THE California WATER ATLAS

Daniel O. Holmes
March 18th, 1980

State of California
GOVERNOR'S OFFICE
OFFICE OF PLANNING AND RESEARCH
1400 TENTH STREET
SACRAMENTO 95814

EDMUND G. BROWN JR.
GOVERNOR

October 24, 1979

Dear Reader:

The California Water Atlas is considered by many reviewers to be the State's most ambitious cartographic undertaking. A staff of researchers, cartographers, and graphic artists worked for over a year and a half to assemble and portray information about water in California. Their efforts were immeasurably aided by a large and dedicated group of advisors, many of whom also contributed narrative portions to the Atlas.

The goal of all this work was to produce a book that would introduce Californians to the complex and compelling issues of water in this state, giving them the information they need to participate more actively in the decisions that governmental agencies make.

In an undertaking of this size, it is inevitable that some inadvertent errors will occur. Such an error appears on page 64, paragraph 3, in which we attempted to summarize a complex legal case which was ultimately decided by the Supreme Court. The statements in the paragraph were derived in part from California Water: A New Political Economy by Merrill R. Goodall, John D. Sullivan, and Timothy DeYoung (Allanheld, Osmum/Universe Books, New York, 1978). The paragraph, which was not intended to imply any wrongdoing on the part of the J. G. Boswell Company, should read as follows:

> The Salyer Land Company brought suit against the Tulare Lake Basin Water Storage District after its property was flooded in 1969. The flood damage could have been reduced and Salyer's property partially protected, had additional Kern River flood water been diverted into the Buena Vista Lake Basin. This would have caused flood damages to agricultural operations in Buena Vista Lake, then leased by J. G. Boswell Company. The flood storage servitude of Buena Vista lake basin, asserted by Salyer, and the District's authority to prosecute a suit against the Kern River interests, were disputed by Boswell and others. Since Boswell held a majority of the votes within the District, the District's board of directors never sought to force the Buena Vista District to take the flood water.

Because of the widespread interest in California water issues and the large demand for the Atlas, we expect it will be necessary to reprint additional copies. In order to keep the document as current, accurate, and useful as possible, we would appreciate your comments and suggestions.

Please send your letter to:

The California Water Atlas: Comments
Office of Planning and Research
1400 Tenth Street, Room 206
Sacramento, CA 95814

Sincerely,

Deni Greene
Acting Director

DG/jp

THE California WATER ATLAS

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ACKNOWLEDGMENTS

The list of contributors in this volume identifies the authors of the narrative sections as well as the two principal cartographers on the project. In addition to these individuals, however, the atlas owes its existence in large part to the efforts of Judith Christner, Mark Goldman, JeanAnne Kelley, Peter Vorster, and the other members of the staff as well as to the distinguished members of the advisory group, all of whom gave far more of themselves to this project than anyone could have asked. Each phase of the project profitted as well from the advice and assistance of scores of people throughout the state who gave freely of their time and expertise because they believed the result might prove worthwhile.

The graphic and narrative elements of the atlas were checked and rechecked by the staff of the Department of Water Resources. The responsibility for coordinating this massive undertaking rested with Glenn Sawyer, whose grace and good judgment made all things possible. In addition, several members of the department's staff proved to be invaluable resources for much of the information included in this volume: special thanks are therefore due to Dick Fields, Bob Ford, James D. Goodridge, Chuck Howard, Norman A. MacGillivray, Jim Morris, Charles Pike, and Maurice Roos. The project itself would probably never have come into being, however, without the unstinting and enthusiastic support of Ronald B. Robie, Director of the Department of Water Resources, whose good counsel and devotion to public service shaped the volume from the very beginning.

The volume has benefited as well from the assistance of public servants in numerous other agencies at the state and federal levels. Those whose contributions are especially appreciated include: Henry Hagenbuch, Jerry King, and Robert Stuart of the Bureau of Reclamation; John Conomos, Leonard Jorgenson, and Loren Young of the United States Geological Survey; Robert Voeks of the United States Fish and Wildlife Service; John Skinner and Emil Smith of the Department of Fish and Game; Doug Ralston of the Department of Parks and Recreation; Jerry Jones of the Water Resources Control Board; Gail Grodhaus of the Department of Public Health; and Robert Zimmerman of the Soil Conservation Service.

The cooperation generously extended by many local agencies proved to be of critical importance at several points during the course of the project. It is hard to imagine, for example what the atlas would have been without the assistance of Miguel Abalos and Duane Georgeson of the Los Angeles Department of Water and Power. Similar debts of gratitude are owed to: Daniel Koss and Hank Martin of the Los Angeles County Flood Control District; Robert Grosh of the Metropolitan Water District of Southern California; Bob Wilson of the Imperial Irrigation District; Roger James and Bob Roche of the Regional Water Quality Control Board of the San Francisco Bay Region; Stanley Barnes of the J. G. Boswell Corporation; and Chris Brewer of the Kern County Museum.

From California's major public institutions of higher learning, the project drew heavily upon the expert advice of: W. O. Pruitt and Bob Washino of the University of California, Davis; Eugene Turner at California State University, Northridge; and Todd Shallat of the Public Historical Studies program at the University of California, Santa Barbara. In addition, the cartography team at California State University, Northridge, benefited from the efforts of a group of student assistants which included Victoria Cline, Nancy Davidson, Richard Dey, Roberta Estes, Lindsay Green, Karla Heerman, Joseph Malin, Lola Mayes, and Jay Osterweil.

The photography that appears in the volume was made available through the courtesy and hard work of: Robert Ekstrand, Ben Padrick, and their staff at the National Aeronautics and Space Administation/Ames Research Center; Nevin Bryant and Steve Friedman of the Jet Propulsion Laboratory; Philip Hoehn and William Roberts of the Bancroft Library; Jack Clark of the Agricultural Extension Service of the University of California, Davis; Bonnie Brittain, Laverne Dicker, Catherine Hoover, and Rob Sawchuck of the California Historical Society; Victor Plukas of the Security Pacific Bank; and Shirley Mackay of the California State Library.

The publication of a book of this kind proved to be a new experience for state government. We might easily have gone astray without the expert advice of numerous professionals in the publishing industry. Special thanks in this connection are due to Jon Beckmann, William Kaufmann, Luther Nichols, Ralph Raymer, and Jeremy Tarcher. We owe a special debt as well to William Loy and Lidia Selkregg, whose experience in developing atlases of their own in Oregon and Alaska helped us avoid many pitfalls; to James F. Clements of George Rice and Sons, whose insight and commitment to excellence in the printer's craft did so much to make the atlas a source of pride for us all; and to George Roth of the California Department of Justice, who helped to steer us through the thickets of copyright law.

The difficulties of administering a project of this complexity might well have proved insurmountable without the assistance and support we received from: President James W. Cleary, Harold Bramsen, and Ralph Vicero of California State University, Northridge; Lawrence J. Andrews and Kenneth Thompson of the University of California, Davis; Kent Stoddard, Rex Norman, and Karen Becker of the Office of Planning and Research; and John Babich and Robert Brownlee of the Department of General Services. Very special thanks are due as well to Jacques Barzaghi and Rusty Schweickart, assistants to Governor Brown, whose faith in the atlas saved the project more than once.

Finally, sincerest thanks are due to the families and friends of the staff members on the project whose patience and support helped to sustain each of us through the long hours the atlas demanded.

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Foreword

This book sets out to tell the biggest story in the richest and most populous state in the Union. Water lies at the basis of the modern prosperity of California, and the history of the state is in large part the history of water development. The problems of water supply and delivery for the future are emerging among the critical issues facing not only California but the entire American Southwest over the next ten years. And yet, at a time when environmental consciousness is high and complex problems of world energy supply and international finance are part of the normal fare in our daily newspapers, water remains probably the least popularly understood of our natural resources.

There are good reasons for this. Water is an immensely complex subject which requires the mastery of many disciplines ranging from the practical sciences of hydrology, engineering, and chemistry to an understanding of history, social organization, and the law. The literature available on the subject is vast, but most of it is highly technical in nature, useful only to those who are already working in the field. In a state which was built on water, we lack even a history of water development. As a result, the interested citizen has had few places to turn for a basic understanding of the critical, water-related issues facing California and the West in the balance of this century.

The atlas has been developed as an attempt to correct this problem by providing the average citizen with a single-volume point of access to understanding how water works in the State of California. The reader will find here treatments of every aspect of water supply, delivery, and use in California—the nature of the water environment, the changes mankind has made in that environment, the history of water development, the operation of the major natural and artificial water systems of today, the relationship of water pricing to water consumption, the uses of water in industry, recreation, and energy development, the problems of water quality, and the current and emerging questions of water policy for the future. The atlas will not answer every question the reader may have. In fact, if our work has been done well, the reader should emerge after completing this book with many more questions than he ever thought to ask before. The atlas can, however, establish a context for understanding how those questions should be posed and where to turn for the answers. And it is by prompting this kind of inquiry that the atlas will succeed in its ultimate purpose of enhancing the opportunities for the people of California to take a direct role in shaping public policy in this critically important area.

The California Water Atlas is the product of a 15-month project sponsored by the Office of Planning and Research in cooperation with the Department of Water Resources. A team of researchers based in the Office of Planning and Research assembled the basic data and detailed information for the preparation of maps from a wide range of local, state, and federal sources throughout the state. This material was then relayed to a team of cartographers assembled at California State University, Northridge, where the finished maps were developed. The narrative sections were prepared by experts in each of the many topics treated in the volume. And the project as a whole operated under the guidance and supervision of an advisory group composed of the most prominent figures in the fields of hydrology, engineering, history, book design, environmental protection, and water law.

The result is not a conventional governmental publication. The sheer heft, size, and sophisticated printing of the volume makes that self-evident. These physical characteristics of the book were dictated by the complexity of the information presented in the maps and other graphic elements. What is more important in distinguishing the atlas from other governmental publications, however, is the absence of policy recommendations. We recognized at the outset that if the atlas ever concluded on any point by saying "therefore" then we would have failed in our central purpose of providing a common basis for understanding which leaves the individual reader free to draw whatever conclusions or raise whatever questions seem most appropriate.

The maps and other graphic elements contained in the atlas are likely to be far more densely packed with information than most readers are accustomed to encountering. The model of California's hydrologic balance on the facing page, which effectively combines in one place all the many aspects of water treated in detail throughout the pages that follow, is probably the most complex piece of design anywhere in the book. An attempt has been made in the design of each of the full-page plates, however, to make them susceptible of being read at several levels of detail. In other words, each plate should readily convey some central relationship or aspect of water upon a quick perusal. The three principal colors used in the design of the hydrologic balance, for example, display the relative proportionality of the volumes of water involved in each of the major parts of the system as a whole. For the serious student of water, for applications by the specialist, or for use in the classroom the plates reveal a wealth of information and precision which should, hopefully make a close reading of them an adventure in seeing and understanding.

The quality of these graphic materials is related directly to the nature of the atlas as a whole and the subject it treats. The plates are not designed simply to illustrate the points raised in the text; nor has the text been prepared simply as a helpful companion to fill out what might otherwise be only a picture book. Instead, the narrative and graphic elements of the atlas have been developed as equal partners which the design of the volume as a whole must make to work together. The topics selected for treatment in the plates are those which can be presented most effectively in a graphic form. The information contained in the design of the hydrologic balance, for example, would require pages and pages of charts and graphs to be treated narratively, and it is doubtful that the reader at the end of such a treatment would be able to grasp the relationship between the many parts of the hydrological balance and the way in which these parts fit together as readily as is conveyed in this single image. By the same token, if some aspect of the water system can be just as well described by a sentence or paragraph, then it has been left to the narrative. In this way, we have attempted to provide within the atlas a model of the ways in which advanced cartography can be used as a medium for conveying complex information on issues of public policy.

