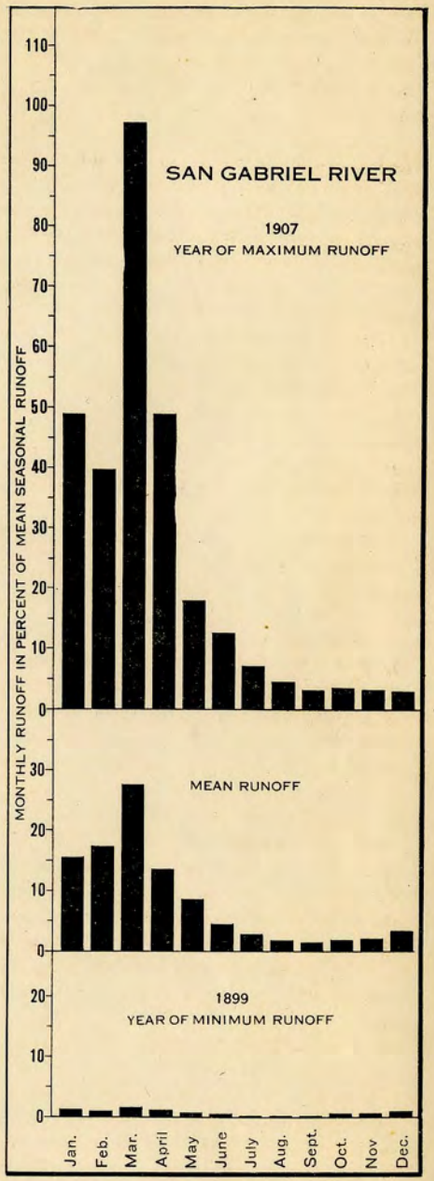
In addition to changing from year to year, all the streams of the state have a fluctuating daily flow. Inclusions have been made in columns 13 to 18, and 35 to 42, of Table I, to define the extremes between which the daily flows are accustomed to range. Columns 13 to 18 give values to the run-off during the months of July and August. These two midsummer months are times of the year of nearly the least flow, and in which water is of much value agriculturally. The quantities include the entire month's run-off expressed in acre-feet, and when divided by sixty afford approximate values of the average daily flow during the low water periods in cubic feet per second. Contrasting them, are the values of flood flows in columns 35 to 42. These entries are of special import in not only indicating the upper limits of variability in stream flow, but also in indicating the maximum











STATE DEPARTMENT OF PUBLIC WORKS
DIVISION OF ENGINEERING AND IRRIGATION
CALIFORNIA WATER RESOURCES INVESTIGATION
CHAPTER 889 -- 1921 STATUTES

CHARACTERISTICS OF RUNOFF
FROM
CALIFORNIA MOUNTAINS

Plate II

CHARACTERISTICS OF RUNOFF
FROM
CALIFORNIA MOUNTAINS

STATE DEPARTMENT OF PUBLIC WORKS
DIVISION OF ENGINEERING AND IRRIGATION
CALIFORNIA WATER RESOURCES INVESTIGATION
CHAPTER 699 — 1931 STATUTES

volumes of water which flood protection works may have to withstand. Comparisons of these flood values with the low water flows of July and August disclose a surprisingly great range in the rate of flow in California's streams.

As an average over the whole state, the greatest daily flow exceeds five hundred times the least. In taking values between these wide limits on every day of the successive years, the greater flows exceed the lesser ones in all degrees of magnitude, but the very large ones are the most infrequent in occurrence. To give perspective to the occurring frequency of exceedingly great flows, the values that may be surpassed within intervals of twenty-five, fifty, seventy-five, and one hundred years, are tabulated in columns 35 to 42. These greatest values of mean daily flow constitute the floods of California's streams. It is to be observed in general, that once in twenty-five years, the extraordinary values of daily flow swell at least forty fold the average volume in their channels; and that once in a hundred years, even these may be exceeded by flows that are one-quarter larger.

So large are the volumes of water that pass down the state's waterways during these great floods that the rate, which is only exceeded on an average of four times a century, would send a plethora of waters into the ocean within four days, whose aggregate is equivalent to the entire production of every drainage basin in the state for their seasons of least flow. During but one of these days, the total flow would be ample to supply an urban population of seventy millions of people with domestic water for a year, or to irrigate four million acres of agricultural land through an entire season, or, still, to generate one hundred thousand horsepower continuously for twelve months when dropping through a height of one hundred feet. Nevertheless, these volumes of water are largely useless to man because of their extremely infrequent appearance in the stream channels. The waters of lesser floods, however, may be caught by storage works constructed in the mountainous regions and be detained for later release to supplement the waning natural flow in the streams. By such detention of the flood waters for subsequent use, the erratic run-off may be equalized and made available to man at times convenient to his special purposes.

The greatest fractions of the mean seasonal flow which may be constrained to man's service through retention in storage reservoirs, are set forth for all the streams, in column 20 of Table I, and in column 21 are found the storage capacities required to do this. The yields from lesser amounts of storage are given in columns 23 to 34. The maximum yield possible from the entire water-producing area of the state is 58,300,000 acre-feet annually, or 80 per cent of the mean seasonal run-off. To secure this maximum yield would require a total capacity in storage works of 184,900,000 acre-feet. This volume is slightly greater than three times the annual equalized yield. Such large proportional amounts of storage are not needed if smaller fractions only of the mean seasonal flow are equalized. Capacity for storage of twice the net annual yield, will develop 70 per cent of the mean annual run-off from the state's drainage areas, and when this capacity is just equal to the annual yield in volume, it will develop 40 per cent of the mean seasonal run-off.

All these hydrographic quantities of Table 1, while having characteristics which qualify the state's waters as a whole, vary considerably for the separate drainage basins. Nevertheless, adjacent basins are sufficiently alike to render distinction to whole regions by reason of their special values. These regional values, in departing from the ones for the entire state, are still only indicative of the predominating characteristics of large areas. Individual basins within the regions may have features widely different from those predominating over them.

The six large topographic divisions of the state have such predominant regional characteristics. Of these, the Sacramento Drainage Basin is the largest. It comprises not only all the area lying between the Coast Range and Sierra Nevada Mountains as far south as Suisun Bay, but also the drainage area of Pit River, to the east of the mountains and in the northeastern corner of the state. This large basin contains one-fourth of the state's water-producing area, and, with the exception of the North Pacific Coast region, it produces more than any other of the six divisions and one-third of all California's waters.

The San Joaquin Drainage Basin is second largest of the six topographical divisions, but produces only one-sixth of the waters. This basin comprises the entire area between the Coast Range and Sierra Nevada Mountains, southerly from Suisun Bay to Tehachapi Pass.

The third largest division is the North Pacific Coast region, which includes all the streams draining in the Pacific Ocean northward from San Francisco Bay. It contains only one-fifth of the water-producing area, but its streams contain over one-third of all the waters of the state. This is a greater yield than in any other of the divisions. For equal area it produces one-third more water than the Sacramento Basin and over twice that of the San Joaquin. This region contains the most productive drainage basin in the state, the Smith River. Although its collecting area is only 627 square miles in extent, the mean annual run-off is nearly three and one-half million acre-feet.

The region that drains into the Pacific Ocean, southward from San Francisco Bay, is called the South Pacific Basin, and for its size is the region of smallest water yield. Although containing one-sixth of the drainage area, but one-twentieth of the state's waters run off its slopes.

Next in size is the region of the Great Basin, which comprises the areas easterly from California's principal mountain system, and whose waters do not reach the ocean. One-tenth of the water-producing area of the state is in this region but it yields only one-twentieth of the waters: its increment in total is about equal to that of the South Pacific region.

The smallest of the six topographic divisions is the area adjacent to San Francisco Bay, exclusive of the Sacramento and San Joaquin rivers. This locality contributes only 1 per cent of the total waters of the state.

There is a great difference between these six regions in the manner in which their waters run off the collecting areas. Generally the regions of least productivity have the greatest variability in run-off and demand the largest capacities in storage works to equalize their variable stream flow. The South Pacific, the least productive of the six state regions, requires almost three times the storage capacity necessary to obtain the same relative effects in equalized stream flow, as the North Pacific region, the most productive of the six state regions.

TABLE 1. WATER RESOURCES OF CALIFORNIA.

Number of drainage basin.	Stream.	Area of drainage basin above gaging station or body of agricultural lands, in square miles.	Seasonal run-off from drainage area above the main body of agricultural lands. For year of mean run-off. Total in acre-feet.	Average acre-feet per square mile of drainage area.	Average depth in inches on drainage area.	For year of maximum run-off. Total in acre-feet.	Average acre-feet per square mile of drainage area.	Average depth in inches on drainage area.	For year of minimum run-off. Total in acre-feet.	Average acre-feet per square mile of drainage area.	Average depth in inches on drainage area.	Run-off during July. Mean of all months of July, acre-feet.	Maximum of all months of July, acre-feet.	Minimum of all months of July, acre-feet.	Run-off during August. Mean of all months of August, acre-feet.	Maximum of all months of August, acre-feet.	Minimum of all months of August, acre-feet.	Water-supply for irrigation use of equalized flow in streams. Maximum net yield possible. In acre-feet per season.	In per cent of mean seasonal run-off.	Net yield of 40 per cent of mean seasonal run-off. Storage capacity required to equalize flow of stream. In acre-feet.	Acre-feet for one acre-foot of net yield.	Net yield of 50 per cent of mean seasonal run-off. Storage capacity required to equalize flow of stream. In acre-feet.	Acre-feet for one acre-foot of net yield.	Net yield of 60 per cent of mean seasonal run-off. Storage capacity required to equalize flow of stream. In acre-feet.	Acre-feet for one acre-foot of net yield.	Net yield of 70 per cent of mean seasonal run-off. Storage capacity required to equalize flow of stream. In acre-feet per season.	In acre-feet.	Acre-feet for one acre-foot of net yield.	Frequency of flood flows. Expected occurrence of once in 25 years of average flows for 24 hours equal in magnitude or greater than tabulated value. In cubic feet per second per square mile of drainage area.	In cubic feet per second.	Expected occurrence of once in 50 years of average flows for 24 hours equal in magnitude or greater than tabulated value. In cubic feet per second per square mile of drainage area.	In cubic feet per second.	Expected occurrence of once in 75 years of average flows for 24 hours equal in magnitude or greater than tabulated value. In cubic feet per second per square mile of drainage area.	In cubic feet per second.	Expected occurrence of once in 100 years of average flows for 24 hours equal in magnitude or greater than tabulated value. In cubic feet per second per square mile of drainage area.	In cubic feet per second.	Stream.	Number of drainage basin.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)	(37)	(38)	(39)	(40)	(41)	(42)	(43)	(44)
	SACRAMENTO BASIN.																																									**SACRAMENTO BASIN.**	
34	Sacramento River (Upper) above Pit River	568	1,486,300	2,616	49.1	3,500,900	6,162	115.5	573,800	1,010	18.9	31,200	73,500	12,000	22,300	52,500	8,600	1,278,220	86.0	3,715,750	2.91	594,520	549,930	0.93	743,150	787,740	1.06	891,780	1,189,040	1.33	1,040,410	1,857,880	1.79	75	42,600	89	59,400	97	54,900	101	57,300	Sacramento River (Upper) above Pit River	34
35	Pit River	5,346	4,204,900	786	14.7	8,220,000	1,538	28.8	2,355,200	441	8.3	252,300	493,200	154,200	79,600	427,400	132,600	1,884,340	87.0	7,358,050	2.01	1,681,840	882,970	0.53	2,102,300	1,303,430	0.62	2,522,760	1,972,070	0.78	2,943,220	2,732,990	0.93	8	44,400	9	48,100	9	49,600	Pit River	35
36	McCloud River	669	1,591,200	2,378	44.6	3,270,000	4,888	91.5	800,500	1,197	22.4	87,500	179,800	45,700	76,600	163,500	41,500	1,284,340	87.0	2,784,600	2.01	636,480	534,150	0.83	795,600	692,370	0.87	954,720	716,040	0.75	1,113,840	1,113,840	1.00	75	50,200	89	59,400	97	54,600	101	57,500	McCloud River	36
37	*Churn Creek Group	100	83,100	830	15.5	294,800	2,938	55.1	3,200	32	0.6	1,700	6,200	70	1,200	4,400	50	61,490	74.0	415,500	6.76	33,240	23,960	0.72	41,550	115,510	2.78	49,860	188,640	3.78	58,170	328,250	5.64	113	.....	124	.....	129	.....	133	.....	*Churn Creek Group	37
38	Cow Creek	444	310,200	1,102	21.7	1,531,300	3,452	64.7	35,900	88	1.6	10,700	32,200	820	7,700	23,000	580	292,550	77.0	1,220,500	4.64	294,080	117,940	0.40	353,100	617,340	2.42	306,120	1,020,400	3.33	357,140	1,857,740	5.29	97	43,900	105	47,700	111	49,500	50,600	Cow Creek	38
39	*Bear Creek Group	137	103,700	756	14.2	312,800	2,280	42.7	1,400	10	0.2	2,200	6,600	30	1,600	4,700	20	79,850	77.0	518,500	6.49	41,480	98,530	2.38	51,850	142,070	2.74	62,220	222,960	3.58	72,590	388,880	5.36	112	15,300	121	16,600	126	17,300	131	17,900	*Bear Creek Group	39
40	Battle Creek	366	421,800	1,151	21.6	1,035,700	2,799	52.5	135,300	377	7.1	8,900	21,500	2,900	6,300	15,400	2,100	345,880	82.0	1,623,950	4.70	168,720	168,720	1.00	210,900	253,080	1.20	253,080	404,930	1.60	295,260	717,090	2.43	103	37,800	113	41,400	118	43,200	121	44,200	Battle Creek	40
41	Ink's Creek	34	28,200	835	15.5	96,400	2,821	52.8	300	6	0.1	500	2,020	Trace	420	1,450	Trace	19,740	70.0	141,000	7.14	11,280	29,330	2.60	14,100	45,680	3.24	16,920	77,550	4.58	19,740	141,000	7.14	133	4,520	145	4,920	149	5,070	153	5,220	Ink's Creek	41
42	Payne's Creek	80	54,200	1,048	19.6	257,800	3,208	60.1	7,700	96	1.8	1,800	5,400	160	1,200	3,900	120	43,680	85.0	334,150	6.55	33,680	69,890	2.08	42,100	111,140	2.64	50,520	191,980	3.80	58,940	370,430	6.29	122	9,770	135	10,750	140	11,200	144	11,500	Payne's Creek	42
43	*Backbone Creek Group	178	207,500	1,166	21.8	642,300	3,609	67.7	2,000	11	0.2	4,400	13,500	40	3,100	9,600	30	157,700	76.0	1,037,500	6.58	83,000	178,450	2.15	103,750	259,380	2.50	124,500	425,380	3.42	145,250	809,250	5.57	89	.....	105	.....	113	.....	120	.....	*Backbone Creek Group	43
44	Clear Creek	251	294,900	1,175	23.0	850,800	3,390	63.6	43,300	173	3.2	6,200	17,900	910	4,400	12,800	650	232,970	79.0	1,356,540	5.82	117,960	191,690	1.63	147,450	300,800	2.04	176,940	471,840	2.67	206,430	884,700	4.29	78	19,550	91	22,900	100	24,950	105	26,300	Clear Creek	44
45	Cottonwood Creek	937	913,300	974	18.3	2,697,100	2,877	53.9	104,400	111	2.1	19,200	56,600	2,200	13,700	40,500	1,600	648,440	71.0	4,018,520	6.20	367,360	365,320	0.99	459,200	593,650	1.29	550,840	940,700	2.06	647,980	1,598,380	2.92	63	59,200	69	64,100	73	66,100	75	70,500	Cottonwood Creek	45
46	*Sacramento River at Red Bluff	9,358	9,929,000	1,072	20.1	22,700,000	2,452	46.0	4,068,800	439	8.2	397,300	908,000	175,600	337,600	771,500	149,300	8,042,490	81.0	34,731,500	4.32	3,971,600	2,680,830	0.68	4,964,500	3,971,600	0.80	5,957,400	6,155,980	1.03	6,950,300	12,609,830	1.81	27	249,000	31	286,000	32	299,000	32	311,000	*Sacramento River at Red Bluff	46
47	*Mill Creek Group	371	1,157,400	1,192	22.4	2,610,000	2,688	50.4	513,000	528	9.9	40,500	91,400	18,000	24,300	54,800	10,800	891,200	77.0	2,314,800	2.60	462,960	370,370	0.80	578,700	567,130	0.98	694,440	868,050	1.25	810,180	1,331,010	1.64	98	.....	113	.....	120	.....	122	.....	*Mill Creek Group	47
48	*Butte Creek Group	231	358,400	1,428	26.8	539,000	3,343	62.7	142,000	566	10.6	6,800	15,900	4,400	5,000	11,700	2,000	272,380	76.0	732,640	2.76	143,360	143,360	1.00	179,200	215,040	1.20	215,040	329,730	1.53	250,880	530,430	2.11	109	.....	122	.....	130	.....	134	.....	*Butte Creek Group	48
49	Feather River	3,627	5,283,500	1,456	27.3	12,090,000	3,333	62.5	2,073,900	572	10.7	163,800	377,400	75,500	100,400	229,700	46,300	4,226,800	80.0	10,567,000	2.50	2,113,400	1,849,230	0.88	2,641,750	2,694,590	1.02	3,170,100	4,121,130	1.30	3,698,450	5,970,360	1.61	47	171,000	52	190,000	57	205,000	59	215,000	Feather River	49
50	*Honcut Creek Group	314	199,400	636	11.9	522,000	1,664	31.2	59,000	188	3.5	1,600	4,200	470	200	520	60	143,570	72.0	498,500	3.47	79,760	105,680	1.33	99,700	165,500	1.66	119,640	243,270	2.03	139,580	408,770	2.93	103	.....	114	.....	121	.....	125	.....	*Honcut Creek Group	50
51	Yuba River	1,300	2,652,600	2,210	41.4	6,176,000	5,147	96.3	998,400	832	15.6	60,000	194,800	20,000	21,200	49,400	8,000	2,173,130	82.0	5,039,940	2.32	1,061,040	1,067,990	0.95	1,326,300	1,458,930	1.10	1,591,560	2,095,550	1.32	1,856,820	2,917,860	1.57	106	127,500	121	145,500	128	153,000	133	160,000	Yuba River	51
52	Dry Creek	79	49,700	627	11.8	137,300	1,733	32.9	14,800	187	3.5	350	960	100	190	520	50	37,770	76.0	124,250	3.29	19,840	22,560	1.15	24,800	39,530	1.59	29,820	51,190	1.72	34,790	79,520	2.29	103	5,170	114	6,020	121	6,510	124	6,770	Dry Creek	52
53	Bear River	262	412,500	1,574	29.5	1,117,900	4,267	80.0	118,800	453	8.5	4,125	11,600	650	2,475	8,900	560	335,880	79.0	1,113,750	3.42	165,000	206,250	1.25	206,250	305,250	1.48	247,500	445,500	1.80	288,750	635,250	2.20	112	29,200	121	31,700	126	33,100	129	33,800	Bear River	53
54	*Coon Creek Group	210	34,100	162	3.0	124,200	591	11.1	6,700	32	0.6	0	0	0	0	0	0	23,190	68.0	88,650	3.83	13,640	22,850	1.68	17,050	34,100	2.00	20,460	51,150	2.50	75	.....	82	.....	86	.....	89	.....	*Coon Creek Group	54
55	American River	1,919	1,581,900	1,033	31.1	7,725,200	4,026	75.5	1,180,900	618	11.6	117,700	392,500	22,800	28,600	92,800	9,500	2,577,340	81.0	5,091,940	1.98	1,272,760	1,113,670	0.88	1,590,950	1,527,310	0.96	1,909,140	2,068,240	1.08	2,227,330	2,990,890	1.34	74	.....	82	.....	86	.....	88	.....	American River	55
56	*Red Bank Creek Group	109	23,000	672	12.6	202,300	1,861	34.9	20,300	187	3.5	510	1,420	140	370	1,010	100	18,910	67.0	219,000	4.29	29,200	35,040	1.20	36,500	54,750	1.50	43,800	94,900	2.17	52	.....	58	.....	61	.....	63	.....	65	.....	*Red Bank Creek Group	56
57	*Elder Creek Group	414	213,000	515	9.7	611,000	1,476	27.7	57,000	138	2.6	1,400	4,280	400	1,070	3,060	290	140,580	66.0	511,230	3.64	85,200	106,500	1.25	106,500	170,400	1.60	127,800	208,200	2.33	52	.....	58	.....	61	.....	63	.....	65	.....	*Elder Creek Group	57
58	Stony Creek	710	555,000	782	14.6	1,495,500	2,106	39.5	124,900	176	3.3	2,890	10,000	900	2,780	11,400	840	360,750	65.0	1,470,750	4.08	222,000	321,900	1.45	277,500	499,500	1.80	333,000	888,000	2.67	63	45,600	69	48,600	72	51,600	75	53,500	Stony Creek	58
59	*Willow Creek Group	394	92,200	234	4.4	265,000	672	12.5	27,000	68	1.3	650	1,860	190	460	1,330	140	61,770	67.0	230,500	3.73	36,883	46,100	1.25	46,100	69,150	1.50	55,320	124,470	2.25	69	.....	74	.....	77	.....	79	.....	*Willow Creek Group	59
60	Cache Creek	1,195	586,000	490	9.2	1,638,000	1,371	25.7	174,600	146	2.7	52,740	147,400	17,300	42,780	119,600	13,900	404,340	69.0	1,172,000	2.90	234,400	175,800	0.75	293,000	263,700	0.90	351,600	468,800	1.33	17	20,550	18	20,900	18	21,500	18	21,850	Cache Creek	60
61	Putah Creek	635	453,000	713	12.1	1,539,000	2,422	45.6	17,000	26	0.5	1,270	3,720	50	840	2,480	30	253,080	69.0	1,265,400	5.00	166,720	366,970	2.18	210,900	603,170	2.86	253,080	1,265,400	5.00	70	45,800	75	49,300	77	50,200	78	51,100	Putah Creek	61
	Totals and means for Sacramento Basin	21,420	25,199,500	1,176	22.1	.....	2,777	52.1	.....	448	8.4	.....	.....	.....	.....	.....	.....	20,263,640	80.4	56,380,930	2.78	10,079,899	9,458,680	0.94	12,599,750	14,032,950	1.11	15,119,700	21,812,690	1.44	.....	.....	.....	54	.....	60	.....	64	.....	66	.....	Totals and means for Sacramento Basin	
	SAN JOAQUIN BASIN.																																								**SAN JOAQUIN BASIN.**	
62	*Orestimba Creek Group	1,340	110,800	83	1.6	450,200	336	6.3	0	0	0.0	4,800	19,400	0	0	.....	0	66,480	60.0	387,830	5.83	44,320	110,800	2.50	55,400	171,740	3.10	66,480	387,830	5.83	.....	.....	.....	32	.....	36	.....	39	.....	40	.....	*Orestimba Creek Group	62
63	Panoche Creek	295	27,100	92	1.7	105,500	358	6.7	0	0	0.0	1,100	3,040	0	0	.....	0	16,830	62.0	89,430	5.32	10,840	30,350	2.80	13,550	44,720	3.30	16,260	74,530	4.58	.....	.....	.....	34	9,900	38	11,100	40	11,900	43	12,700	Panoche Creek	63
64	*Cantua Creek Group	208	12,500	60	1.1	55,500	267	5.0	0	0	0.0	540	2,400	0	0	.....	0	7,250	58.0	42,500	5.86	5,000	13,130	2.63	6,250	22,500	3.60	7,500	36,750	4.90	.....	.....	.....	24	.....	28	.....	31	.....	33	.....	*Cantua Creek Group	64
65	Los Gatos Creek	119	9,700	82	1.5	41,300	347	6.5	0	0	0.0	420	1,783	0	0	.....	0	5,950	61.0	34,130	5.74	3,900	11,600	2.98	4,880	16,870	3.46	5,850	29,740	5.08	.....	.....	.....	30	3,320	35	4,170	38	4,320	38	4,480	Los Gatos Creek	65
66	*Arroyo Cantua Creek	341	95,600	71	1.3	414,000	309	5.8	0	0	0.0	4,100	17,800	0	0	.....	0	54,400	67.0	382,400	7.03	38,240	109,500	2.13	47,800	205,000	4.29	.....	.....	.....	.....	.....	.....	31	.....	34	.....	36	.....	37	.....	*Arroyo Cantua Creek	66
67	Caliente Creek	471	45,000	96	1.8	201,000	427	8.0	0	0	0.0	1,900	8,600	0	0	.....	0	23,400	52.0	225,000	9.62	18,000	92,250	5.13	22,500	189,000	8.40	.....	.....	.....	36	17,100	43	20,300	46	21,600	48	22,800	Caliente Creek	67
68	Kern River	2,410	760,400	316	5.9	2,474,500	1,027	19.2	283,000	117	2.2	82,900	402,300	17,300	34,200	143,300	9,700	577,900	76.0	1,748,920	3.03	304,160	190,980	0.63	380,200	342,180	0.90	456,240	593,110	1.30	532,280	1,054,560	2.00	6	14,940	7	16,400	7	16,850	7	17,600	Kern River	68
69	*Poso Creek Group	576	47,200	82	1.5	184,500	320	6.0	0	0	0.0	2,000	7,900	0	0	.....	0	31,220	66.0	141,900	4.55	18,920	41,190	2.18	23,650	60,070	2.54	28,380	86,560	3.05	.....	.....	.....	22	.....	25	.....	27	.....	28	.....	*Poso Creek Group	69
70	Deer Creek	110	20,650	187	3.5	67,000	608	11.4	4,100	37	0.7	630	2,820	160	410	1,340	80	15,283	74.0	91,630	5.99	8,260	31,030	3.76	10,330	42,150	4.08	12,390	59,810	4.83	14,460	95,110	6.43	24	3,560	26	3,850	28	3,990	28	4,150	Deer Creek	70
71	Tule River	390	141,500	363	6.8	448,800	1,152	21.6	27,000	69	1.3	4,390	29,740	840	1,560	7,000	300	107,540	76.0	353,750	3.29	56,600	49,530	0.88	70,750	84,900	1.20	84,900	134,430	1.58	99,050	222,160	2.24	24	9,250	26	10,070	27	10,600	28	11,000	Tule River	71
72	*Yokohl Creek Group	98	14,800	151	2.8	58,500	598	11.2	0	0	0.0	640	2,520	0	0	.....	0	9,923	67.0	48,840	4.93	5,920	11,840	2.00	7,400	16,580	2.24	8,880	25,160	2.83	.....	.....	.....	32	.....	35	.....	36	.....	38	.....	*Yokohl Creek Group	72
73	Kaweah River	514	407,900	794	14.9	1,083,400	2,118	39.7	49,300	96	1.8	34,700	211,000	4,100	8,570	42,500	1,040	342,840	84.0	815,800	2.38	163,160	171,220	1.05	202,950	216,100	1.06	244,740	285,530	1.17	285,530	387,500	1.36	23	11,780	26	14,100	28	14,500	29	14,500	Kaweah River	73
74	*Limekiln Creek Group	201	62,200	310	5.8	198,100	987	18.5	7,500	37	0.7	2,700	8,500	320	0	.....	0	46,650	75.0	155,500	3.33	24,880	32,970	1.33	31,100	49,760	1.60	37,320	71,530	1.92	43,540	108,850	2.50	32	.....	35	.....	36	.....	38	.....	*Limekiln Creek Group	74
75	Kings River	1,925	1,925,100	1,126	21.3	5,221,000	3,083	57.8	334,000	197	3.7	221,400	1,000,000	38,400	67,400	264,000	11,700	1,540,080	80.0	5,101,520	3.31	770,040	577,530	0.75	962,550	866,300	0.90	1,155,060	1,155,060	1.00	1,347,570	1,540,080	1.14	20	34,200	23	38,200	24	39,900	25	41,800	Kings River	75
76	Dry Creek	48	4,500	94	1.8	18,100	379	7.1	0	0	0.0	100	430	0	10	50	0	3,150	70.0	11,250	3.57	1,800	1,800	1.00	2,250	3,090	1.64	2,700	5,760	2.13	3,150	11,250	3.57	46	2,190	48	2,320	50	2,390	51	2,450	Dry Creek	76
77	San Joaquin River (Upper)	1,631	2,056,900	1,261	23.6	5,732,000	3,514	65.9	[470,000	288	5.4	205,690	587,900	47,000	65,800	183,400	15,000	1,645,520	80.0	4,112,800	2.50	822,760	573,930	0.70	1,028,450	843,330	0.82	1,234,140	1,151,860	0.93	1,439,830	1,604,580	1.11	22	35,600	24	39,000	25	40,800	26	42,100	San Joaquin River (Upper)	77
78	Cottonwood Creek	28	2,300	81	1.5	10,500	368	6.9	0	0	0.0	50	240	0	10	50	0	1,470	64.0	8,280	5.63	920	1,840	2.00	1,150	2,810	2.44	1,380	5,060	3.67	.....	.....	.....	43	1,230	47	1,340	50	1,420	51	1,460	Cottonwood Creek	78
79	Fresno River	270	68,300	253	4.7	233,600	867	16.3	4,300	18	0.3	1,570	5,370	140	340	1,170	14	49,860	73.0	204,900	4.11	27,320	35,520	1.30	34,150	49,860	1.46	40,980	71,030	1.73	47,810	114,060	2.39	40	10,850	42	11,620	45	12,010	46	12,500	Fresno River	79
80	*Daulton Creek Group	66	5,200	78	1.5	24,100	363	6.8	0	0	0.0	120	550	0	10	120	0	3,430	66.0	20,800	6.06	2,080	4,160	2.00	2,600	6,240	2.40	3,120	11,960	3.83	.....	.....	.....	43	.....	47	.....	50	.....	51	.....	*Daulton Creek Group	80
81	Chowchilla River	238	67,700	284	5.3	195,100	820	15.4	1,200	5	0.1	1,560	4,490	28	340	976	6	48,740	72.0	121,860	2.50	27,080	40,620	1.50	33,850	54,940	1.62	40,620	74,470	1.83	47,390	108,320	2.29	38	8,780	41	9,530	43	10,000	44	10,350	Chowchilla River	81
82	*Dutchman Creek Group	72	8,300	115	2.2	31,500	438	8.2	0	0	0.0	190	720	0	40	160	0	5,150	62.0	21,580	4.19	3,320	8,300	2.50	4,150	12,040	2.90	4,980	18,680	3.75	.....	.....	.....	44	.....	50	.....	53	.....	54	.....	*Dutchman Creek Group	82
83	Mariposa Creek	103	12,500	120	2.2	45,200	439	8.5	0	0	0.0	290	1,110	0	30	240	0	8,190	64.0	30,720	3.75	5,120	10,240	2.00	6,400	14,720	2.30	7,680	21,760	2.83	.....	.....	.....	41	5,280	54	5,550	56	5,830	56	5,830	Mariposa Creek	83
84	*Owens Creek	66	6,500	98	1.8	27,900	421	7.9	0	0	0.0	150	640	0	30	140	0	4,030	62.0	19,500	4.84	2,600	6,180	2.38	3,250	8,780	2.70	3,900	15,600	4.00	.....	.....	.....	36	2,290	40	2,660	43	2,840	44	2,930	*Owens Creek	84
85	Bear Creek	71	7,500	105	2.0	29,700	416	7.8	0	0	0.0	70	280	0	40	150	0	4,730	63.0	21,000	4.44	3,000	7,880	2.63	3,750	11,250	3.00	4,500	16,130	3.58	.....	.....	.....	40	2,670	45	3,240	48	3,450	50	3,580	Bear Creek	85
86	*Burns Creek Group	171	24,400	143	2.7	80,200	469	8.8	0	0	0.0	70	240	0	0	.....	0	15,020	64.0	68,320	4.38	9,760	29,280	3.00	12,200	40,600	3.33	14,640	62,480	4.27	.....	.....	.....	63	.....	66	.....	69	.....	71	.....	*Burns Creek Group	86
87	Merced River	1,054	1,133,500	1,075	20.2	2,955,000	2,803	52.6	220,000	209	3.9	99,800	385,000	13,000	23,900	58,300	3,800	895,470	79.0	1,813,600	2.03	453,400	430,730	0.95	566,750	612,090	1.08	680,100	884,130	1.30	793,450	1,224,180	1.54	35	36,000	38	38,900	40	41,600	43	44,400	Merced River	87
88	Tuolumne River	1,543	2,055,850	1,332	24.9	5,099,000	3,305	61.8	561,000	363	6.8	166,320	712,900	16,900	32,990	135,900	2,500	1,655,760	82.0	3,494,860	2.07	822,320	472,860	0.58	1,027,900	719,530	0.70	1,233,480	1,110,120	0.90	1,439,060	1,644,940	1.14	26	40,300	31	47,700	34	51,800	35	54,000	Tuolumne River	88
89	*Wildcat Creek Group	59	8,850	151	2.8	32,900	560	10.5	0	0	0.0	320	1,100	0	0	.....	0	5,490	62.0	35,670	4.66	3,540	9,740	2.75	4,430	12,390	2.80	5,310	21,760	4.09	.....	.....	.....	78	.....	84	.....	87	.....	89	.....	*Wildcat Creek Group	89
90	Stanislaus River	983	1,376,000	1,393	26.1	3,580,000	3,642	68.2	62,900	64	1.2	76,700	318,200	3,520	16,400	64,000	0	1,032,000	75.0	3,027,200	2.93	550,400	688,000	1.25	688,000	550,400	0.80	825,600	866,880	1.05	963,200	1,651,200	1.71	51	50,200	60	55,200	66	64,600	69	67,500	Stanislaus River	90
91	Littlejohns Creek	41	8,150	201	3.8	28,700	709	13.3	400	10	0.2	20	90	Trace	0	.....	0	5,380	66.0	18,750	3.48	3,260	6,760	2.08	4,080	9,540	2.34	4,890	13,200	2.70	.....	.....	.....	51	3,310	94	3,860	101	4,130	107	4,400	Littlejohns Creek	91
92	*Martells Creek Group	122	14,300	117	2.2	44,900	368	6.9	0	0	0.0