A friend of mine in hydrology once described the construction of a dam as man's ultimate way of thumbing his nose at God. Certainly the story of the development of the modern water system in California presents one of the most massive rearrangements of the natural environment that has ever been attempted. The book, therefore, begins with a detailed examination of the nature of the original water endowment as a way of establishing an understanding of the limits it placed upon human settlement. The subsequent sections treat the ways in which these limits were confronted and in most cases overcome through the construction of the various principal components of the modern water system. The water system of today, however, is not simply the inevitable result of the natural water endowment. Rather, each of the major artificial water delivery systems developed out of specific historical circumstances and were designed to address particular problems. The first half of the volume, by treating in sequence the development of these systems, thus deals essentially with the question of how things got to be the way they are today. The balance of the volume, beginning with the section on the modern water system, examines how things work today, the ways in which water is used, the problems that result, and what the modern water system can and cannot do.

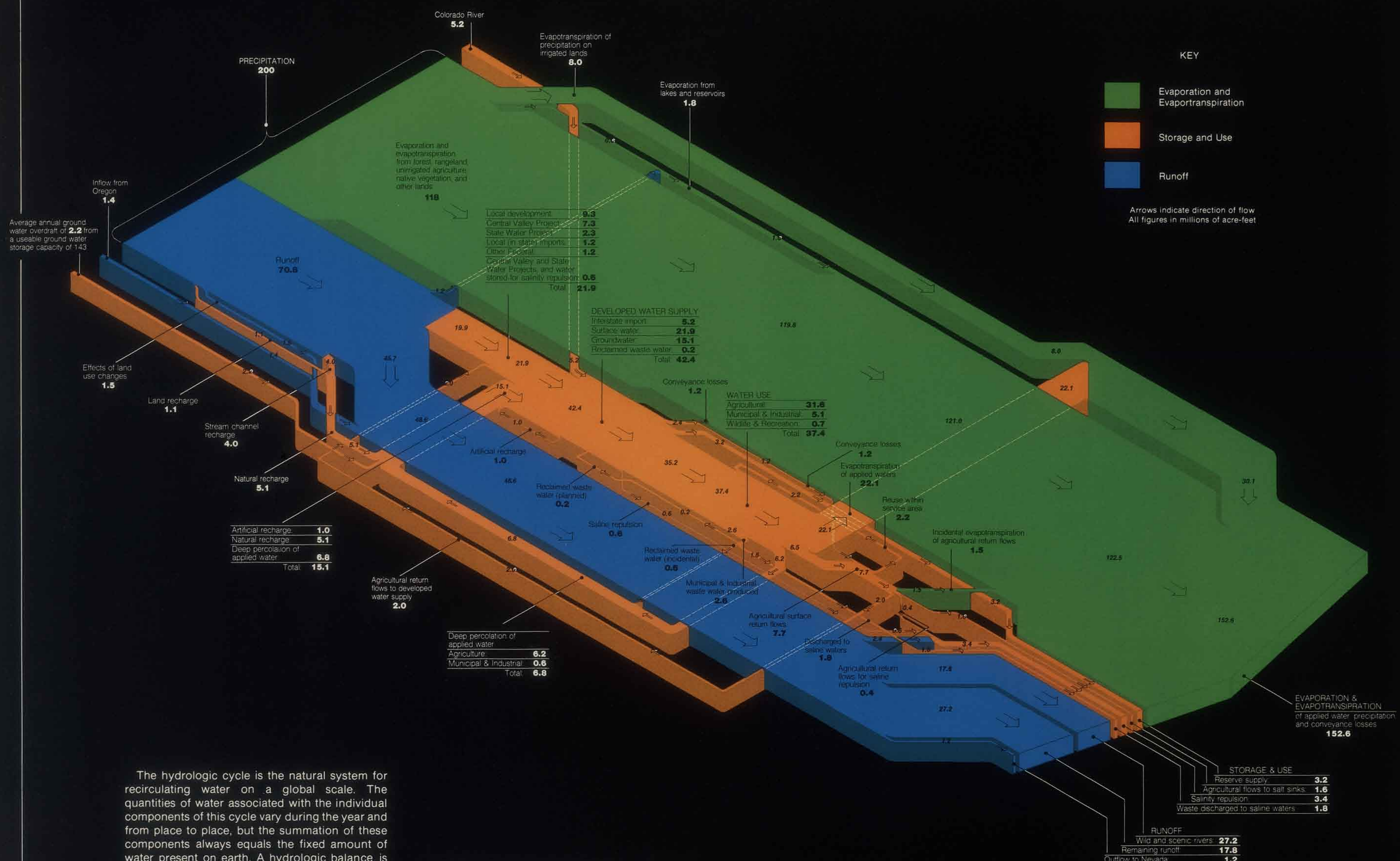
Inevitably in a volume which attempts to treat so vast a subject in so brief a space there will be disagreements as to which topics to bring up and where the emphasis should be placed. The project was conceived from the beginning as a cooperative venture and the book that has been produced as a result is a reflection necessarily of the special talents and interests of the authors, advisors, and staff members involved. Had any one of the more than 50 people who ultimately had a hand in shaping the volume been different, the atlas itself would have been changed.

The cooperative nature of the enterprise was represented most clearly in the development of the narrative. Once we had agreed upon an outline of the book, we divided the topics to be covered according to the expertise of the authors we had selected. As a result, each of the chapters that appear in the volume is made up of parts prepared by several different hands. And all of the original manuscripts were substantially revised and edited to establish a consistent style and tone, to fill in missing elements, and to provide the connectives which knit the pieces together into a whole. Nevertheless, each author approached the topic assigned with his or her own perspective and sense of priorities. As a result, the reader should be able to detect the sound of many voices running through the narrative, and this diversity was felt to be healthy to the extent that it provides a sense of the multiplicity of viewpoints that exist with respect to the various aspects of water in California.

There were, of course, constraints of time, available space, and subject matter imposed on what we could do. In developing the plates, for example, we began with a list of all the subjects we wished we could treat and then began to reduce that list based upon the information that was actually available. Hydrology, as the experts often say, is an inexact science. Cartography, however, is a most exacting art form. If you are preparing a narrative and have 95 percent of the information on the topic being treated, you can safely write a conclusion; but if you are preparing a map of California and have data for every community but one, you might as well have nothing at all.

There is more information available on water through the federal, state, and local agencies used in this project than exists on probably any other topic. And yet, a surprising amount is incomplete, inconsistent, or inaccurate. In addition, there is substantial disagreement between agencies as to methods of reporting, systems of calculation, and even the names of places and facilities.

Hydrologic Balance for California



The hydrologic cycle is the natural system for recirculating water on a global scale. The quantities of water associated with the individual components of this cycle vary during the year and from place to place, but the summation of these components always equals the fixed amount of water present on earth. A hydrologic balance is the local version of the hydrologic cycle. Like the hydrologic cycle, average annual quantities are commonly employed to express the magnitude of the separate components of a hydrologic balance. From these values a hydrologic balance can be calculated for the earth's land surfaces, for the oceans, or for smaller systems such as an individual state or drainage basin. Unlike the hydrologic cycle, however, a hydrologic balance is not presented as a closed, recirculating system but involves instead the combination of natural processes which can be designated as input, storage, or output. The summation of storage and output in a hydrologic balance will always equal the total input.

Normally, precipitation is the principal source of the natural supply of water. In California, however, the input from precipitation is augmented by comparatively small amounts of water derived from the overdraft of the state's groundwater basins, inflows from Oregon, and diversions from the Colorado River. The width of the arrow on the left side of the graphic is scaled to portray the 200 million acre-feet of average annual precipitation received by California. The width of the arrows for supplemental inputs and other components of California's hydrologic balance have been scaled proportionately. The disposition of inputs can be traced as the water moves from left to right in the graphic. California's hydrologic balance, however, is a complex system of components which vary greatly across the state and throughout the year. This graphic simplifies the complexity of the system by portraying each of the principal components as if it were a single unit for the state. Quantities shown for each component are the average annual magnitude of water associated with that function or process.

When precipitation arrives at the earth's surface it is allocated to various outputs and forms of storage by an environmentally controlled priority scheme. Depletion of the input from precipitation occurs within three major categories: return flows to the atmosphere, storage and use, and runoff. The natural demands for evaporation and evapotranspiration receive first priority in this natural scheme, and return flows of moisture to the atmosphere by evaporation and evapotranspiration account for approximately 76 percent of the precipitation input. Most evaporation and evapotranspiration occur from natural land and water surfaces and from nonirrigated agricultural land.

Computation of the hydrologic balance for California, however, requires consideration of the effects of human modifications of the hydrologic environment. For example, irrigated agriculture increases evapotranspiration and reduces runoff while asphalting land surfaces reduces moisture infiltration and increases runoff. The evapotranspiration of water used for irrigated agriculture and urban purposes accounts for 15 percent of the total depletion of input which is attributable to evaporation and evapotranspiration. In addition, many of the various components of the hydrologic balance are linked and some categories of water disposition are consequently not necessarily mutually exclusive. Water allocated originally to a specified use, as in the State Water Project, for example, may be largely evapotranspired or a portion may become runoff. On the other hand, moisture returned to the atmosphere by evapotranspiration from a forest is not available to become runoff or to be applied to some further use.

The disposition of water for storage receives second priority in the natural operation of the hydrologic balance. Water may be stored as soil moisture or in glaciers, snow, lakes, and groundwater basins. A number of alternatives, however, operate among the different forms of water storage. Glaciers and snow, for example, store water temporarily at the surface. After melting, some of this water may be evaporated, some may become runoff, and some may enter another form of storage by infiltrating into the soil to be retained as soil moisture or by percolating deeper to recharge groundwater storage. In computing the hydrologic balance as shown here, soil moisture storage and groundwater storage were not included because net changes in annual soil moisture levels occur only during extremely arid years, while net changes in groundwater storage are indicated by the average annual overdraft that is shown as a supplemental input.

Runoff, the principal source of water for human use in California, is the third priority for disposition of the input to California from precipitation. Consequently, runoff receives only those residual amounts of precipitation which remain after evaporation, evapotranspiration, and natural storage requirements have been satisfied.

The magnitude of all the storage and use components is small when compared with the magnitude of evaporation and evapotranspiration. A summation of the components of the storage and use category is provided by the developed water supply figures. In-state development represents 39.2 million acre-feet but 56 percent of the developed water is consumed ultimately by evapotranspiration. Only 3.2 million acre-feet is retained as a developed water reserve while flows into salt sinks and runoff total 4.4 million acre-feet of developed water. Depletion of the inputs produces a residual of 51.4 million acre-feet of total runoff. The state-generated portion of runoff is slightly less than 50 million acre-feet, but only 27.2 million acre-feet is unencumbered runoff.

These differences, for example, proved determinative in the decision to prepare the atlas using traditional units of measurement. Probably no subject was debated as vigorously by the advisory group as the question of metrics; but when we found that the major water agencies had still not agreed upon what the metric units for the measurement of water will be, we felt we had no choice but to proceed as we have, providing metric conversions wherever appropriate.