TABLE I. WATER RESOURCES OF CALIFORNIA.

Of the basins of intermediate water productivity, the Sacramento and San Joaquin are about equal in relative storage requirements. Although the streams of the San Joaquin drainage have a much greater range in variation of annual run-off than those of the Sacramento, the bulk of the San Joaquin waters run off later in the season than those of the Sacramento, and so, in general, storage works are about equally effective in each basin. These two basins require slightly less storage capacity for equal relative results to that required by the North Pacific region, for the North Pacific region has the smaller summer flow in its streams. However, the relative storage requirements in these three regions are nearly alike.

The San Francisco Bay region, because of its smaller fluctuation in annual run-off than the South Pacific, and greater than the Sacramento or San Joaquin, falls intermediate in effectiveness of storage on its streams, between the South Pacific region and the three greatest water producing basins of the state, in which storage capacity, on the whole, is nearly equally effective. Almost twice as much capacity in storage works is necessary in the San Francisco Bay region to gain equal relative results in equalizing its stream flow as in either of the Sacramento or San Joaquin basins.

The relative amounts of storage required to equalize stream flow, largely pertain to the range in variation between years of maximum and minimum run-off and to the apportionment of the annual run-off between the winter and summer months. The North Pacific region has the smallest variation in annual run-off, and there the maximum is only five times that of the minimum season. The maximum year in the Sacramento Basin is six times the least, while in all the other regions the variation is much larger than in these two. In the San Joaquin it is fifteen times the least, in the San Francisco Bay region it is seventy times the least, and in the South Pacific the year of maximum run-off is one hundred times the least year.

While the San Francisco Bay region has the smallest portion of its waters wetting the stream channels during the summer months, the Great Basin drainage, east of the Sierras and southern California mountains, is distinguished by having the largest apportionment of summer flow of any of the six regions. The streams of the San Joaquin Basin are next in order and those of the Sacramento not far behind. The North Pacific region has an intermediate apportionment in the summer months between that of the San Joaquin and that of the South Pacific region.

Similar comparisons may be made between any of the individual drainage basins in the state by referring to Table I in the proper columns. The flow in all streams during the largest, the smallest, and the average season, as well as during the midsummer months, is there. Also the storage capacity required to equalize their variant flows and the size of extreme floods are enumerated. So, comprised within Table I, is a complete inventory of all the waters of the state, which includes their locations, their quantities and their variabilities. The values entered in the table are averages for the past half century and should be indicative of future expectancies, so that this table presents in full the water resources of the State of California with their characterizations.

CHAPTER V.

UTILIZATION OF THE STATE'S WATERS.

Only one-half of the wide expanse of California contributes much to the waters of its streams. The other half, lower in altitude and more even of surface, is favorably disposed for occupancy by man, and its populated sections need water in order that their industrial expansion may continue and their communal civilization progress steadily onward. The production of food, the generation of power, and the supply of water for domestic use, in the drier half of the state, are largely dependent upon the waters of the streams which have their source in the more elevated regions. The farmer relies upon the streams during the warm, dry summers for supplementary moisture to mature his crops and upon their hydro-electric energy to pump his irrigation waters. The electric energy, generated by the waters of the streams as they descend the mountains' slopes, furnishes power and illumination to the industrial centers, and light and heat and means of operating many conveniences, to the entire social state. But most of all, the cities, towns, and villages, the pleasures and comforts of their congregated peoples, require these waters in abundance for drinking and household purposes. The expansion of all these benefits to include larger populations, demands increased supplies of water for the future with uninterrupted service in purity and plenty, at all times of the year, and in all successive years alike.

The vital importance of water in the economic development of California is succinctly shown in the history of the state's production. By 1920, with but three per cent of all the people in the entire United States residing within California's borders, this state, eighteenth in the area of land farmed, was fifth in position among the states of the Union in value of farm crops; and while in the eighth position in value of manufactures, was second in the installed capacity of water wheels for the hydro-generation of electric current. Since 1920, this state has advanced from fifth to fourth[1] among the states of the Union in value of agricultural products.

The advance to so favorable a comparison in agricultural output with the other forty-seven states of the Union, has been made without any increase in the total area in improved farms. In fact, thirty-five years have elapsed since the aggregate area in improved farms in California has increased. Although there are twenty-three million acres of land susceptible of agriculture within the state's borders, the enlargement of the area tilled ceased when but half of the total had been brought under cultivation. As a result of the unprofitable farming conditions obtaining on the remaining millions of acres, the area under cultivation did not further enlarge; the experience of the practical farmer limited the total area cultivated to but half the agricultural lands. Some

[1]Statistics of California State Department of Agriculture show that this state was exceeded in value of agricultural products by Texas, Iowa and Illinois.

additional areas having inadequate natural moisture have since been added to the total area of improved farms by developing accessory water supplies, but the abandonment of other areas previously farmed has compensated in their summation so that the total acreage in improved farms has remained practically unchanged for thirty-five years.

This limit to the area in improved farms was reached in the year 1885. Prior to this year, the tilled area had expanded in leaps and bounds from the great impetus to farming enterprises that followed the world wide movement to this state after the discovery of gold at the midway point of the last century. This enlargement of the farmed area continued at a rapid rate for a third of a century, then slackening, it ceased about 1885.

With less than 12,000,000 acres cultivated, all of the state's agricultural area with sufficient natural moisture to mature a profitable crop had been brought into use. Since 1885, the state has had no additional area that could be profitably utilized for agriculture in its natural condition, so that in response to the continuing favorable market for agricultural products, a more intensive farming of the land already under cultivation has been in progress. All through these thirty-five years, the demand for products of California's agriculturists has never ceased to increase at an accelerated rate. California, favorably situated, its fertile agricultural soils producing to capacity under conditions of dry farming, required only that additional water be applied to these lands to multiply their yield. The practical farmer, answering to the ever-enlarging market for his products, increased the yield of many acres by supplementing the soil's natural moisture with water applied through irrigation. In this way the state has continued. through the last thirty-five years, to respond to the constantly increasing demand for its farm products, and in this way the potent possibilities of California's farm lands are being invoked to a yield greater in value than in any other state of the Union.

The utility of the state's waters in augmenting the yield of its agricultural lands and the demands of the future, may best be ascertained through an investigation of the use of water in the past. The quantity of accessory water needed for growing crops to an harvestable maturity, may best be derived from the results of experience and practice. California's lands, deficient in natural moisture during the growing season of agricultural plants, have received varying quantities of water. The amounts applied on the sundry tracts in the divers localities, differ widely with all the circumstances and conditions affecting the use of water. The application to different fields has varied greatly even for like crops, for not only do the quantities of water used vary with the incentive for their economic application, but the amounts that are dissipated in the process of irrigation change greatly with contingent circumstances, and even the actual quantity necessary for absorption by the root systems of the plants, is conditional.

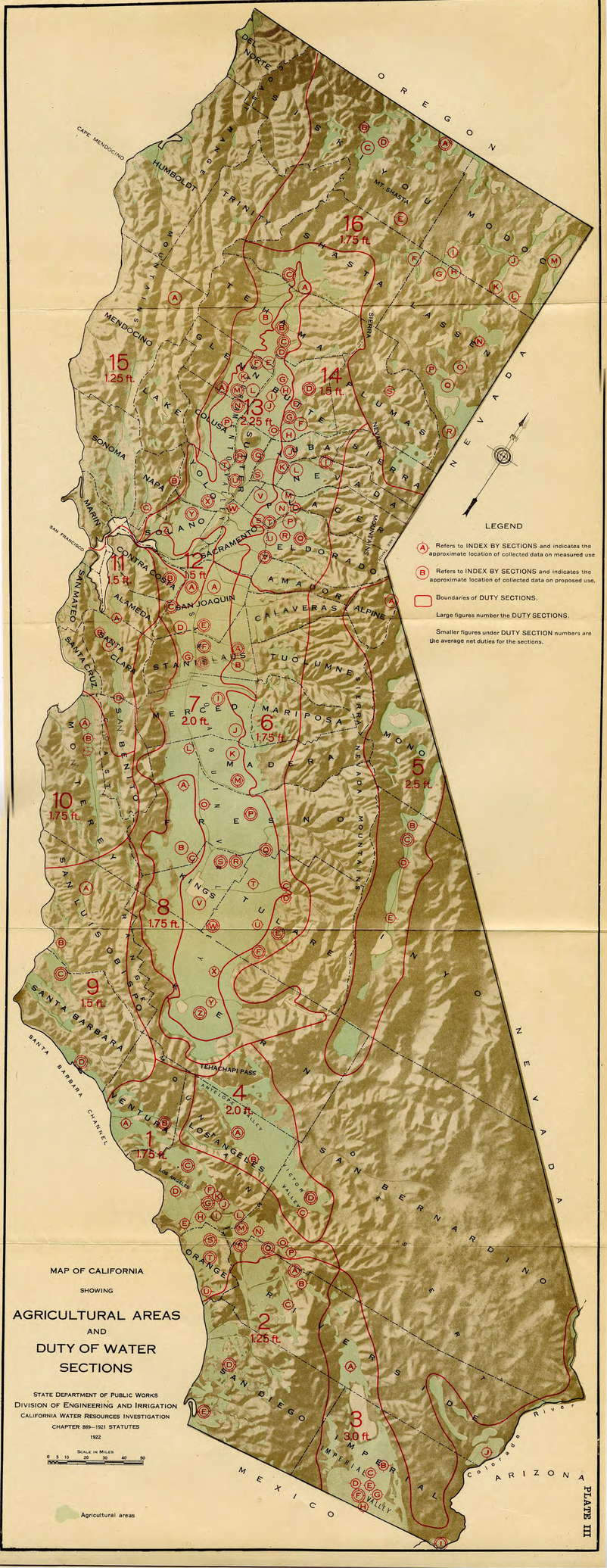
These circumstances and conditions necessitating the application of more or less accessory water, are so vast in number, changing with every variation in soil, crop, and preparation for spreading water, that on small tracts of land, the effect of one may predominate, but on greater areas they tend to neutralize in effect. For this reason the average use of water on very large areas approaches like figures, while the use on small tracts within these large areas, may take wide numer-

ical departure from the general average. The larger the areas compared, usually the closer is the agreement of numerical values in the records of use. From the average use of water on large areas, sufficiently great to suppress the predominance of effects peculiar to small parcels, natural divisions of the state, sixteen in number, have been evolved, and called duty of water sections. These sections comprise within their boundaries, lands of approximately like geographic position, similar surface conformation, of analogous economic environment, and equal climate, and so form convenient segregations for the disclosure of the irrigation requirements of California's agricultural lands.

Delineated on Plate III, "Map of Agriculture Areas and Duty of Water Sections," the boundaries of these sections show as red lines following natural dividing conformations of the land surface. The agricultural lands show as light green areas within the delimiting red lines. Letters within circles, interspersed throughout the green areas, indicate the location of individual irrigation systems or of divers tracts of land for which data on the actual use of water or on proposed uses, have been collected by these investigations. A searching inquiry of the use of water has been made and water measurements have been assembled applying to an area that equals more than half the lands irrigated in the entire state during 1919. These records are the summation of the labors of a great many engineers and hydrographers that cover the major portion of the last two decades. These extensive data are included with pertinent material in Appendix "B" to this report and the letters within the circles on the map, are attached to the data on the plates and in the tables of this appendix, so that the approximate geographic situation of the lands to which the data apply may be traced.

That the water requirements for each of the several sections of the state might be derived from this great assemblage of information, an examination of the circumstances and a close scrutiny of the conditions were made, surrounding the use of water in each section. All information on the types and fertility of soils, the crops grown, the climate, the water supply, the surface conformation of the land, and all other subjects related to irrigation requirements, was reviewed and compared with the measured and proposed uses of water. Practical working quantities required of accessory water supplies in each section, were so evolved and recorded in Table 2, "Agricultural Area and Net Duty of Water in the Sixteen Sections of California." The total area of agricultural land in each section is also recorded in this table and numbers are given to each section that show their location on the map, Plate III.

These practical working quantities in Table 2 that set forth the general water needs of the agricultural areas in each section, are expressed as the amount of water required on a unit area of cropped land and are named the "Duty of Water." Originally an expression for the area of land that a measure of water would irrigate when flowing continuously through the irrigation season, custom has inverted the first meaning and more conveniently utilizes the term "Duty of Water" to name the quantity of irrigation water required to furnish throughout one season, an adequate supplementary supply to the soil moisture on a unit area of land. This quantity is usually expressed as feet-depth on the land, meaning the depth that the total amount of water required each year for one acre, would cover its surface if it


OREGON
NEVADA
ARIZONA
MEXICO
CAPE MENDOCINO
HUMBOLDT
DEL NORTE
TRINITY
SHASTA
LASSEN
MODOC
SISKIYOU
MT. SHASTA
MENDOCINO
LAKE
GLENN
TEHAMA
PLUMAS
SIERRA
BUTTE
COLUSA
YUBA
NEVADA
SONOMA
NAPA
YOLO
SUTTER
PLACER
EL DORADO
MARIN
SAN FRANCISCO
SACRAMENTO
AMADOR
CONTRA COSTA
ALPINE
CALAVERAS
SAN MATEO
ALAMEDA
SAN JOAQUIN
SANTA CLARA
STANISLAUS
TUOLUMNE
SANTA CRUZ
MERCED
MARIPOSA
MONO
SAN BENITO
MONTEREY
MADERA
FRESNO
INYO
KINGS
SAN LUIS OBISPO
TULARE
SANTA BARBARA
SANTA BARBARA CHANNEL
TEHACHAPI PASS
KERN
SAN BERNARDINO
VENTURA
ANTELOPE VALLEY
LOS ANGELES
MOJAVE DESERT
LOS ANGELES
COLORADO DESERT
ORANGE
RIVERSIDE
SAN DIEGO
IMPERIAL
IMPERIAL VALLEY
Colorado River
16
1.75 ft.
15
1.25 ft.
14
1.5 ft.
13
2.25 ft.
12
1.5 ft.
11
1.5 ft.
10
1.75 ft.
9
1.5 ft.
8
1.75 ft.
7
2.0 ft.
6
1.75 ft.
5
2.5 ft.
4
2.0 ft.
1
1.75 ft.
2
1.25 ft.
3
3.0 ft.
LEGEND
(A) Refers to INDEX BY SECTIONS and indicates the approximate location of collected data on measured use
(B) Refers to INDEX BY SECTIONS and indicates the approximate location of collected data on proposed use.
Boundaries of DUTY SECTIONS.
Large figures number the DUTY SECTIONS.
Smaller figures under DUTY SECTION numbers are the average net duties for the sections.
MAP OF CALIFORNIA
SHOWING
AGRICULTURAL AREAS
AND
DUTY OF WATER
SECTIONS
STATE DEPARTMENT OF PUBLIC WORKS
DIVISION OF ENGINEERING AND IRRIGATION
CALIFORNIA WATER RESOURCES INVESTIGATION
CHAPTER 889—1921 STATUTES
1922
SCALE IN MILES
0 5 10 20 30 40 50
Agricultural areas
PLATE III

MAP OF CALIFORNIA
showing
AGRICULTURAL AREAS
AND
DUTY OF WATER
SECTIONS
STATE DEPARTMENT OF PUBLIC WORKS
DIVISION OF ENGINEERING AND IRRIGATION
CALIFORNIA WATER RESOURCES INVESTIGATION
BULLETIN No. 22 - PLATE 2
1931
Agricultural Areas
OREGON
NEVADA
ARIZONA
MEXICO
PLATE II

TABLE 2. AGRICULTURAL AREAS AND NET DUTY OF WATER

in sixteen sections of California, shown on Plate III

Section number.	Description of section.	Agricultural area.	Net duty of water.
		Acres.	Feet depth on land.
1	Los Angeles area, Ventura to Redlands	1,310,000	1.75
2	San Diego area, Mexican boundary to San Jacinto and Yucaipa	984,000	1.25
3	Imperial, Coachella and Palo Verde valleys	1,299,000	3.00
4	Antelope Valley and Mojave River areas	1,107,000	2.00
5	Inyo-Kern, Owens and Mono valleys	657,000	2.50
6	Sierra foothills and rolling plains east and south of San Joaquin Valley floor	1,800,000	1.75
7	San Joaquin Valley floor	5,468,000	2.00
8	Western slope of southern San Joaquin Valley	971,000	1.75
9	Santa Barbara, Santa Maria and San Luis Obispo areas	410,000	1.50
10	Salinas and contiguous valleys	296,000	1.75
11	Santa Clara and adjacent valley areas	530,000	1.50
12	Delta lands of San Joaquin and Sacramento valleys	453,000	1.50
13	Sacramento Valley floor	2,694,000	2.25
14	Sierra foothills, and rolling plains east and west of Sacramento Valley floor	2,305,000	1.50
15	North coast area	624,000	1.25
16	Northeastern mountain-valley and plateau areas	1,598,000	1.75
	Total	22,506,000	.....

were all accumulated and confined above that acre. Conventional use, however, has resulted in dropping the unit of area, the acre; and of time, the year; and although not expressed, these are now implicitly contained in the phrase "Duty of Water."

Qualifying terms are in common use, such as "Net" and "Gross." "Net Duty" is the quantity of water measured at the point nearest to its entry and spreading out upon the cropped land. It thus contains the water required for plant growth, together with the spreading or application losses and the losses contingent to storage in the soils prior to absorption by the roots of plants. The "Gross Duty" is this same quantity of water in lake or flowing stream, reservoir or place of storage, together with the conveyance losses and waste over spillways incident to its flow through canals or conduits from the first point of diversion at its natural source, to its point of entry on to the cropped soil. "Net Duty" of water is best adapted to considerations of the requirements of accessory water supplies and in comparing the needs of different localities. "Gross Duty" is a subject for consideration in canal and conduit design and in initial diversion quantities.