In preparing this volume, we have consequently had to resolve many differences of this kind and fill in numerous gaps in the available data with research of our own. The result may be the most comprehensive assembly of information on water in California that has ever been available to the public. Whether we have succeeded in this lofty objective or not, the effort itself establishes a value for the project which is greater than the subject matter involved. For, we began with the assumption that it is a valid public service to take the vast quantities of information government collects and turn it back to the public in a readily accessible form in order to enhance public understanding of the problems we must confront together. And our success in this greater endeavor will be measured not by the volume itself but by the uses to which the reader puts it in the years ahead.

William L. Kahrl
Sacramento, 1979

Glossary

ACRE-FOOT. A standard measurement of volume equivalent to the amount of water required to cover one acre one foot deep. One acre-foot is approximately the amount of water that the average family of five uses in one year, including lawn and garden irrigation.

APPLIED WATER DEMAND. The quantity of water delivered to the user at the point of use, exclusive of any water lost in transport to that point.

AQUIFER. Any geologic formation of sufficient porosity and permeability to store, transmit, and yield water to wells and springs. An aquifer which is surrounded by impermeable materials is a confined aquifer.

ARTESIAN WELL. A well tapping an aquifer in which the water level will stand above the bottom of the confining bed of the aquifer because the hydraulic pressure of the water in the aquifer is greater than the force of gravity. Where the water rises to ground level, a flowing artesian well is created.

BASE FLOW. That portion of the discharge of a stream or river that is not attributable to runoff from rain or snow. Such a flow may be sustained by drainage from natural storage.

BENEFICIAL USE. A use of water for some economic or social purpose. The specific identification of beneficial uses may vary with locality or custom, although the term is most frequently defined by statute or court decision. The State Water Resources Control Board recognizes 21 beneficial uses of water and establishes the levels of water quality required for each.

BIOCHEMICAL OXYGEN DEMAND. The quantity of oxygen used in the oxidation of organic matter in water in a specified time, at a specified temperature, and under specified conditions.

BLOWDOWN. Water discharged from a boiler or cooling tower to dispose of accumulated salts. Also, the removal of a portion of any process flow to maintain the constituents of the flow within desired levels.

BYPASS. A channel used to divert flows from a mainstream, as for the diversion of flood waters.

CLOUD SEEDING. A method of weather modification in which clouds are injected with a seeding agent such as dry ice or silver iodide in order to enhance precipitation, clear fog, or inhibit the severity of storms.

CONJUNCTIVE USE. The coordinated use of surface and groundwater supplies. One technique is to recharge a groundwater basin during years of above-average precipitation so that the water can be withdrawn during years of below-average surface runoff.

CUBIC FEET PER SECOND. A basic unit for measuring the flow of water past a given point over time. Equivalent to 449 gallons per minute and 1.98 acre-feet per day.

DRAWDOWN. A lowering of the water level in an aquifer or reservoir.

EFFLUENT. Liquid or gas issuing from a contained space, as in the discharge of wastewater from a treatment plant.

ENTITLEMENT WATER. As used in connection with the State Water Project, the amount of project water made available at a delivery structure provided for the contractor under the terms of a contract with the state.

FLUME. An artificial water channel supported on or above the ground for the conveyance of water or materials such as logs or gravel.

HEADGATE. A gate, flap or valve at the entrance to a conduit, ditch, canal, or penstock which is used to control water flow.

HYDROGRAPH. A graphic representation of some property of water which is displayed with respect to time.

INSTREAM USE. A beneficial use of water in a stream channel as for recreation, fish and wildlife, navigation, the maintenance of riparian vegetation, or scientific study.

LEVEE. A ridge of material along a stream bank. A natural levee is formed by the deposition of sediment when a stream overtops its banks during a flood. An artificial levee, constructed of earth, rock or concrete, may be used to contain or direct water flow.

NAVIGABLE WATER. In general, any body of water which, during a substantial portion of the year, is capable of floating watercraft for purposes of trade, commerce, transport, or recreation. The United States Congress exercises regulatory authority over those navigable waters (and their tributaries) which are susceptible to use for trade and commerce. For purposes of defining ownership of stream and lake beds by the State of California, navigable water includes any body of water which was in fact navigable at the time of California's admission to the Union.

OUTFALL. The point, location, or structure where sewage or other drainage is discharged.

PERCOLATION. The movement of water through the interstices of soil or rock.

POINT SOURCE. Any discernable, confined and discrete conveyance from which pollutants are or may be discharged; this is distinguished from a non-point source, which is so general or covers so wide an area that no single, localized source can be identified.

RECLAMATION. As applied to land, the development or improvement of land through drainage, leaching to remove salts, flood control, or the provision of irrigation water. As applied to water, the treatment of wastewater so as to make it suitable for some beneficial use.

REIMBURSABLE COSTS. That portion of the cost of developing and distributing a water supply which the water users are held responsible to repay.

REPAYMENT PERIOD. The period of time prescribed for the payment of reimbursable costs. This period is commonly 40 or 50 years measured from a date specified in a contract for water delivery or from the time that the first services of a water project are made available.

RETURN FLOW. Any unconsumed water which returns to its source or some other water body after diversion from a surface water supply or extraction from a groundwater basin.

SAFE YIELD. As applied to groundwater, the maximum quantity of water that can be continuously withdrawn from a groundwater basin without producing an undesirable result. As applied to surface water, it is the maximum annual dependable supply from a water source during the driest period likely to occur.

SEDIMENTATION. The settling of solids in any body of water because of gravity or chemical precipitation.

SLOUGH. A creek in a marshland or tidal flat or an inlet from a river.

SPREADING. The application of water over areas of porous material in order to recharge an underlying groundwater basin.

STORAGE, CAPACITY. As applied to groundwater, total storage capacity is the amount of water that could potentially be extracted from a given depth of a totally saturated aquifer without regard to quality or economics; usable storage capacity, however, is the amount of water of acceptable quality that can be economically withdrawn from the aquifer. As applied to surface water, total storage capacity is the total amount that can be stored behind an impoundment structure or in a natural lake; usable storage capacity is the amount of water that can be drained through the lowest outlet of an impoundment structure.

TOTAL DISSOLVED SOLIDS. The quantity of minerals in solution in water, usually stated in nearly equivalent terms of parts per million (ppm) or milligrams per liter (mg/1).

TURNOUT. The point at which water is diverted from a main channel or water delivery facility to a distributing facility.

WATERSHED. The total land area that contributes water to a river, stream, lake, or other body of water. Synonymous with drainage area, drainage basin and catchment.

WATER YEAR. A continuous 12-month period within which hydrologic data is compiled and reported. In California, the water year starts on October 1, when groundwater and reservoir levels are usually at their lowest and the rainy season is about to begin.

WEIR. Any structure across a water course used to control, raise, or measure flows.

WETLAND. Any area in which the water table stands near, at, or above the land surface for at least part of the year. Such areas are characterized by plants that are adapted to wet soil conditions.

TO WHEEL. As applied to water and power, to provide the use of one agency's conveyance facilities for the purpose of transporting another agency's supply.

Metric Conversion Factors

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches	2.54	centimeters
	feet	0.3048	meters
	yards	0.9144	meters
	miles	1.6093	kilometers
Area	acres	0.40469	hectares
	square miles	2.5898	square kilometers
Volume	gallons	3.7854	liters
	acre-feet	1,233.5	cubic meters
	cubic feet	0.028317	cubic meters
Discharge	cubic feet per second	0.028317	cubic meters per second
	gallons per minute	3.7854	liters per minute
Weight (Mass)	pounds	0.45359	kilograms
	tons	0.90718	tons (metric)
Temperature	degrees Fahrenheit	$\frac{t_F - 32}{1.8}$	degrees Celsius
Electrical conductance	mho	1.0	siemens

CHAPTER 1

California's Water in Context

Numerous aspects of the urban, industrial and recreational uses of water are illustrated in this view of the east side of San Francisco Bay. Oakland is at the bottom of the photograph, Berkeley to the north, and the fringes of Lafayette can be seen at the far right. Intensive water use for vegetation in public parks, which appear here as vivid red, contrast markedly with the urbanized areas and watershed lands where the East Bay Municipal Utility District maintains its reservoirs.

Too many of us know only that water comes from the tap and then disappears down the drain. We trust that it will be available when we want it and that we can dispose of it without causing obvious pollution in our immediate surroundings. This lack of knowledge is unfortunate because water and its development for human use forms the basis of California's modern prosperity, the framework of our history, and the substance of our existence. Seventy-five percent of our body weight is water, and blood plasma is 90 percent water. Water is so important to our body functions that a loss of only 20 percent brings death. The inventive mind of man has developed no substitute for water in the production of food and fiber to sustain our lives. In our urban centers today, the use of water in homes averages 150 gallons per day for each person in the United States. Per capita use in California is generally greater than the national average and varies greatly with the season of the year, location and climate, and with the density and affluence of our population. During the winter months in high density neighborhoods, per capita use averages 100 gallons per day, but during the summer in the hot Central Valley, suburban dwellers may use as much as 660 gallons.

The amount of water we use directly in our homes, large though it may appear to be, is only a small fraction of the water used to produce our food and fiber, to provide manufactured goods, and to supply many of our other needs for such things as electrical energy. This overall use of water has climbed steadily from a per capita average of about 600 gallons daily in 1900 to 1,800 gallons in 1975. Water is the life blood of agriculture, California's largest industry. Assuming that approximately 1,600 pounds of food are produced to supply the 1,500 pounds consumed annually by a typical person and that an average of 1,000 gallons of water are needed to produce each pound of food, then it takes about five acre-feet of water to produce the food the average American consumes each year. The water requirements of food items in our diet, however, vary greatly. A pound of bread takes 136 gallons to grow the wheat, a pound of potatoes 23 gallons, a pound of tomatoes 125 gallons, and a pound of steak 2,500 gallons. In addition, one gallon of milk requires 932 gallons of water to grow the silage and alfalfa, water the cows, and clean the barns. Water is also an irreplaceable item in many manufacturing processes and the availability of water in adequate quantity and quality is necessary for economic growth and the standard of living we enjoy. As a result, we are coming increasingly to appreciate the essential role of water in our total environment and also the importance of our environment to human well-being and to the maintenance of numerous delicately balanced life-support systems which sustain us.

Water, however, makes up only one-tenth of one percent of the earth's mass and very little of the world's water can be used directly for human agricultural, industrial, and domestic needs. Ninety-seven percent of the world's water is in the ocean where it contains many dissolved and suspended materials. Of the remaining three percent, 2.2 percent is locked up in the polar ice caps, and three-tenths of one percent is too deep underground to recover and use. Less than one-half of one percent of all the water on earth can be used directly to support human life. Moreover, the earth's water supply is fixed; the quantity available is essentially the same now as it was more than five billion years ago when the planet was formed. Consequently, all the water we use is recycled. Every drop we drink, cook with, wash with, or use to irrigate our crops has been used countless times before.

Solar energy is the driving force behind this continuous recycling process. The sun, warming the surfaces of rivers, lakes, the ocean, and even the water in plants and the soil, agitates water molecules until their increased motion causes them to escape and be carried into the atmosphere by warm air currents. As these water molecules break away, they leave behind all minerals and other pollutants dissolved or suspended in the water. This is how our water is periodically cleaned for re-use. As these water molecules rise, they may be carried over land and mountains before they cool, condense into drops, and fall as rain or snow. Whether it occurs as rain or melting snow and ice, water immediately starts running downhill toward the ocean, first as streams, and then combined into rivers. Some is trapped in lakes and some percolates into groundwater basins. But it is this water, recycled and redistributed by nature, which we store, transport, pump, and use to sustain our lives on earth.