The application of waters to large areas in the quantities tabulated at "Net Duty of Water" in Table 2, provide adequate moisture for their intensive cultivation; but in estimating the total water requirements in any locality, portions of the entire area will not need water. Contingent to an intensively developing agricultural community, the rural and urban dwellings, routes of communication and transportation, industries, and improvements, occupy an increasingly large portion of the total area. As the small farm holdings become greater in number, the land is more vigorously cultivated and the production per acre is enhanced; the farm buildings needed for this great activity occupy a larger proportion of the cultivatable area. The total value of improvements, the wealth created and the income derived from agriculture vastly increases, but the farmed area would tend to diminish except for the cultivation of new areas previously unprofitable to farm. The inclusion of new areas among the tilled lands, however, is limited, for after the entire area is brought into use, no additions can be made without destroying improvements which themselves are essential for the tilling of the soil, and also, there are always some lands naturally unfit for cultivation, such as rocky and alkali spots, high knolls and stream beds. These will never be irrigated. Further, in each season a portion of the total area will remain fallow, other portions will be planted but not watered and irrigation water will not be required for either. So, in closely settled irrigated communities, the sum total of the unirrigated lands may be a considerable part of the total area. The studies made in these investigations, indicate that the part of the gross area ultimately requiring agricultural water, is from sixty to ninety per cent in the various sections of the state.

Of all the waters in use for the various purposes of civilization, that employed in agriculture is predominant. In the year 1920, with three and one-half millions of people in California and one-quarter of its arable lands under irrigation, about one-fourth of all waters that can ultimately be made available through storage within the borders of the state, were in use for domestic and industrial supply, irrigation, power generation and mining. The domestic and industrial use was about four per cent of the total, while much of the waters used for generating electric power and in mining, being on elevated lands, was employed a second time at lower levels in irrigating the state's dry soils.

CHAPTER VI.

COMPREHENSIVE PLAN FOR ACHIEVING THE MAXIMUM SERVICE FROM THE WATERS OF THE STATE.

Plans for converting the waters of California to their greatest service in this generation and for all posterity, must give precedence among the many uses for water, to those purposes which are indispensable to man's continued existence. Water for drinking and household use takes priority over that for growing food-stuffs, while water for growing food-stuffs is primary to that for industrial purposes. Were there abundant water for all needs, cognizance of its relative importance in domestic, agricultural and industrial service, could be disregarded. In California, however, where the waters in the streams are replenished by rains that largely occur in a few months of the year, and seasons of meager or bountiful rainfall succeed each other in all variations of sequence, there would be deficiencies of water for present needs during every season, were it not for impounding works already constructed. Only through the construction of still greater and more elaborate works to equalize the erratic stream flow and to transport waters to localities of urgent need, can California continue to enhance its wealth and increase the numbers of its people at the prevailing rate which for the past decade has exceeded that of all other states of the Union but two.[1] The combined increase of population in these two states, however, was only one-third that in California.

A comprehensive plan must primarily insure a full supply of water for drinking and household purposes. But since the present needs for domestic and industrial water supplies are only a twenty-fifth the amount required for irrigation of the agricultural lands now using water, the principle constructive features of a plan for obtaining maximum use of the state's waters, must revolve about its distribution for the greatly preponderant use in agriculture. Further, the magnified urban communities of the future must largely encroach upon lands now classed as agricultural, for these farm areas comprise all the lands that are suitable for residence, except those about the state's seaports. Because of their harbors, commerce and strategic locations, the seaports will expand over adjacent lands now excluded from the agricultural areas on account of being scatteringly settled fringes to population centers or on account of being too rough of surface or steep of slope. But metropolitan areas in all other parts of the state will undoubtedly arise upon the flatter lands classed in this report as agricultural. As these are relinquished for city development, the total consumption of water in any district for both domestic and irrigation supplies will not increase very much, since cities of fairly mature growth use water about

[1] U. S. Census—1920. Population of Arizona increased 63.5 per cent, Montana 46 per cent, while California increased its numbers 44 per cent during the preceding decade.

equal to that required for irrigating crops on the same area. Consequently any comprehensive plan for supplying water to all parts of the state in amounts suited to its future needs for urban and agricultural development, will have accomplished both purposes when all the present lands, classed as agricultural, are provided with an adequate allotment of water to irrigate their surface, and additional allowances are made for the dense urban development that will occur about the state's seaports.

Of other uses for water, though subservient to the primary demands of the household and for growing food-stuffs, that of generating hydro-electric power to light and heat the homes in rural and urban communities, to operate factories, railroads and car lines, to illuminate the streets of cities and towns, as well as to pump and deliver water for the domestic and agricultural use, undoubtedly ranks close to the employment for agricultural purposes. It is through these agencies that accessories to raising food-stuffs are supplied, that farm produces are prepared for consumption, and the necessities and conveniences of civilization are conveyed to all alike, so that a comprehensive plan to obtain the maximum use of the state's waters must dispose of these waters in such a way that a full measure of hydro-electric energy may also be generated.

The agricultural lands of the state, situated on the lower levels, are favorably located to receive the flowing waters of the streams after they have exhausted their inherent energy in tumbling down the steep mountain slopes. Three-fifths of the agricultural area of the state is less than five hundred feet in elevation, and seven-eighths of it is less than twenty-five hundred feet in elevation, while the mountainous water-producing region ascends to heights as great as ten thousand feet above the twenty-five hundred foot level. This spacious region, a steep and rugged country that spreads over half the state, yields practically all of California's waters. These drain into the stream channels and flow past the bulk of the lower-situated agricultural lands in their descent toward the ocean. Thus, the region that abounds in the sheer declivities and swift flowing streams, most essential for the generation of hydro-electric energy, lies above seven-eighths of California's agricultural lands and above those areas that will be mostly occupied by urban development. If the diversions of domestic and agricultural waters from the streams are generally confined to points below the twenty-five hundred foot contour, the areas most favorable for power development one-half the total surface of the state, with its waters nearly all of the state's supply, remain intact for the unimpaired generation of electric energy and these waters may then be re-used on the lower levels for domestic, agricultural and industrial purposes. Therefore a comprehensive plan to serve the maximum area of agricultural land with irrigation water, that makes its diversions of water below the twenty-five hundred foot elevation and that provides additional waters for the growing urban communities about the seaports that are not spreading over agricultural lands, is the constructive measure that will enable the greatest use to be made of California's water resources, and such a plan would give the greatest service to the primary needs of man and provide domestic and irrigation waters in their largest amounts, without

particularly abridging the use of waters for the industries and the generation of electric power.

While the entire amount of California's waters for an average year would submerge the twenty-three million acres of tillable land in this state to a depth of three and a quarter feet if evenly spread over and confined above them and the necessary application to the soil is but two feet in depth annually as a statewide average, still the disparity in location of these agricultural lands with respect to the sources of abundant water supply, presents insurmountable obstacles to the utilization of a considerable part of these waters on the lands that need them most urgently.

In northwestern California lies the area most productive in water of all regions in the state, the North Pacific Coast region. From the evergreen slopes of its timbered mountains, more than one-third of all the state's waters drain off into the ocean, passing on their course, only two per cent of the agricultural lands of the state. This immense volume of water, enough to cover the arable lands of the entire state to an average depth of one foot every year, joins the ocean deep without opportunity of infusing harvest-maturing moisture into those portions of California's soils that are too dry for maximum production without accessory supplies. The oceanward slopes of the Coast Range are separated by more than one hundred miles from the nearest large body of farming land that is deficient in local waters. In attaining heights in an unbroken barrier of from four to nine thousand feet, the Coast Range Mountains effectively block the transportation of the waters from their western slopes to the extensive area of agricultural lands lying to the east and south. Only in projects of great magnitude can portions of these waters be captured and delivered for use on the lands that need them.

Diagonally across the state from this great waterproducing basin of the North Pacific Coast, lies a region in the southeastern corner of California, one-fifth the entire area of the state, mountainous for a large part, but containing at least four million acres of flat lands of which the geography is only partly recorded because of the extreme aridity and uninviting aspect of its parched expanse. Some of the flat lands that skirt the edges of this moistureless solitude, have been fortunate in securing waters for their dry soils. These have responded to irrigation, and their great fertility has brought forth bountiful harvests to repay the pioneer. There were 546,000 acres of this region so irrigated in 1920. However, an area of 2,400,000 acres of the flat lands have been listed as agricultural, for water may ultimately be obtained for considerable areas in this region. Thus in one corner of California, one-third of its water resources are dissipated into the ocean with but small possibility of use, while in the opposite corner of the state, over six hundred miles distant, considerable areas of potentially fertile soils await the import of plant-nurturing waters to awaken their powers of production.

Intermediate in geographic position between these extreme regions, lies the Great Central Valley containing three-fifths of all the agricultural lands of the state. The northerly part of this area, the Sacramento Valley, contains five and one-half million acres of agricultural lands and enough water courses through the streams traversing it, to

submerge these lands on an average four and one-half feet in annual depth; while its southerly part, the San Joaquin Valley, contains eight and one-quarter million acres of arable land, but only enough water flows in its stream to cover them a foot and a third in average depth if spread evenly over them each year. To the west and south of these lands and disposed along the coast from San Francisco to the Mexican boundary, is the South Pacific Coast region, which contains a tillable area of over three million acres, but its streams on an average, yield only water enough to cover these lands a little more than one foot in depth annually. Other agricultural lands, about a half million acres in the San Francisco Bay Region and four and one-half million acres easterly from the Sierra Nevada and the mountain range extending southerly from Tehachapi Pass, have water in adjacent streams that will cover them annually to less than an average depth of one and a quarter feet, excepting those areas that can receive water from the Colorado River. Areas that are irrigable from the Colorado River may obtain amounts more than double this. *To evolve works by which waters may be transported to overcome this uneven geographic distribution of California's waters, so that, as nearly as possible, all these diversely situated bodies of agricultural lands may be served with their needed waters at the least expense, is the main problem to be solved in unfolding the comprehensive plan.*

However, other most important considerations intervene in preparing plans. In addition to the seventy-three million acre-feet of California's waters being located in geographic positions adverse for use on much of the agricultural lands, these waters course down their stream channels in capriciously erratic rates of flow and three-fourths of them reach the lower levels at a season of the year during which they are of little use for irrigation, because the same storms that precipitate the run-off on the mountain collecting areas, usually wet the lower agricultural lands as well. Thus works must be provided to detain large volumes of flood waters on their catchment areas and hold them in reserve for supplementing the diminishing summer flow of the streams at the time needed for irrigation. In holding waters in storage for later use, evaporation is continually active on their surfaces and the stored volumes are constantly depleted through loss to the atmosphere. It is revealed by these investigations that, even with unlimited storage capacity available on every stream, not more than eighty per cent of the state's waters can be brought into use as uniform flow; that, with maximum equalization of stream flow, one-fifth of all the waters would be lost by evaporation while being detained in reservoirs until the time arrives for their use. Thus the four great basins deficient in waters for their agricultural lands, the San Joaquin Valley, the South Pacific Coast Basin, and the regions of San Francisco Bay and of the Great Basin drainage, within whose confines lie two-thirds of all the agricultural lands of the state, would have their already inadequate waters, if developed in their entirety, reduced one-fifth in volume by losses of evaporation.

To further complicate the problem, the waters of some streams, in their flow being less erratic, can be more easily equalized to uniform discharge than in others. To minimize the cost of the works, those streams must be most heavily drawn upon for water that require the least storage capacity to equalize their flow and upon whose drainage

areas cheap reservoir sites may be found. The capacities of storage required to yield the maximum amount of uniform flow for irrigation use varies widely on the different streams. On the streams of least requirements, the maximum development may be obtained with a storage capacity whose volume is less than the annual yield of uniform flow, while on the streams of greatest requirements, a storage capacity fifteen times as large as the annual equalized flow is necessary to obtain the maximum yield. In general, the greatest storage requirements are on streams in the regions of least water production, so that the most effective use of the state's waters may be accomplished only through a superlatively scientific plan.

That the highest attainments of science could be introduced in the preparation of a comprehensive plan, the investigations have assembled masses of data and completed intricate analyses concerning the location, the quantities and the variability of occurrence of the waters of the state. This digest of information has been all-inclusive, and is presented in full in Appendix "A" to this report. It is summarized in Table 1, "Water Resources of California." This audit of California's waters results in the first complete inventory of the waters of an entire state that has ever been assembled.

In addition, data on twelve hundred and seventy reservoir sites have been examined and preliminary estimates of the reservoir capacity and of the water yield were made on nearly eight hundred of these. The field parties of the department made reconnoissance surveys of one hundred and seventy-six reservoir sites and searched three thousand five hundred miles of stream bed for other possible locations. Further, that the amounts of water needed for irrigated agriculture might be ascertained, data were gathered on the quantities of water used on over two million acres of irrigated lands in the state, or more than half the total area irrigated in 1920. These records of water use extend over an average of four years. They are presented in Appendix "B" to this report.

An analysis of all this data discloses that four-fifths of all the agricultural lands of the state may be watered. Additional investigation would probably result in finding means of irrigating still larger areas, but the water would be very costly. The 18,000,000 acres which it is found possible to water is an expanse greater than the entire area in all the western states irrigated in 1919, and three times as large as the area under water in California in the same year.

To accomplish the irrigation of this large area will require the construction of reservoirs having an aggregate capacity of 50,000,000 acre feet, and many miles of large canals to transport water from its source to the regions of need for it. Because of the inclusion of the maximum area in the estimates of cost, the average price per acre for accomplishing the irrigation of the 18,000,000 acres is greater than most projects that are now under construction, but additional areas to those watered at the present time can only be irrigated at greater costs, for they are the residual lands as the more favorable areas for constructive enterprises are selected.