The size and power of this natural recycling and distribution system can be appreciated by a few simple comparisons. A single one-inch rainfall on a 160-acre farm delivers 4,356,000 gallons or 36,300,000 pounds of water. To transport this 18,150 tons of water would require 544 tank cars operating as four trains each over a mile long. To evaporate this amount of water from the ocean requires the equivalent of over a million horsepower of energy. Worldwide, about one-fourth of the total energy of sunlight is used to evaporate water, more than 4,000 times the total power now available to the world's industrialized civilizations. This water cycle is absolutely vital to the continuing renewal and purification of our water supply and thus it is essential to all life.

Nature does not, of course, distribute its freshwater supplies equally. In terms of water supply, California is made up of two very dissimilar areas: the northern portion shares characteristics with the more humid areas of Oregon and Washington while its southern half is a part of the most arid region in the United States. As a result, the total water supply in California is much less than that of many other regions of the nation with which California competes industrially and agriculturally. Although annual average precipitation per square mile in California is equivalent to 79 percent of the average for the entire United States, it is only 44 percent of the average per

California In Context

Population and Water Use

State	A	B	C	D
Arizona	7,000	7,800	211	2,360,000
California	35,000	51,000	185	22,018,000
Colorado	9,300	10,000	200	2,644,000
Idaho	15,000	17,000	236	855,000
Montana	11,000	12,000	267	764,000
Nevada	3,100	3,500	321	637,000
New Mexico	2,900	3,200	236	1,202,000
Oregon	6,000	6,900	190	2,373,000
Utah	3,500	4,100	331	1,264,000
Washington	5,500	7,200	256	3,697,000
Wyoming	6,800	7,200	191	407,000

A. *Irrigation water withdrawn (million gallons per day, 1975)*
B. *Water withdrawn from all sources, fresh and saline, except hydropower (million gallons per day, 1975)*
C. *Water withdrawn for public supplies from all sources (gallons per capita per day, 1975)*
D. *Estimated population 1978*

Selected Western Rivers

Average Annual Discharge (acre-feet)*

Stream	Gaging Station	Discharge
Columbia	The Dalles, Oregon	140,600,000
Snake	Clarkston, Washington	36,225,000
Willamette	Wilsonville, Oregon	20,540,000
Pend Oreille	Ione, Washington	20,540,000
Sacramento	Sacramento, California	17,870,000
Clark Fork	Cabinet, Idaho	15,920,000
Klamath	Klamath, California	12,900,000
Colorado	Compact Point, Arizona	12,860,000
Skagit	Mt. Vernon, Washington	12,000,000
Yellowstone	Sidney, Montana	9,353,000
Flathead	Polson, Montana	8,469,000
Salmon	White Bird, Idaho	8,013,000
Cowlitz	Castle Rock, Washington	6,618,000
Spokane	Long Lake, Washington	5,793,000
Umpqua	Elkton, Oregon	5,387,000
Eel	Scotia, California	5,379,000
Green	Green River, Utah	4,614,000
Rogue	Agness, Oregon	4,411,000
Deschutes	Biggs, Oregon	4,196,000
Trinity	Hoopa, California	3,958,000
Platte	South Bend, Nebraska	3,912,000
San Joaquin	Vernalis, California	3,197,000
Chehalis	Porter, Washington	3,018,000
Smith	Crescent City, California	2,819,000
American	Fair Oaks, California	2,765,000
Pit	Montgomery Creek, California	2,721,000
Bighorn	Bighorn, Montana	2,721,000
Payette	Payette, Idaho	2,199,000
Quinault	Quinault Lake, Washington	2,037,000
San Juan	Bluff, Utah	1,892,000
Yuba	Smartville, California	1,866,000
Gunnison	Grand Junction, Colorado	1,860,000
Coeur D'Alene*	Cataldo, Idaho	1,827,000
Russian	Guerneville, California	1,712,000
Kings	Pine Flat Dam, California	1,624,000
Salmon	Somes Bar, California	1,331,000
Mad	Arcata, California	1,137,000

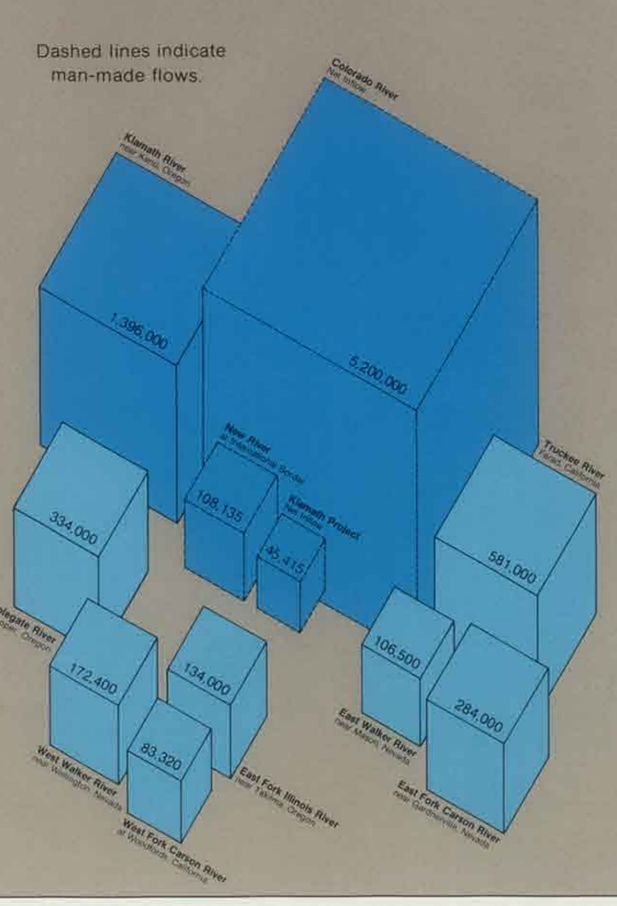
* *Average annual discharge to 1975 is shown for California rivers, to 1970 for other rivers, and for the period 1913-1962 for the Colorado.*

Selected Western Reservoirs

Reservoir	Stream	Capacity (acre-feet)
Lake Mead	Colorado	29,755,000
Lake Powell	Colorado	27,000,000
Fort Peck	Missouri	19,432,000
F. D. Roosevelt Lake	Columbia	9,562,000
Lake Koocanusa	Kootenai	5,809,000
Shasta Lake	Sacramento	4,552,000
Flaming Gorge	Green	3,789,000
Lake Oroville	Feather	3,538,000
Hungry Horse	Flathead	3,468,000
Dworshak	Clearwater	3,459,000
Lake Umatilla	Columbia	2,500,000
Clair Engle Lake	Trinity	2,448,000
Elephant Butte	Rio Grande	2,109,000
Canyon Ferry Lake	Missouri	2,051,000
San Luis	San Luis Creek	2,039,000
Don Pedro	Tuolumne	2,030,000
Lake Mojave	Colorado	1,818,000
Navajo	San Juan	1,709,000
American Falls	Snake	1,700,000
Riffe Lake	Cowlitz	1,685,000
Lake Berryessa	Putah Creek	1,602,000
Lake Pend Oreille	Pend Oreille	1,561,000
Brownlee	Snake	1,427,000
Ross Lake	Skagit	1,405,000
Palisades	Snake	1,400,000
T. Roosevelt Lake	Salt	1,382,000
Yellowtail	Bighorn	1,375,000
Tiber	Marias	1,369,000
Lake Wallula	Columbia	1,350,000
Lake Almanor	Feather	1,308,000
Banks Lake	Columbia	1,275,000
Abiquiu	Rio Chama	1,225,000
San Carlos	Gila	1,210,000
Strawberry	Strawberry	1,107,000
Alamo	Bill Williams	1,043,000
Lake McClure	Merced	1,026,000
Pathfinder	North Platte	1,016,000
Seminoe	North Platte	1,012,000
Folsom Lake	American	1,010,000
Pine Flat Lake	Kings	1,002,000

California Surface Inflows & Outflows

Average Annual Inflows (acre-feet)
Average Annual Outflows (acre-feet)



square mile in the South Atlantic and East Gulf states. And while the average annual runoff in California is more than nine times that of the Colorado River Basin as a whole, it is eqivalent to only 51 percent of the average runoff per square mile in the Ohio River Basin and 36 percent of the annual averages that obtain in New England.

California is, however, unique in many ways. It has a 1,072-mile coastline on the Pacific Ocean which greatly moderates its climate, affects its water supply and use, and provides a sink for outflows from rivers and streams and from our agricultural and urban developments. The state is essentially cut off hydrologically by mountains from its neighboring states to the east. Consequently, except for some inflows from Oregon, small outflows to Nevada, and the significant quantities of water from the Colorado River which California shares with other states and Mexico, our water supply is essentially independent of other states.

Precipitation is the principal source of California's water supply. The state's average annual precipitation is about 200 million acre-feet. Two-thirds of this total falls on the northern one-third of the state. About 65 percent of this precipitation is lost by evaporation directly into the atmosphere leaving only 71 million acre-feet for the average annual runoff in streams. Forty percent of this runoff or 28 million acre-feet occurs in north coastal streams; 31 percent or 22 million acre-feet in the Sacramento River system; nine percent or seven million acre-feet in the San Joaquin River system; and 20 percent or 14 million acre-feet is scattered over the rest of the state. Approximately one-fourth of the total average runoff or 18 million acre-feet is now protected from development under the state's wild and scenic rivers program.

Groundwater is an important adjunct to the natural supply provided by surface streamflows. The vast groundwater basins which underlie the Central Valley and other areas of the state have an estimated total capacity of 1.3 billion acre-feet with a usable capacity some estimate to be as high as 143 million acre-feet. In years of normal rainfall, groundwater supplies 40 percent of the water used in the San Joaquin Valley. In the drought year 1977, however, groundwater provided about 80 percent of agriculture's needs when 9,000 new wells were drilled in this valley alone. Statewide, more than 20,000 new wells were brought into production in 1977, further aggravating the serious overdraft or mining of California's groundwater. During recent years of average precipitation, groundwater overdraft has approximated two million acre-feet; the groundwater overdraft in 1977, however, has been variously estimated at four to ten million acre-feet. Overdraft in future dry years could go higher unless steps are taken. Failure to control such overdrafts will increase energy requirements for pumping, decrease water availability, produce water of poorer quality, encourage saltwater intrusion along the shores of saline bays and the ocean, and bring about significant and sometimes serious land subsidence.

Views on water development and use are changing. Historically, Californians have developed and used water so as to minimize constraints on the growth of our cities and irrigated agriculture. Nature may have intended much of California's now highly populated areas and most productive croplands to be brown, but we have turned them green with produce or gray with concrete according to our will. More recently, however, we have come to realize that water is itself a limited resource. The emphasis today is not so much upon water development as upon water management. What this alteration in our attitudes will mean for the future of California cannot easily be predicted. But the situation clearly calls for increasing scrutiny of the reasonableness or efficiency of present water uses.