Quoting from the 1919 report to the Smithsonian Institution on irrigation in the western states, "The great bulk of the land west of the hundredth meridian which is not too high, cold, or rocky for agriculture, is arid. Of this arid portion, over 15,000,000 acres have been

placed under irrigation by private or public enterprise, and in carrying out this work, of course, the most favorable opportunities for such irrigation have been developed. It will still be possible to add many million acres to the irrigated area and perhaps to double the area now irrigated, but this must generally be done at a high cost, as the cheap opportunities have been long since exhausted. There are remaining, however, many areas which can be irrigated within feasible costs and will develop values far in excess of the necessary expenditures." These investigations show that it is possible to complete the irrigation of 18,000,000 acres in California alone. This would add 12,000,000 acres to the area under water in the western United States.

In preparing a general plan for this attainment, the complexly involved rights and claims to rights for the use of water in this state were not considered, but rather a plan was devised which comprehends the state as a virgin territory with its waters and soils unsegregated in private ownership. However, inclusion was made of all constructed works, so that the plan does not contain proposals for discarding monuments of attainment of this or preceding generations. The plan would use all existant reservoirs, main canals and distribution ditches. Waters from new sources would be turned into the systems now in use on their arrival in that locality.

In the estimates of cost, entries were included for expenditures made in building all existing works except distribution canals, so that the total cost estimated is for a complete system of storage works and main canals giving uniform service to all lands irrespective of their present stage of development. It was found to be impossible in a general layout to separate the service and costs between areas now under water and those yet to be irrigated, because large areas, now classed as irrigated lands, have supplies that are deficient during the latter part of summer and many projects are short of water during the entire season in years of subnormal stream flow. To make this segregation would require a detail design of the plan in each locality, a work of great magnitude for so large an area as 18,000,000 acres. Therefore the cost estimates here given are the average cost per acre to develop a first-class water supply for all irrigable lands, whether they are now watered or not. They include all costs of construction and of rights of way, for storing waters and transporting them into the regions of use, but do not include the cost of constructing distributing canals or of operating the works, or the costs of acquiring water-rights, of litigation over claims to water-rights, or of damage suits. Neither have credit allowances for power that might be developed at or in the vicinity of the many dams for storing water been deducted in the cost estimates.

The average cost of storage works necessary to develop a full supply for the entire 18,000,000 acres, through all seasons without shortage, is twenty-five dollars per acre-foot of water developed, while the cost to the land for adequate amounts would be forty-five dollars per acre. The cost of canals with appurtenant structures to transport this water to the regions of use would average thirty-five dollars per acre. The total average cost per acre to deliver a first-class supply to the region of use is, therefore, eighty dollars. These costs vary greatly in the different localities.

To effect the watering of so large an area at these costs, it is necessary over the bulk of California's lands to adopt a coordinated scheme of development and distribution of water, that comprise very large areas in interrelated works. To store the waters at the cheapest locations of abundant supply and transport them long distances to the localities of use requires inter-service works of great dimensions. Areas greater than are now under irrigation may be watered without coordinated development and distribution, but a limit is being approached whereby united endeavors almost statewide in extent will be necessary to secure greater service from the state's waters at reasonable costs.

The plan herein set forth requires complete coordination of the distribution of water over large areas, as well as in the construction of the works. This is necessary in order to utilize the inexpensive storage sites to the greatest advantage. Dam sites of low cost often have limited catchment areas draining into their reservoirs that do not yield enough water to warrant the construction of high dams when the draft on them is uniform. But under the coordinated scheme of operation of the comprehensive plan, these dams may be erected to their full height and the cheap storage capacity thus created, utilized to the same advantages as the capacities behind other more expensive dams.

To secure this advantage requires that the draft on all reservoirs be pooled so that in apportioning the total draft between the reservoirs in each season, the largest amounts may be taken from the reservoirs that are filling the quickest. In this way, the draft may be apportioned to small reservoirs situated on large drainage areas so as to empty them more than once a season and thus use excess water that otherwise would flow over their spillways; similarly, reservoirs with watersheds of small yield may be left to fill with accumulating waters during the seasons of plenteous run-off and may be drawn on only during the drier seasons.

In so apportioning the draft, exactly the same results are attained in irrigating the land as by the customs in present use whereby the waters from each reservoir become attached to a particular tract of land and the reservoir is drawn on regularly each year at its maximum rate of yield. Under this prevailing system of individual reservoir-draft it would be useless to build dams to greater heights than is required to equalize the flow of their tributary drainage area for a uniform draft, because no greater yield would be obtained with the higher dams. But when their waters are utilized for over year storage only, for holding over the surplus of wet seasons to dispense it for use in the dry ones that may come several years later, these cheap reservoirs answer just as well as the more expensive ones with larger drainage areas. In either case the same amount of water must be held in storage somewhere for the same length of time, but a great advantage in cost is gained over the customary system of individual reservoir-draft, by the selection of the cheapest sites for storing this water under the system of pooled draft. The scheme of pooled draft of the comprehensive plan, allots the total draft to the various reservoirs so that the greatest efficiency is attained in operating the works. To obtain equal yield to that of the customary system of individual draft on reservoirs, the coördinated scheme of pooling the draft contained in the comprehensive plan, would result in an average construction cost of storage works only slightly more than half that of the individual reservoir-draft system.

The preliminary comprehensive plan outlined in this report will accomplish the irrigation of the maximum area of the state's agricultural lands at the least cost, as well as provide waters for the primary use of domestic supply and leave the great mountainous area above the twenty-five hundred foot contour free for the generation of hydro-electric energy, except for the irrigation of the beautiful mountain valleys, that dot these regions and the table lands in northeastern California. Their total area, however, is only one-eighth of all the tillable soil. On the other hand, much power can be generated below the twenty-five hundred foot level and above the irrigation diversions, especially at the high dams of many of the storage reservoirs. This plan, then, outlines a scheme that will obtain the maximum service from the waters of the state and provide for all users in order of their importance to man's continued existence.

In this plan the source of supply has been selected as close to the needy land as possible, the least expensive storage sites have been selected, and the canals have been routed over the least obstructed paths and a scheme of coordinated use of reservoirs has been included that makes it possible to attain the most efficient service in their operation. The main features of the plan are delineated on the map of California Plate IV, "Preliminary Comprehensive Plan for Maximum Development of California's Water Resources."

Because of the physical limits which the mountain ranges and great distances in California place on the transportation of water, bounds are placed on the areas that naturally group together to their mutual advantage quite like the bounds of the great drainage basins of the state. The plan will therefore be described by major drainage groups.

SAN FRANCISCO BAY DRAINAGE.

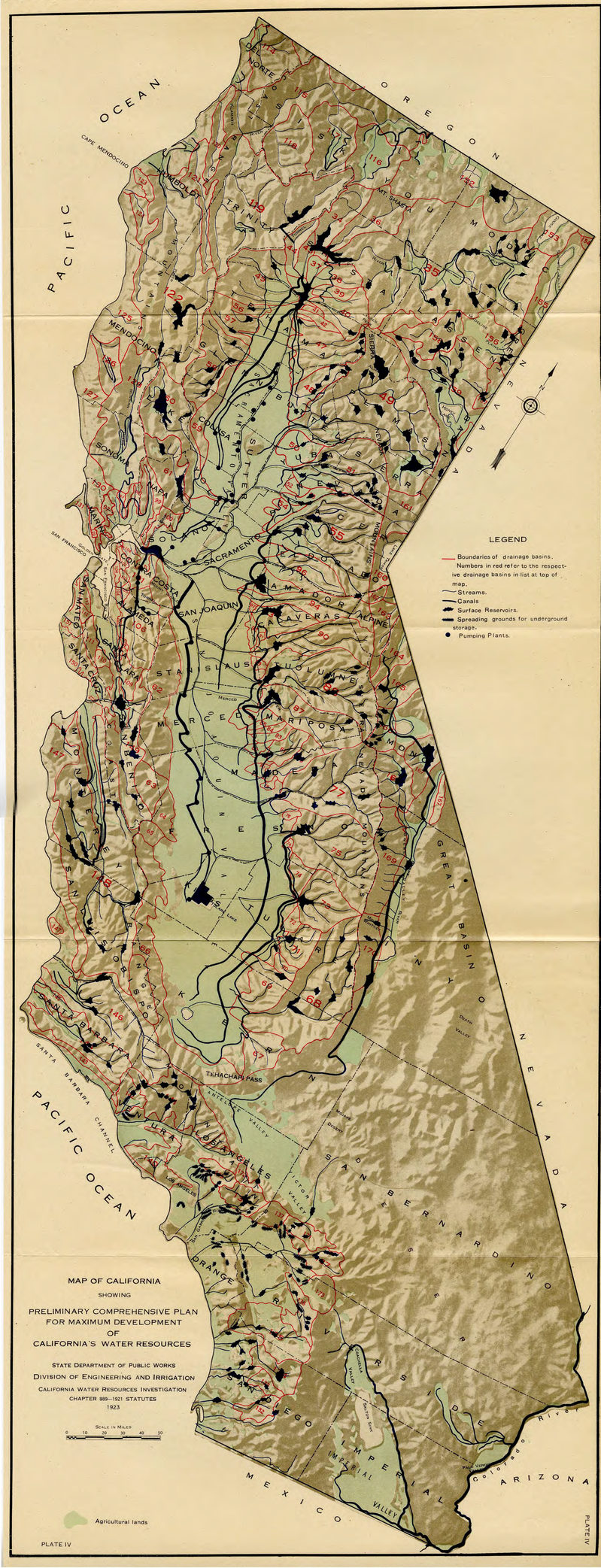
Half the waters of the state in their natural course drain into San Francisco Bay. From the Pit River, which rises in the extreme northeast corner of the state, to the Kern, three-fourths the length of the state towards its southern extremity, these waters gather into the Sacramento and San Joaquin rivers to join with smaller streams that empty directly into San Francisco Bay, in issuing through the Golden Gate into the Pacific Ocean. Within these drainage basins are 14,800,000 acres of lands suitable for agriculture. The comprehensive plan provides for irrigating all but two and one-half per cent of this entire area. Only 4,260,000 acres are now irrigated in these regions.

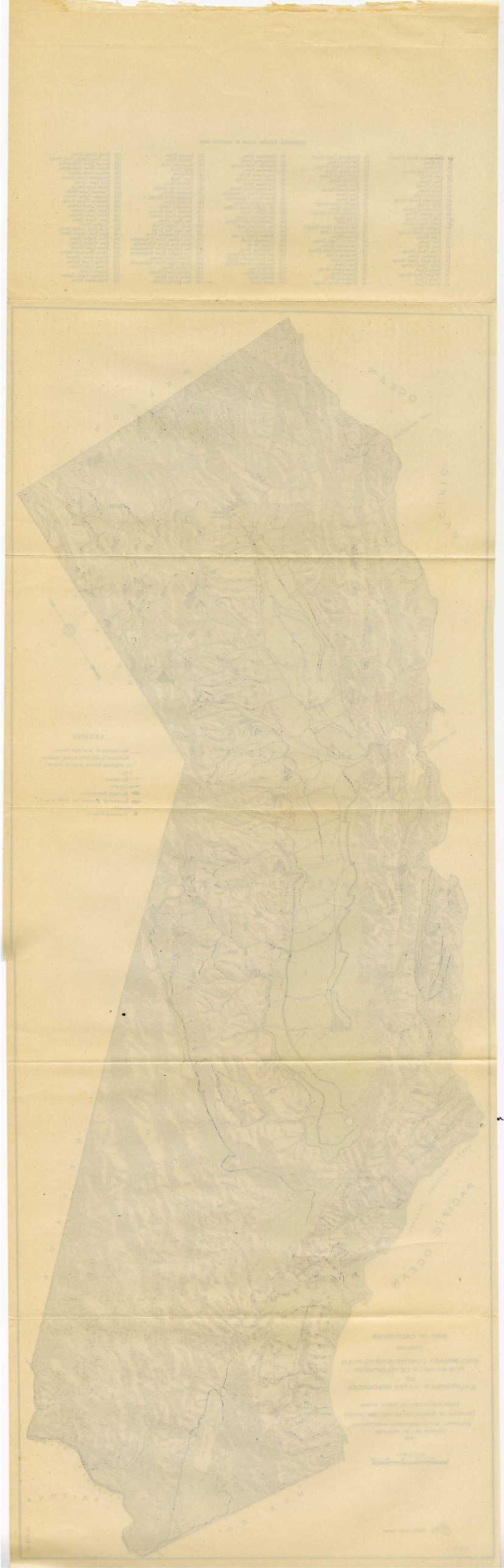
Ninety-five per cent of the 14,800,000 arable acres in these basins lies in one large continuous body of land on the floor and skirting the edges of the Great Central Valley. Sloping from elevations of five hundred feet above sea-level at the extreme northerly and southerly ends, these lands are barely higher than the sea in the central parts. With an extreme length of five hundred miles, the economic conveyance of the surplus waters of the north half of this valley to the southerly areas that are lacking in water, demands that the plan be adapted to the natural topographic and hydrographic features of the area.