There is considerable misunderstanding about water use. The term "use" sometimes refers to the total quantities diverted from surface water sources or pumped from groundwater. Alternatively, it may be applied to mean only that portion of the supplied water which becomes unavailable for further use by being lost in evaporation from water, soil, or plant surfaces or incorporated into plant tissue or into manufactured goods. Accordingly, some water uses are non-consumptive and others are consumptive. More than half the water delivered to California's irrigated farms, on the average, is lost to the atmosphere by evaporation from soil and transpiration by plants. Evaporation from soil can be partially controlled by the installation of efficient irrigation systems and management practices. But the process of evapotranspiration from plant leaves remains largely uncontrolled and presents, therefore, a tremendous challenge to those seeking efficient conservation. Water use in homes, except that lost to the air in irrigating plants, is generally non-consumptive. Typically, more than 90 percent of the water used in homes is degraded and disposed of down the drain. Similarly, water delivered to most industrial plants is used non-consumptively to convey, wash, cool, or heat materials. Most of this water becomes effluent and remains a part of the state's water supply. But pollution itself can be equivalent to a consumptive use when the water becomes so degraded that the treatment necessary for its re-use may not be technically or economically feasible and its discharge to the ocean or other sink is consequently the most practical solution to the problem of its disposal.

In terms of withdrawals, 87 percent of California's developed water is taken for irrigation; 8.5 percent for domestic, commercial, and institutional uses; 2 percent for manufacturing; and about 2.5 percent for other purposes. But in terms of consumptive use, 91 percent goes for irrigation, 5 percent for domestic and related uses, one percent for manufacturing, and about 3 percent for others. By the year 2000, the portion used consumptively by irrigation is expected to decline slightly to 89 percent accompanied by small increases in municipal and industrial uses.

Predictions of water use are highly controversial, however, due to uncertainties about projected population levels and our inability to predict the domestic and international markets for various agricultural products as well as other changes related to crop production. Based on four population alternatives and four alternative levels of crop production, it has been estimated that present water diversions will increase from about 37 million acre-feet today to 41-46 million acre-feet by 1990 and 43-55 million acre-feet by 2020. An unquantified amount of water will also be needed to provide instream flows for fish and wildlife, to preserve wetlands for birds, and to protect water quality in areas such as the Sacramento-San Joaquin Delta and the San Francisco Bay.

How can water be managed so as to meet as fully as possible the needs of diverse and legitimate interests at all levels and in all geographic areas? There are no easy answers. Sound water policy and action programs require that account be taken not only of the scientific and technical aspects of water management but also of the numerous historic, economic, social, environmental, legal, institutional, and political interests involved. The sections of the atlas that follow treat these many factors and their interrelationships in detail. Only through enlightened public understanding of these complex issues can we hope to integrate divergent viewpoints and contending interests into a wise policy of water management which will have sufficient resiliency to cope with climatic change and other developments in our society which could substantially alter California's efforts to achieve a balance between water supply and water demand.

CHAPTER 2

The Natural Endowment

Water has shaped California from the very beginning. Ever since the Sierra Nevada and coastal ranges rose as obstacles to the eastward flow of air from the Pacific, water has been carving canyons; steepening, lowering, and smoothing slopes; forming vertical walls; and carrying the debris from the mountains to the lowlands where sediments accumulated to form broad plains and valleys of rich soil. The gold of the Mother Lode got there partly by hydrothermal action, and subsequent stream erosion sorted the gold into auriferous gravels where men later found it in 1849. The winter-moistened slopes of the mountains have been conducive to the growth of the world's largest living things—the Sequoia sempervirens of the Coast Range and the more massive Sequoiadendron giganteum in the Sierra Nevada. East of the Sierra, water deficiency produced an austere environment requiring the utmost in survival techniques, and here the bristlecone pine achieved outstanding success as the oldest of all living things.

This diversity of climates both reflects the diversity of environments within the state and contributes to that diversity. Most water provides life support for plants and animals only after it has seeped into the ground; but the upland redwood forests are an exception to this rule, as are certain fern-related species that collect fog and water vapor. Along the sheltered inland margins of bays, lagoons, and estuaries, salt and brackish water marshes provide fertile and productive habitats rich in nutrients which support grasses, pickleweed, mussels, clams, herons, egrets, and hosts of migrant waterfowl. Further inland where the land is relatively flat, freshwater marshes and swamps, which once covered an estimated 500,000 acres of California, provide habitats as well for ducks, marsh wrens, rails, swans, and geese.

As water enters streams, it brings nutrients, sediments, and aeration that create a diversity of in-stream plant and animal communities. Wildlife along the riverbanks varies according to climate, elevation, the temperature of the water, the rate at which it flows, and the seasons of the year when flows are sufficient to sustain life. Plants that are specially adapted to saturated soils and flooding are found here, such as the red alder and aspen, the sycamore and valley oak in the Central Valley, and the cottonwood and willow along the Colorado. Where conditions are right, riparian habitats also support myriads of insects which draw insectivorous birds, amphibians, and reptiles as well as the predator birds which feed on them in turn. Raccoons and golden beaver come for shade and shelter and it is here too that the yellow-billed cuckoo makes his home. Salmon and the native golden trout are found in colder waters, while catfish and bass prefer warmer temperatures.

Where water falls as snow, two immediate plant communities are created: the snow cup red algae community that is found throughout the Sierra; and the snow margin community of high alpine meadows which is especially adapted to cold water. In the mountain meadows, burrowing animals flourish, and the hardy water ouzel strides the banks of mountain streams. In the harsh desert climes, widely scattered springs, seeps, and holes support stickleback, chubs, and a variety of species of pupfish. And scattered throughout the Central Valley, the foothills of the Coastal Range, and the mesas of Southern California, vernal pools spring to life and then die back with the passing of each rainy season, rare and transitory habitats which are found only in South Africa and California.

Unlike many other parts of the country, California has but two seasons, a dry summer and more or less humid winter. Throughout the state approximately 80 percent of the annual precipitation occurs in the five months November through March. Although the rains commence in October of some years and sometimes continue into April, the months of May through September—the principal growing season in most other states—are rainless or nearly so. There is, however, no single dormant season for plant life in California; instead, there is something growing all the time.

In general, the qualities of a dry summer season and a mild humid winter are found in the southwest corners of many major continents. These conditions are identified as a Mediterranean climate but they exist as well in southwest Africa, Chile, and parts of Australia. Although California does not have an equivalent to the Mediterranean Sea, which extends maritime conditions and mild winters eastward from the Atlantic Ocean to the Middle East, it does have a high mountain barrier separating it from the more severe winters of the continental interior. And so, California competes successfully with the balmiest parts of Europe, North Africa, and the Middle East, with commodities that thrive in mild winters and sunny, dry summers such as cereals, grasses, olives, citrus fruits, grapes, wine, tourists, and horses.

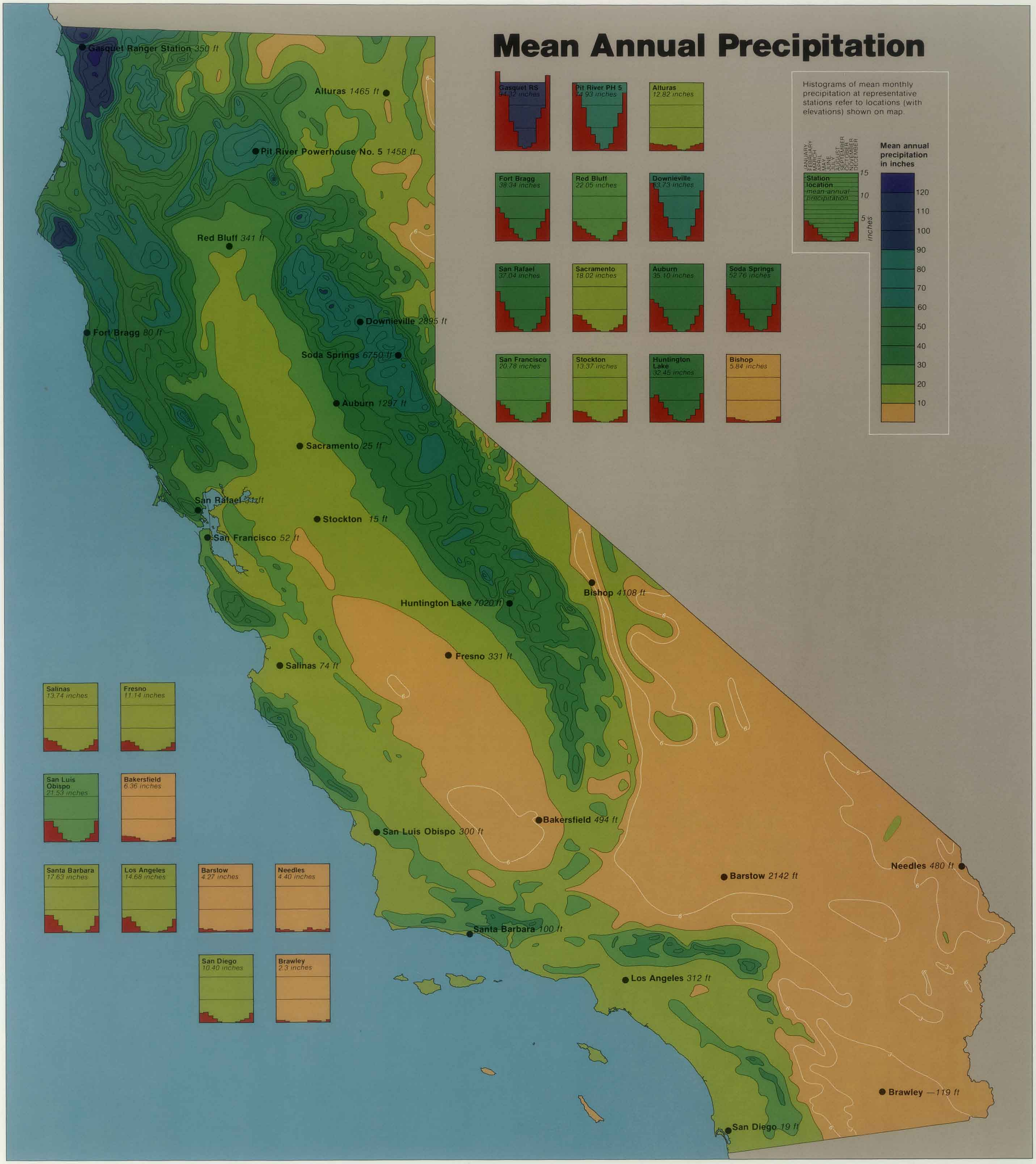
Wildfowl in flight over the marsh-lands of the Sacramento Valley today. Such areas once covered an estimated 500,000 acres of California.

ATMOSPHERIC WATER

The Pacific Ocean is the source of water that enters California through the atmosphere. Along the coast in early morning the relative humidity generally exceeds 80 percent, with little difference from month to month or from north to south along the coast. The degree of saturation is likely to decrease during the day because of heating of the atmosphere, but the relative humidity generally remains above 60 percent along the coast.

In winter the land surface is colder than the ocean and there is rain because the moist air is cooled as it

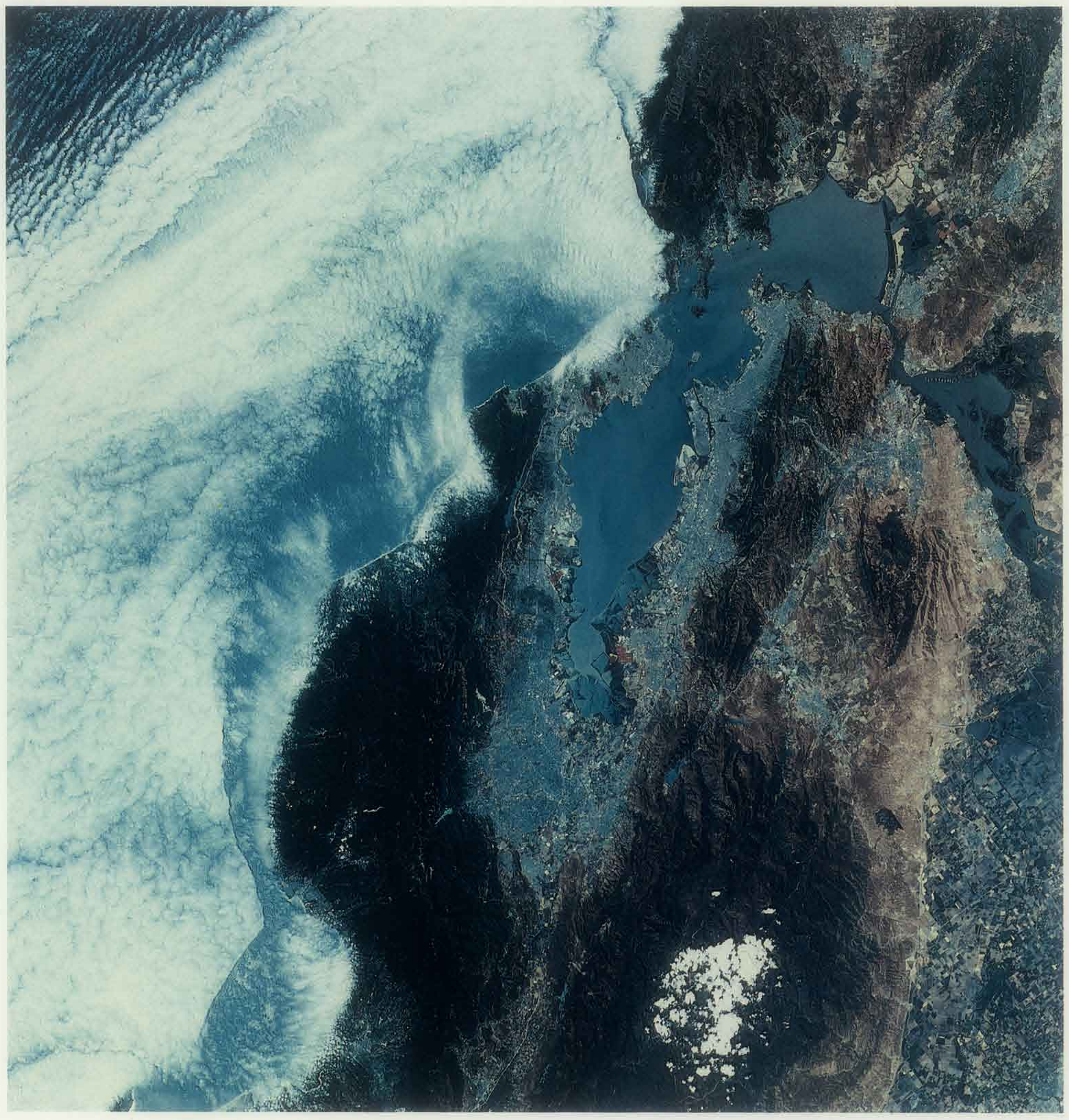
Mean Annual Precipitation



moves inland. Continued cooling as the air is forced up over mountains, and the influx of cooler air masses from the Gulf of Alaska produce more rain or snow. In summer the ocean surface is colder than the land and the difference is accentuated by the cold California current moving from the north and near the shore. The air from the ocean has relatively high humidity and may produce fog offshore that envelopes some coastal areas night and morning; but the warming effect of travel overland permits retention of the water vapor, and precipitation is rare.

Solar energy is the driving force behind the movement of atmospheric water. This energy, which is greatest in the tropics where the noonday sun is overhead part of the time and at a high angle all year, heats water and land and air at the earth's surface, and creates water vapor which rises with the hot air until it is cooled enough to condense and drop out and return to water or land, still within the tropics. The dehydrated air moves out of the tropics at high levels and is replaced by nearsurface "trade winds" moving toward the equator. The high, dry, upper air eventually descends to form cells of high pressure, calms, and light changeable winds within the "Horse Latitudes" (30-35 degrees North) where sailors, becalmed like the Ancient Mariner, could soliloquize about horses aboard ship and whether to water, dunk, or eat them.

Each year on June 21 the sun is directly over Mazatlan in Mexico, and cloudless skies can be expected throughout the area dominated by the Pacific High, the high pressure zone over the Pacific Ocean which extends as far as 40 degrees North Latitude. Hot sun and cloudless skies will also be the rule throughout the summer for the deserts of northern Mexico and the southwestern United States. The sun then appears farther south each day until, by December 21, it is directly over Antofagasta in northern Chile. Thousands of recreational vehicles follow it part way each year and the center of the Pacific High in most years moves several degrees southward, perhaps as far as the southern boundary of California. The southward retreat of the Pacific High is important for the peace of mind of Californians: so long as it remains in its northern position, it blocks the progress of low-pressure cells generated near the Aleutian Islands, and the winter rainy season is delayed or thwarted.



Fog bank crossing over San Francisco Bay

Precipitation includes all forms of water that fall from the atmosphere and reach the ground as rain, snow, drizzle, hail, ice crystals, or pellets. The flow of precipitable water into California is greatest along the North Coast and progressively less to the south. In an average year the North Coast has more than 75 days and Southern California less than 40 days of measurable precipitation. The mean annual rainfall on coastal plains near sea level is about 40 inches along the North Coast, decreasing to 20 inches in the San Francisco Bay Area and to 10 inches near San Diego.

Topography is a controlling factor in the distribution of precipitation throughout the state. The mean annual precipitation on mountains adjacent to the coast may exceed 100 inches along the North Coast, 50 inches near San Francisco, and 30 inches near Santa Barbara. Less than 100 miles to the east and at the same latitudes, the mean annual precipitation drops to 23 inches at Red Bluff, 14 inches at Stockton, and 6 inches at Bakersfield because the Central Valley is in the "rain-shadow" of the Coast Ranges. Still farther east, along the 400-mile Sierra Nevada, mean annual precipitation at these latitudes rises again to about 80 inches, 60 inches, and 40 inches as the mountains wring out a large proportion of the precipitable water in the air masses attempting to surmount them. And Nevada, as a result, becomes the driest state in the Union, at least so far as water is concerned.

Mean annual rainfall is less than 10 inches in extensive areas south of 37 degrees North Latitude, including the Colorado and Mojave deserts in Imperial, Riverside, and San Bernardino counties; the southern part of the Central Valley; and several desert valleys in the Great Basin, which extends eastward from the Sierra Nevada to the Wasatch Mountains and high plateaux of Utah and Arizona. These desert valleys are bordered by mountains which are also arid, but which may be high enough to intercept some moisture and wear a winter snowcap once in awhile.

The mean annual precipitation map in this volume is a graphic portrayal of the concept that precipitation in California increases with increasing latitude or increasing altitude, and decreases in the lee of mountain interceptors. The map does not, however, depict usual conditions, those that can be expected in most years. Variations in precipitation are so great that the state rarely enjoys a "normal" year in which precipitation would conform to the means portrayed on the map. Instead, California's climate is likely to be a product of the extremes rather than a product of the means. Records of precipitation characteristically show successions of several years when precipitation was below the long-term average, perhaps interrupted by a year or two above average, followed by a series of years when precipitation was generally above average. Major trends in precipitation, including the intensity and duration of alternating wet and dry periods, are shown in the graphic comparisons of precipitation variability. Thus the pattern of precipitation throughout California is irregularly cyclic: "cyclic" enough to be recognized in history, and "irregular" enough to defy prediction.

In addition to driving the air masses from which California derives its precipitation, solar energy also works to return water from the earth's surface to the atmosphere, through evaporation from land and water surfaces, and through transpiration by plants. The operation of these natural demand factors helps to determine which areas of California will experience water deficiencies while others enjoy a surplus.

The annual evaporative demand is less than 40 inches along the North Coast and in the high Sierra Nevada, where annual precipitation may be twice as great. These are consequently the principal areas of surplus within the state. In the rest of California the average water income from the atmosphere through precipitation is insufficient to balance the demand for evaporation, and water deficiencies result. The demand is less than 50 inches throughout the Sierra Nevada and in coastal areas as far south as Monterey; but, even though the annual precipitation in these areas is of similar magnitude, the rainfall occurs in winter and may not be available for evaporation in summer when the demand is greatest. Evaporative demand exceeds 60 inches a year throughout the Central Valley, far greater than the annual precipitation. And in the southeastern deserts where precipitation is least, the evaporative demand rises above 70 inches and approaches 120 inches in Death Valley.

Because natural demand is at a minimum during the rainy winter season, and at a maximum during the rainless summer season, most of California experiences both a water surplus and a water deficiency each year. The northwest corner of California and the highest Sierra Nevada are the only areas wet enough to have little or no deficiency in any season. At the other extreme, the southeastern deserts, the San Joaquin Valley, and several smaller valleys in southern California have little or no water surplus in any season. All the rest of California—about two-thirds of the total area—has a winter surplus and a summer deficiency of water. The amount of surplus in any given area changes from storm to storm and then dwindles to become a deficiency that changes from month to month, and these seasonal variations in surplus and deficiency are modified from year to year by California's wet and dry cycles.

Water deficiencies are limiting factors in terrestrial life. If people, animals, or plants are to survive in times and areas of deficiency, they must either adapt, draw their water supplies from some distant source, or depend upon the storage of water from the surpluses of yesterday or yesteryear. Where surpluses occur, on the other hand, they are the stuff that create and maintain river systems.