Since seven-eighths of all the waters of these regions drain off the Sierra Nevada Mountains, there is ample for spreading on the easterly side of the valley. In the Sacramento Valley, the east side lands would be served almost entirely by gravity diversions from adjacent streams

DRAINAGE BASINS—Listed in numerical order.

34 Sacramento River (Upper).
35 Pit River.
36 McCloud.
37 Churn Creek Group.
38 Cow Creek.
39 Bear Creek.
40 Battle Creek.
41 Ink's Creek.
42 Payne's Creek.
43 Backbone Creek Group.
44 Clear Creek.
45 Cottonwood Creek.
46 Sacramento River.
47 Mill Creek Group.
48 Butte Creek Group.
49 Feather River.
50 Honcut Creek Group.
51 Yuba River.
52 Dry Creek.
53 Bear River.
54 Coon Creek Group.
55 American River.
56 Red Bank Creek Group.
57 Elder Creek Group.
58 Stony Creek.
59 Willow Creek Group.
60 Cache Creek.
61 Putah Creek.
62 Orestimba Creek Group.
63 Panoche Creek.
64 Cantua Creek Group.
65 Los Gatos Creek.
66 Tejon Creek Group.
67 Caliente Creek.
68 Kern River.
69 Poso Creek Group.
70 Deer Creek.
71 Tule River.
72 Yokohl Creek Group.
73 Kaweah River.
74 Limekiln Creek Group.
75 Kings River.
76 Dry Creek.
77 San Joaquin River (Upper).
78 Cottonwood Creek.
79 Fresno River.
80 Dauiton Creek Group.
81 Chowchilla River.
82 Dutchman Creek Group.
83 Mariposa Creek.
84 Owens Creek.
85 Bear Creek.
86 Burns Creek Group.
87 Merced River.
88 Tuolumne River.
89 Wildcat Creek Group
90 Stanislaus River.
91 Littlejohns Creek.
92 Marsella Creek Group.
93 Calaveras River.
94 Mokelumne River.
95 Sutter Creek Group.
96 Cosumnes River
97 Petaluma Creek Group.
98 Sonoma Creek Tributaries.
99 Napa River Tributaries.
100 Suisun Creek Group.
101 Mt. Diablo Creek Group.
102 San Pablo Creek.
103 San Leandro Creek.
104 Claremont Creek Group.
105 San Lorenzo Creek.
106 Alameda Creek.
107 Mission Creek Group.
108 Penitencia Creek.
109 Coyote River.
110 Guadalupe River.
111 Los Gatos Creek Group.
112 San Francisquito Creek.
113 San Mateo Creek Group.
114 Smith River.
115 Klamath River.
116 Shasta River.
117 Scott River
118 Salmon River.
119 Trinity River.
120 Redwood Creek.
121 Mad River.
122 Eel River.
123 Bear Creek
124 Matole River.
125 Noyo River Group.
126 Navarro River.
127 Gualala River Group.
128 Russian River.
129 Lagunitas Creek.
130 Salmon Creek Group.
131 Bolinas Creek Group.
132 San Diego River.
133 Santa Ysabel Creek.
134 San Luis Rey River.
135 Santa Margarita River.
136 San Jacinto River Tributaries.
137 Santa Ana River Tributaries.
138 San Gabriel River Tributaries.
139 Los Angeles River Tributaries.
140 Malibu River Group.
141 Santa Clara River Tributaries.
142 Ventura River.
143 Jalama Creek Group.
144 Santa Ynez River.
145 San Antonio Creek.
146 Santa Maria River.
147 San Luis Obispo Creek Group
148 Salinas River Tributaries.
149 Pajaro River Tributaries.
150 Soquel Creek Group.
151 Pescadero Creek Group.
152 Tule Lake Group.
153 Goose Lake Group.
154 Coyhead Lake Basin.
155 Surprise Valley Group.
156 Madeline Plains Group.
157 Smoke Creek Group.
158 Eagle Lake Group.
159 Honey Lake Group.
160 Lake Tahoe Basin.
161 Truckee River.
162 West Fork Carson River.
163 East Fork Carson River.
164 West Walker River.
165 East Walker River.
166 Mono Lake Group.
167 Adobe Meadows Group.
168 Owens River (Upper).
169 Bishop Creek Group.
170 Owens Lake Group.
171 Mojave River.
172 Antelope Valley Group.
173 Whitewater River.





and the main canals would be short, but southerly from the American River, a series of five long canals would be necessary in order to completely irrigate the areas eastward from the valley trough. These canals generally would be on the valley floor and serve to transfer waters southerly as they cross the distributing canals now in use. By this means all of the east side of the San Joaquin Valley may be served by gravity.

The westerly side of the Great Central Valley is deficient in local waters, particularly in the San Joaquin where their average annual amount is only 250,000 acre-feet. Their full amount, however, would be distributed by gravity to the higher lands on the edge of the valley floor. In the Sacramento Valley, three canals, each some sixty miles in length, would divert from the main channel of the Sacramento River and spread water to the south and west, but a very considerable area would be served by pumping diversions with comparatively short main canals leading to adjacent lands. Many of these are already constructed. Some areas to the west of the gravity canals would also be served by pumping from these mains. The pumping lifts would generally be less than fifty feet.

The west side of the San Joaquin Valley would be served by one grand canal two hundred miles long. This would follow the flat lands of smooth surface and have nine pumping plants at intervals along its course to raise the water against the natural grade of the valley floor. The greatest lift of the water flowing in this canal to its extreme southern end, would be 400 feet. There would be 650,000 acres served out of the grand canal by gravity, but the other 1,380,000 acres that could take their supply from this canal, require that the water be lifted by pumping for distribution over the land surface. The total pumping lift would be high for most of these lands. About 600,000 acres only would have a total pumping lift of less than three hundred feet, 1,100,000 acres between three and six hundred feet, and 350,000 acres a lift of more than six hundred feet if they are to be watered.

As great as these pumping lifts would be, this plan of distributing the water is much less costly than one of gravity conveyance. To import water to this area by gravity, would require a canal of large dimensions, tortuously following a grade contour on steep mountain hillsides and winding in and out around every rocky spur and into each receding ravine. The total length attained in its devious route would double or treble the air line distance of five hundred miles between the source of supply in the Sacramento River and the extreme southerly lands to be watered. The cost of constructing crossings for a gravity canal at the innumerable drainage channels that it would intercept, alone would probably exceed the total cost of all the works of the comprehensive plan.

In the comprehensive plan, the excess waters of the Sacramento drainage basin would be collected in the main river channels and, by means of a dam across Carquinez Straits below the mouth of both the Sacramento and San Joaquin rivers, this water would be diverted into the lower San Joaquin River from which the grand canal would take its water. Thus the cost of conduit would be obviated for the full length of the Sacramento Valley. The grand canal would follow the smooth valley floor and its excavation would be the cheapest type of

earth work. It is so designed that by utilizing the storage capacity of Tulare Lake, the pumping plants along its course may operate eleven months in the year, resulting in a considerable reduction in size of canal and of pumps. The waters pumped during the winter months would be stored in Tulare Lake for use the following summer. No flood menace would be involved in filling the Lake during the winter with the comprehensive plan in operation, for the complete development of both the Kings and Kern rivers would absorb in their reservoirs, the flood flows that occasionally fill this lake.

In general, there is opportunity to generate ample electricity for the pumping required in the comprehensive plan, at the dams of storage reservoirs distant less than one hundred miles from the pumping stations. The total cost of these generating works would be very much less than the difference in cost between the canals and pumping plants of the comprehensive plan, and any gravity system that might be devised.

The dam across Carquinez Straits would have many other advantages in addition to diverting the Sacramento waters into the lower San Joaquin River. During seasons of small stream flow, there is a tendency for the salt water of San Francisco Bay to work up into the network of channels that divide the rich delta lands at the mouth of the two rivers, into many islands. The dam below the mouth of these two rivers would prevent any damage to these fertile soils that might result from such occurences. Further, this dam would maintain Suisun Bay in fresh water and make it possible to profitably reclaim all the tidal flats along its margin, and bring unlimited quantities of fresh water to the manufacturing centers arising along the bay shore from Benicia and Port Costa easterly to Antioch. It would provide a low level crossing for railroads and highways whose traffic now crosses Carquinez Straits on ferries. By constructing locks of adequate dimensions, this barrier would offer no obstruction to navigation. It can be designed to afford ample water way for floods of the Sacramento and San Joaquin rivers so that flood heights on the lower river will not be increased over those of the past.

The practicability of locating and constructing such a dam below the mouth of the Sacramento and San Joaquin rivers, has been investigated as far as could be without exploration borings at the various possible sites for its location. It was concluded that a dam in this vicinity is feasible but that extended studies of all possible sites should be pursued before a selection is made.

This dam would be of added value in creating a large fresh water reservoir in Suisun Bay and the delta regions that would have a storage capacity of 500,000 acre feet between the present levels of high and low tide. Supplies of fresh water might be pumped from here for consumption, after filtration, in the metropolitan areas of San Francisco Bay, as well as for agricultural use to supplement the local supplies of the bay region. Thus water might be brought close into the bay region without cost of conduit from the distant sources. These investigations show that waters of the Trinity River and the three forks of the Eel River in the North Pacific Coast region, might be diverted into the Sacramento River drainage through tunnels under the Coast Range Mountains, not prohibitive in expense if their waters

are developed in large quantities. With these diversions effected, there would be plenty of water, in the Great Central Valley drainage area, to supply all its future needs as well as the requirements for all purposes about the San Francisco Bay region.

The diversion for agricultural use from Suisun Bay would be by a canal leading southward through Ygnacio Valley. The water would be elevated in successive lifts into the Livermore Valley. A pumping head of slightly more than four hundred feet would be necessary to lift the water into Livermore Valley and additional pumping would be required to distribute the water over all of its arable lands. A tunnel through the hills separating Livermore Valley from San Francisco Bay would take this water into the Santa Clara Valley at an elevation sufficiently high to permit gravity distribution to practically all lands of this valley not irrigable from the waters of local streams.

The agricultural areas of the bay region to the north, would be irrigated from diversions from the Eel and Russian rivers. Water would be carried in a gravity canal almost one hundred miles in length into the Sonoma and Napa valleys to supplement their local supplies.

Several hundred thousand acres of agricultural lands within the Sacramento drainage area, are isolated from the main body of its lands by the Sierra Nevada Mountains. The Pit River, in the northeastern corner of the state, drains part of a great plateau region to the east of the Sierra Nevadas on the edge of the Great Basin of North America, and cuts through these mountains for a distance of sixty miles in a deep rock gorge to join the waters of the Sacramento River before they emerge into the Great Central Valley. The agricultural areas of the Pit River lie in several parcels along its upper reaches and vary in elevation from 3000 to 5000 feet above sea-level. The comprehensive plan provides for irrigating 263,300 acres of these areas by gravity diversions from the Pit River or its tributaries. Seventeen reservoirs of varying capacity will be required to equalize the stream flow for these diversions.

PACIFIC COAST DRAINAGE BASINS—SAN FRANCISCO TO SANTA BARBARA CHANNEL.

Comprised within five larger valleys and several smaller ones, 890,000 acres of tillable lands lie along the Pacific Coast between San Francisco Bay and Santa Barbara Channel. Of these 135,000 acres are under irrigation at the present time. The water supply in the streams traversing these valleys is enough to cover their agricultural lands to a depth of two feet in an average year, but the flow is so flashy that with unlimited storage, only two-thirds of their waters could be suitably equalized for irrigation use. Nevertheless, three-fifths of the total area can be irrigated under the comprehensive plan. In this plan the waters would be diverted from the streams in each valley and carried to the lands in gravity canals. The costly tunnels through the mountainous regions separating these valleys largely prohibit the importation of any small surplus waters that may occur in adjacent regions, so that the agricultural lands of each valley would be largely irrigated by independent systems.

PACIFIC COAST DRAINAGE BASINS—SANTA BARBARA CHANNEL TO MEXICAN BORDER.

Southward from Santa Barbara Channel skirting the coast and on the Pacific slope of the Southern California mountains, lie 2,300,000 acres of fertile soils. These lie in the valleys of streams draining into the Pacific Ocean that are less separated by mountains than the valleys northward from the Santa Barbara Channel and form an almost continuous body of agricultural land. Although several large streams traverse portions of this area, the total waters are hardly sufficient to cover the arable lands to half a foot in depth in the average year. Their flow is erratic and would require much storage capacity for their complete development for irrigation use. Reservoir sites are few in number and dams expensive. However, it is found that the water supply can be perfected on a large part of the 759,000 acres now irrigated and perhaps 250,000 additional acres be brought under water.

Under the comprehensive plan, surface reservoirs would be constructed and largely used for the temporary detention of the waters in the streams that they might be released in a more or less uniform flow for spreading over gravel beds. Excepting in the southern areas of this region, there are coarse alluvial fills that have a large water-holding capacity and easily yield their contained waters to wells sunk into their depths. Waters spread on the gravel beds of these valley fills would be absorbed to join the subterranean waters of these basins. Severed from contact with the atmosphere, these waters would be held in storage in the porous substrata without loss by evaporation and would be available as needed through pumping from wells. By combining surface and underground storage in a coordinated plan, the maximum service will be attained from these waters, even a greater service than could be obtained from storage in surface reservoirs, for with complete development by surface storage, about one-third of all the water would be lost by evaporation. Without some surface storage, however, to partially equalize the flow, large volumes of flood water would rush off into the ocean too quickly for absorption by the gravels in the stream beds or diversion to artificial spreading grounds. The artificial spreading of water is being practiced with success in some of the basins by diverting the clear waters that follow the first turbid flood flows. These spreading operations can be much extended by the use of surface storage works to partially equalize the flood flows and the employment of additional spreading areas.