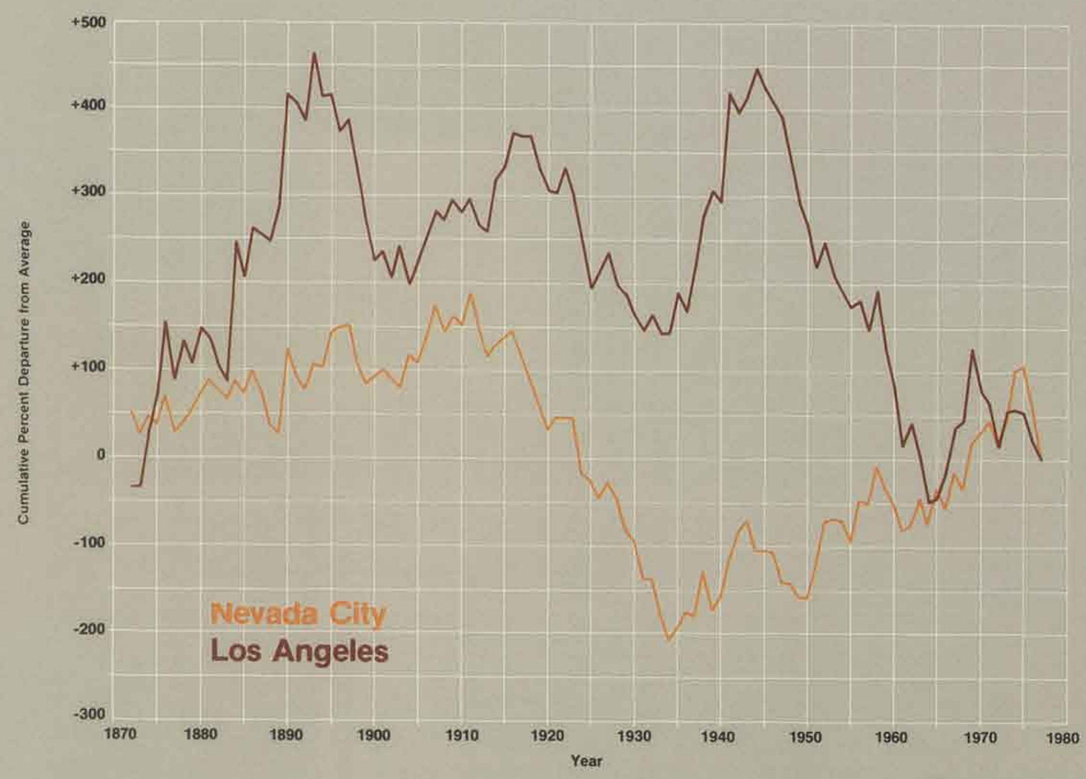
RIVER SYSTEMS

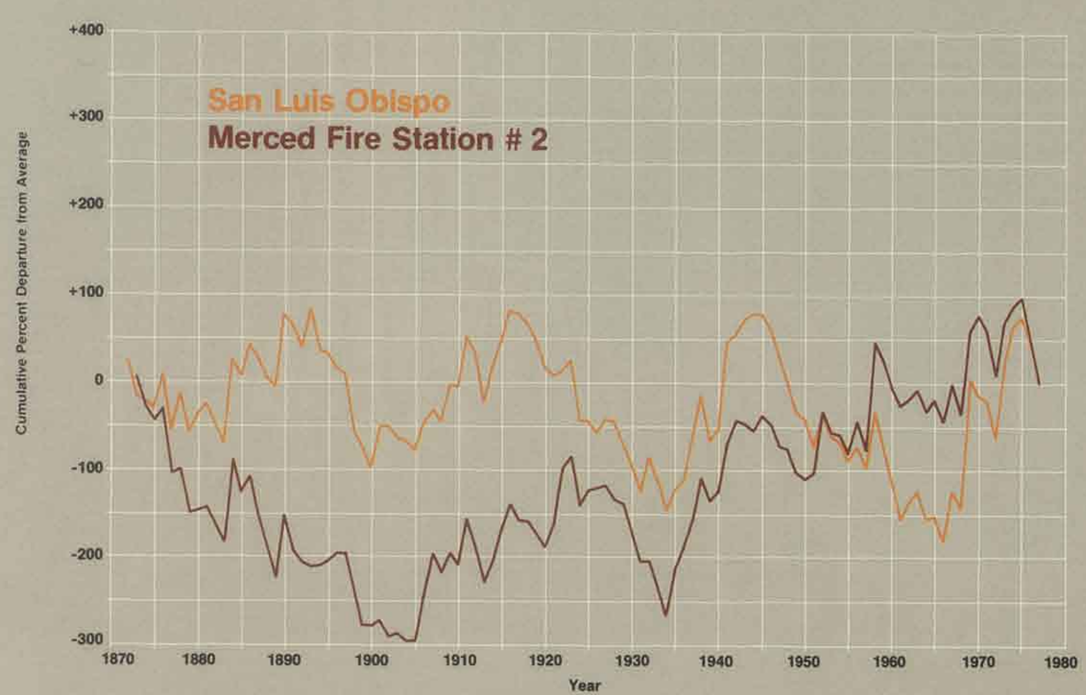
Runoff occurs wherever or whenever there is more water than can be retained in various water-storage facilities. Runoff may derive from surpluses of rainfall or snow melt that cannot be absorbed into the ground; from ponds or lakes or swamps that overflow; from the discharge of springs or seeps into

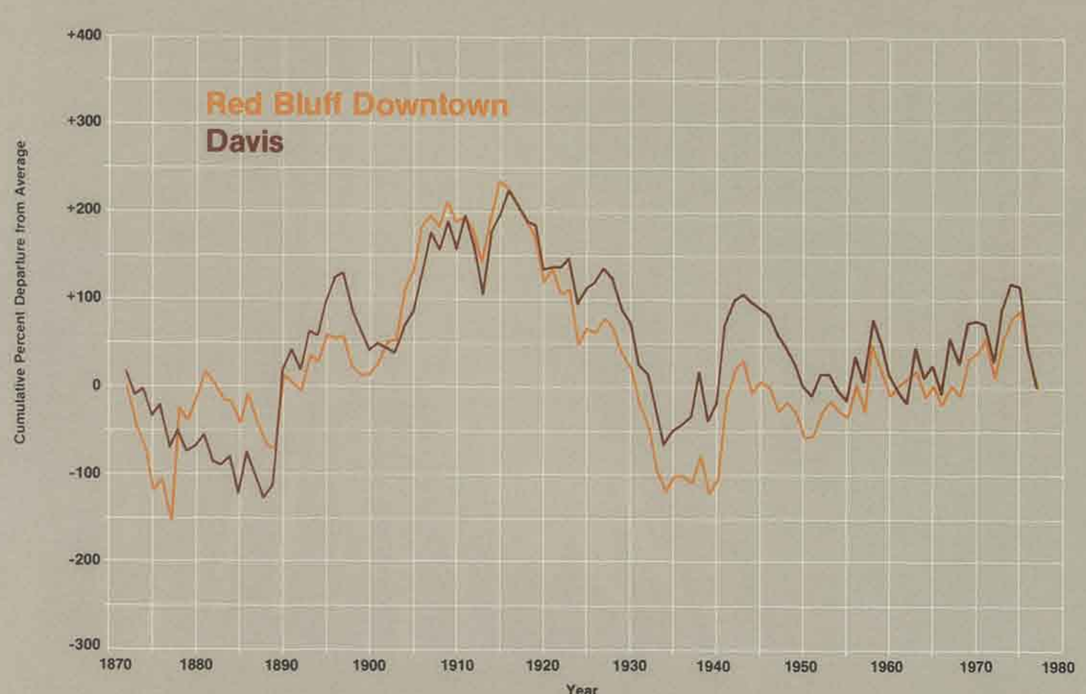
Precipitation Variability

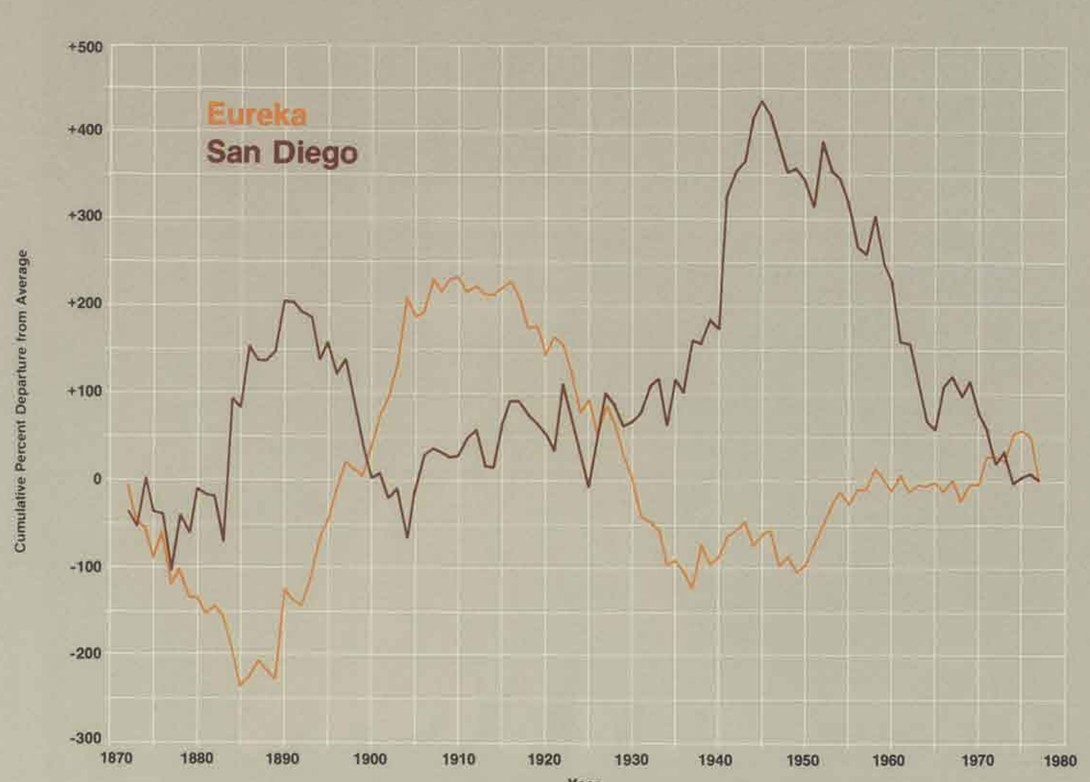
Precipitation is expected to vary with the season, but annual variations in precipitation are just as significant and much less predictable. The arithmetic mean of annual precipitation is widely used as an indicator of the precipitation that can be expected in a given year. As the magnitude of average annual precipitation decreases, however, the variability of annual precipitation increases, and the average becomes a less efficient indicator of expected precipitation. The bar graphs portray the year-to-year variability in precipitation and illustrate that average precipitation is the exception in California. (The average annual precipitation is given in parentheses after the station name on each graph.)

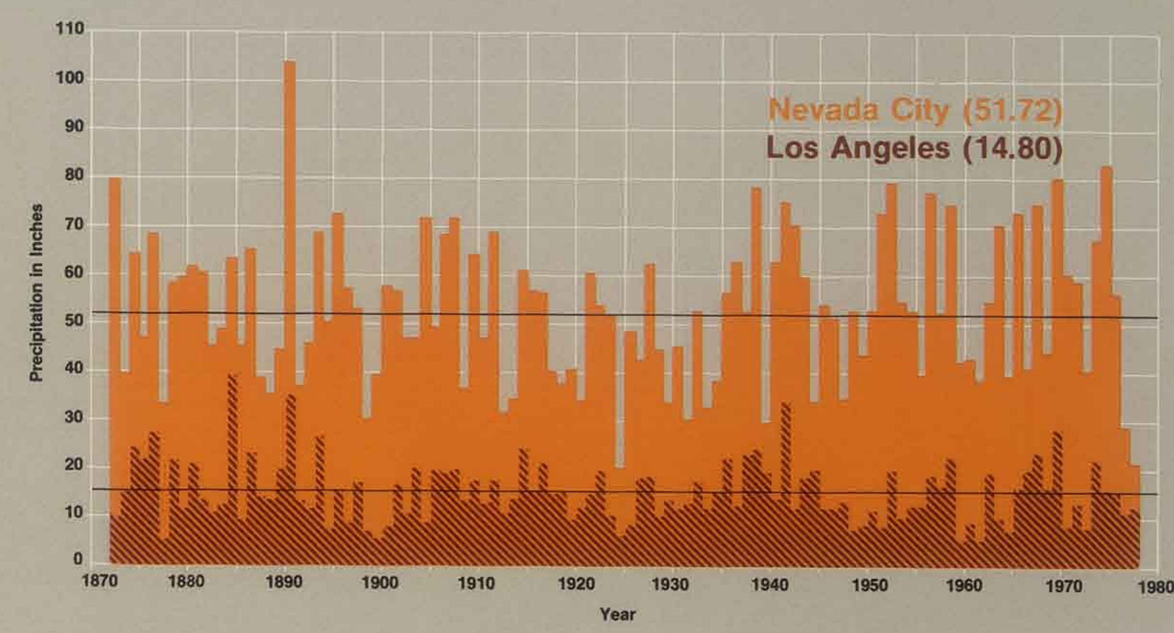
Longer term trends in precipitation variability are portrayed by the graphs of cumulative departures from average precipitation. Wet periods of above-average precipitation produce upward-tending curves while dry periods of below-average precipitation produce downward-tending curves. These graphs show that wet and dry periods are variable in length and are not coincident statewide.