These investigations have mapped the location of the absorptive basins in this territory and collected much data on the surface and underground waters.[1] Considerable amounts of water spread on the surface of these basins in irrigation, are known to sink to join the ground waters and increase the available supply for other areas. The total quantity of water in this region is so limited, however, that there cannot be any great increase in the areas watered unless means are discovered of maturing crops with smaller applications of water than are now customary. It is possible as water increases in value, that much may be accomplished in reducing losses by evaporation while applying the waters to the soils but at greater expense than is justifiable at the present time.

[1] See Appendix "C" to this report, Bulletin No. 7, State Department of Public Works, for maps of absorptive areas and underground water contours.

GREAT BASIN DRAINAGE—SOUTH OF LAKE TAHOE.

More than 3,000,000 acres of excellent agricultural lands lie in the south half of the state eastward from the Sierra Nevada Mountains and the range extending southerly from Tehachapi Pass. These are situated in several parcels varying in elevation from below sea-level to 5000 feet or more above. The local waters are small in amount, for of all the waters collected by the mountains that separate these areas from the rest of the state, only ten per cent run off their easterly slopes. But a small part of the entire area could be irrigated if it were not for the Colorado River bringing waters from drainage areas outside the state to within reach of 939,000 acres of these lands in the extreme southeastern corner of the state. There are now 500,000 acres irrigated from the natural flow of the Colorado River in this region, but the area can be almost doubled by the construction of storage works for saving over flood waters. These waters would be diverted in the plan, by gravity canals, that serve the greatest possible area.

The local streams in the northerly part of this region are much more productive than in the south. The adjacent agricultural lands are at elevations greater than 5000 feet. The comprehensive plan would carry most of these waters southerly in a canal two hundred and eighty miles long to areas 4000 feet or less in elevation. The waters of local streams are sufficient to irrigate 430,000 acres, and in all, 1,369,000 acres can be irrigated in these regions.

GREAT BASIN DRAINAGE—NORTH OF LAKE TAHOE.

Eastward from the Sierra Nevada Mountains and northward from Lake Tahoe, there are 667,000 acres of tillable lands situated in mountain valleys and on the plateau region of northeastern California that drain easterly toward the Great Basin of North America. These vary from 4000 feet to 5000 feet or more in elevation and occur in parcels of many sizes. There are now 82,500 acres under irrigation in this region and the comprehensive plan would increase this area by 48,000 additional acres. Storage reservoirs would regulate the stream flow, and the diversions would generally be near the lands to be watered. Short gravity canals would lead the water to the regions of use.

NORTH PACIFIC COAST DRAINAGE.

About half of the agricultural areas of the Pacific Coast drainage lie adjacent to Mount Shasta on the northern and western sides. Situated at elevations of from 2500 to 4000 feet, these lands would take their waters from adjacent streams, principally the Klamath or its tributaries, and convey them by gravity to the regions of use. The other arable lands of the Pacific Coast drainage basins lie in lower levels. Mostly less than 500 feet above the sea, these lands lie in the valleys or on the detrital flats along the lower reaches of the streams. Gravity conveyance of the waters requires one canal over seventy miles in length and two more than twenty miles long. In all 699,200 acres can be irrigated under the comprehensive plan. Only 87,300 acres are now served with water out of a total area of 786,000 acres of agricultural lands in this region.

CHAPTER VII.

SETTLEMENT.

The four millions of people within the confines of California in nineteen hundred and twenty-three markedly distinguish this state from the wild and uninhabited mountains, the unsettled valleys and vacant plains of one hundred years ago. Transfigured through years of toil, the state's lands are now of immense wealth and the source of a great income in foodstuffs and minerals, while in the cities and towns are a multitude of industries that enhance the value of the natural products. Each succeeding generation contributes to these accumulated works that transform the fruits of the valley soils and the minerals and waters of the mountains into means of sustaining greater numbers of people in prosperity and contentment. But the value of these resources and the value of these works is contingent upon their service to people. Neither fertile soil, crop-maturing waters or irrigation and hydro-electric structures; nor harbors, railroads, or industrial centers disclose their intrinsic value or seethe with industry without man's vitalizing energy: rather, they are lifeless encumbrances on wide-flung landscapes unless experiencing human exploitation. So, without man to animate and guide them, great works constructed for converting the resources of the state into life-sustaining and comfort-giving commodities, neither increase its wealth nor add to the contentment of its inhabitants.

Projects for transforming the immense potential wealth of the state's waters into food or into light and warmth, must then grow in size and capacity of output in consonance with the augumenting numbers of people waiting to put their product into use, or those industrial structures, inanimate and without volition, will weather in the elements, and, through nonuse, will deteriorate to early decay before opportunity of service arrives. Enterprises that are carriers of water for domestic and industrial purposes or those which are to distribute its tireless energy in electric current to population centers and rural communities, are readily designed in size to accommodate themselves to growing communities, and select without difficulty, small numbers of employees to operate the works under the direction of trained and skilled superintendents.

However, this not so with systems for carrying the waters of the streams to the agricultural lands that these may produce to their full capacity. On these systems, the users of the water are so intimately dependent upon the supply, their successes and failures are so wrapped up in the cost of the waters and excellence of service, that they are as workers in the larger enterprise of developing water for the land in order that it may produce irrigated crops, rather than as consumers of water furnished by the distribution system. The works, the dams, the canals and the distribution ditches are but part of a system for

increasing the productivity of the soil and until this soil produces with greater abundance, the water impounding and distributing works are of no service to the people. For these reasons, private enterprises, distributing water for agricultural use and selling it as a commodity, have been supplanted in irrigation development, by mutual companies, district organizations or by the governing political subdivision.[1] In no other way have the interests of constructors of the works and users of the water become sufficiently coordinated that success could be attained in the enterprise as a whole.

There are now perhaps, a million or more acres[2] in California, fertile enough, and with water at hand, but which are failing to produce adequately to pay for all the costs including improvements on the land. Much of this is in large holdings and in new districts that have recently been brought under irrigation and, although it will undoubtedly be closely settled and produce to capacity within a few years, at present these lands are lacking in numbers of tillers of the soil to respond to the propitious agricultural environment of this state. At the same time, while these vast areas are but partially productive, eager workers and potential farm owners, anxious to prove their worth, but without money to make a start; skilled university-trained agriculturalists, capable of directing agricultural effort and anxious to exercise their training and accumulated knowledge, are about us in numbers ample to people and intensively farm these million or more acres and many more besides, if provision were made for their occupying the land.

It is generally estimated that a settler, in addition to being an experienced farmer, should have at least from two to five thousand dollars capital to make the start under existing conditions with reasonable expectancy of ultimate success; the success so necessary for maintaining the credit of irrigation enterprises. This ready money is required to level the land, to build a house, a barn, fences; to purchase a plow and harrow, a mower, rake and seed; to procure a horse, and cow, as well as to plant the first crop and sustain the settler until the first harvest is sold. Two thousand to five thousand dollars, often the savings of a life-time, is not possessed by a large number of people experienced in farming, and who are desirous of undertaking the intensive cultivation of an irrigated farm. These requirements so limit the number of prospective occupants for California's agricultural lands that the rate of settlement [3] on the great irrigation projects already constructed is not as rapid as might be desired. In order to enlarge the number of people who may become settlers by reducing the initial cash outlay required, provisions are being made by some colonization enterprises, through which land may be purchased with small payments that extend over longer periods of time than have heretofore been granted.

Although the million or more acres of land in California now failing to put its water supply to use represents a partially idle value in land and works of perhaps $200,000,000, the future is more concerned with

[1] In 1920, less than 10 per cent of the irrigated area of the whole United States was served by commercial enterprises, U. S. Census Report.

[2] U. S. Census Report states that there were 1,675,426 acres which were not irrigated in 1920 but which the works were capable of irrigating. (Some of this is probably land that never will be irrigated.)

[3] U. S. Census, 1920, reports 533,981 acres of irrigated land available for settlement by owners' statements. The Real Estate Commissioner of California, after a canvass of the state, estimates that there are now 950,000 acres available for settlement of which 80 per cent is under irrigation.

increasing the rate of settlement than the present. The lands that are yet to receive irrigation waters are lands that have been left after the more easily developed projects have been completed, and the cost of water for them will be at an enhanced rate per acre over that which has prevailed in the past. These residual lands are equally fertile, but are usually situated more distant from the source of supply. Some are tracts more uneven of surface and so require eleborate systems of canals to carry the waters to the place of pouring out upon the soil. Others have to acquire water rights before a supply may be obtained, and all of them will have to construct storage works to hold over winter flood-waters for summer use and the run-off of wet seasons for times of drouth. The cost of these projects will be large in comparison with the ones undertaken in the beginning of irrigated agriculture when projects were small and the works simple.

Future enterprises also must organize in increasingly large units, for there will be many more problems presented for solution than heretofore, and these must be surmounted in order to consummate ultimate success. Practically all the summer flow of California's streams is now diverted for irrigation use and the lands which can be watered by constructing short canals have been put under irrigation; but only one-quarter of the state's lands that need accessory moisture for greatest productivity can be watered by projects already constructed. Even now, huge combinations of hundreds of thousands of acres have been found necessary that lands situated remote from stream channels or source of supply may be improved. By building many miles of canals and huge reservoirs to augment the summer flow with saved-over flood waters from winter, these projects are preparing to carry water to the lands that, through intensive farming, they may be made to yield harvests commensurate with the favorable climate and fertile soils of California. The united efforts of whole communities is proving to be necessary to bring water to the needy lands which would otherwise remain dry and unproductive or whose yield would only be realized during seasons of copious rains. So that to bring water to the land, large projects with their immense construction programs are proving necessary even at this time, and their size and complication will grow with the future.

The successful culmination of extensive and costly enterprises not alone necessitates that sound plans be adopted for the construction of the works, not alone that they may be erected in an efficient manner, not alone that they bring water to fertile soil at the time and in the quantity needed, but also that the land be quickly occupied by the large number of tillers of the soil, which irrigated agriculture demands to nurture and harvest the increased yield. The fruition of effort, the repayment of borrowed capital in interest and principal, and the production of wealth to the community involve thousands of operators in these large enterprises, each farming from twenty to forty acres of irrigated lands. The running of the waters through the constructed ditches or even on to the plowed fields does not make the land produce. The yielding of harvests is just as necessary for the successful project as to secure adequate sums of borrowed money with which to build the works. The very essence of utility of these works is the interested and tireless efforts of the farm operators that strive with

and overcome the many annoyances incident to maturing crops on the land.

But are there sufficient numbers of people possessing the experience and skill, the capital and desire, to animate these works and quickly bring the lands to fruitful harvests under the requirements of existent conditions of land sales and farm credits? The holders of large properties for several years past have been searching for them and many still believe that they may be found, but their only partly rewarded efforts are indicative that perhaps they are not to be immediately found in the numbers desired.

As the years succeed themselves, the markets for California's farm products are ever widening. Refrigerator cars, fast express trains, and the cold storage of ocean transport are carrying California's fruits and foods for display in markets undreamed of a few years ago, and the demand for these is increasing at an accelerated rate. With propitious climate and soils, this state is attaining ranking position, a precursor to all the states of the Union in value of agricultural and horticultural products yielded by their lands, and an analysis of the reports of the United States census indicates that there will be a market for California's products in 1940, but seventeen years hence, three-fold greater than in the year 1920. The multiplying population of this state also demands food in greater and even greater amounts, for the state is growing fast. During the decade that closed with 1920, California experienced an enlargement in the numbers of people inhabiting its farms and cities, of forty-four per cent of the aggregate of 1910.

These investigations show that there is land and water ample for production commensurate with this enlarging demand for California's agricultural products, and the past success in financing irrigation construction demonstrates that money will be at hand to erect the works and fashion the canals, but the greatest success can only be attained through effecting a system of colonizing the land that will hasten the influx of settlers and secure a multiplicity of tillers of the soil without delay, so that long periods of stagnation between their construction and time of use may not bring embarrassment to the enterprises. The large units in which future development must be organized will make it increasingly desirable to accelerate the rate of rural settlement of this state.

Two examples of well coordinated and systematized colonization may be seen at Durham in Butte County, and at Delhi in Merced County, the two state land settlement projects.[1] However, these two colonies are but a demonstration of possibilities in stimulating rural settlement for their combined area is only 13,920 acres. A statewide stimulus to the occupancy of farm lands would greatly increase the naturally expeditious growth of California's irrigated communities, insure a full measure of production to meet all demands, and assist California in seizing and holding agricultural and horticultural supremacy among the states of this nation.

[1]For description of these projects see "Report of Division of Land Settlement," a subdivision of the Department of Public Works of the State of California, the report being Part V of the first biennial report of that department, dated September 1, 1922.

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