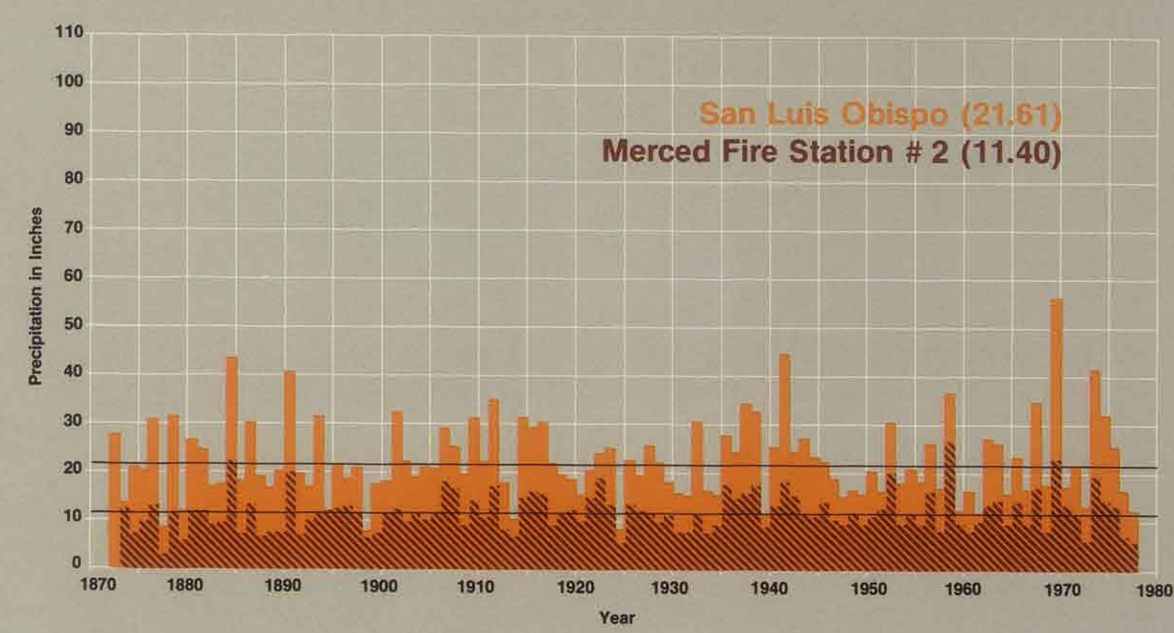


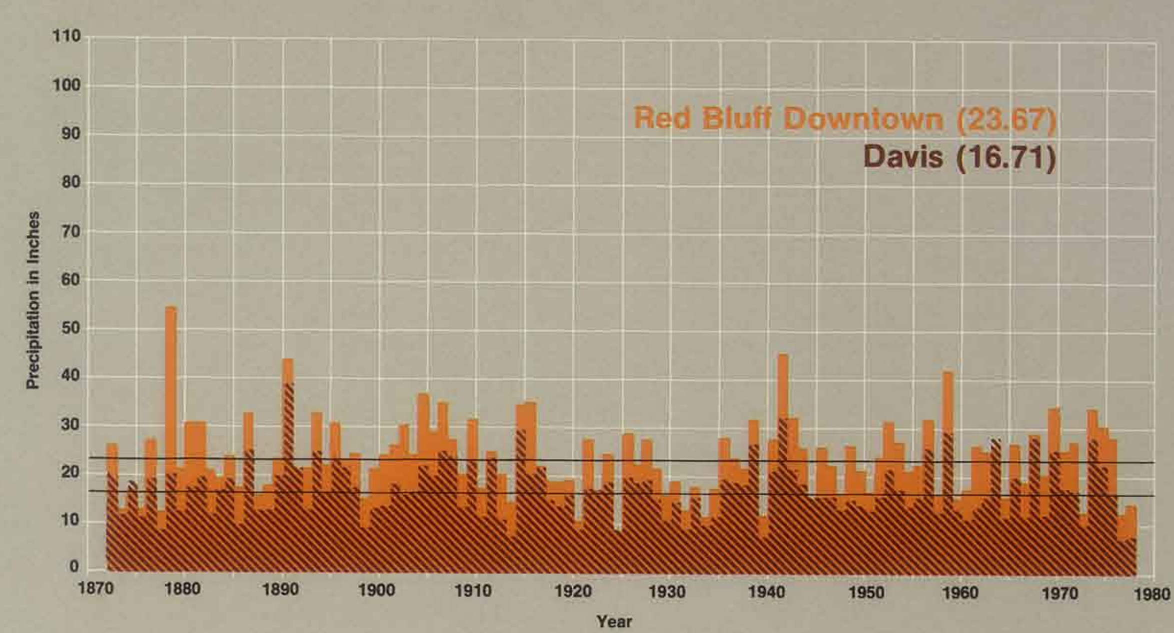


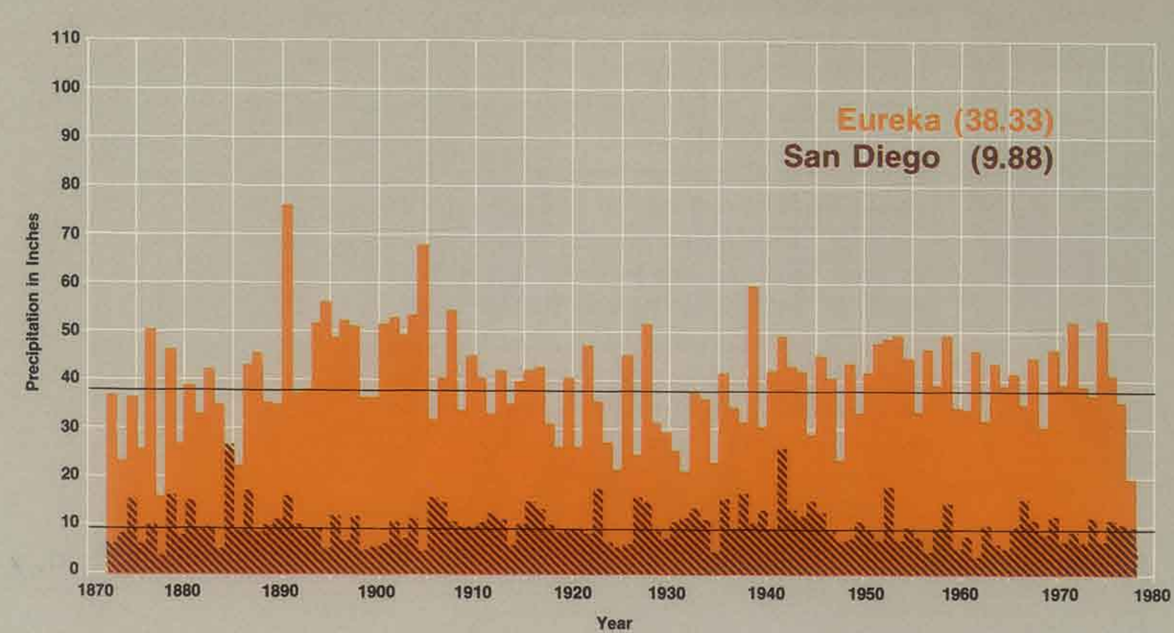












Annual Runoff and Seasonality

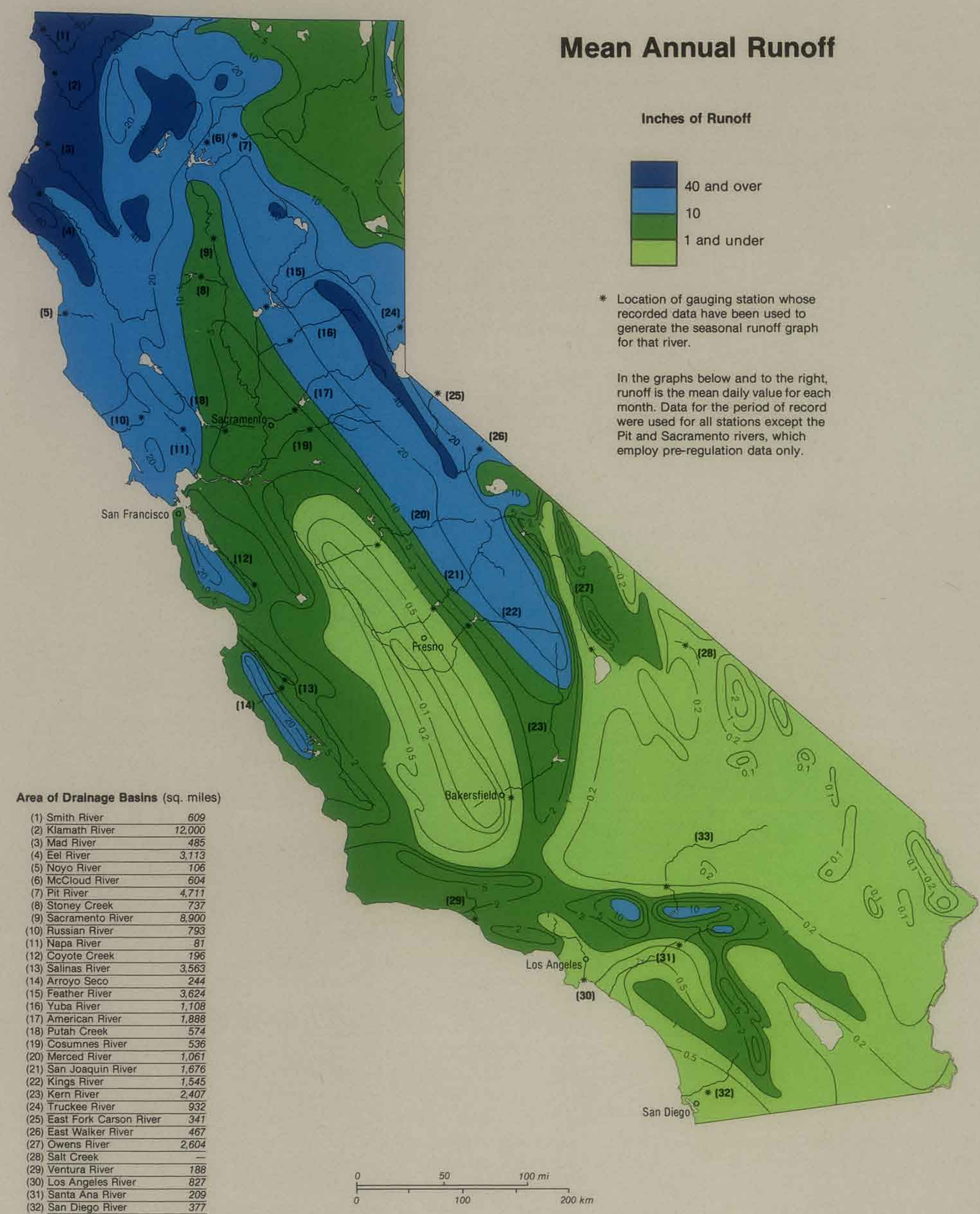
Mean Annual Runoff

Inches of Runoff

- 40 and over
- 10
- 1 and under

* Location of gauging station whose recorded data have been used to generate the seasonal runoff graph for that river.

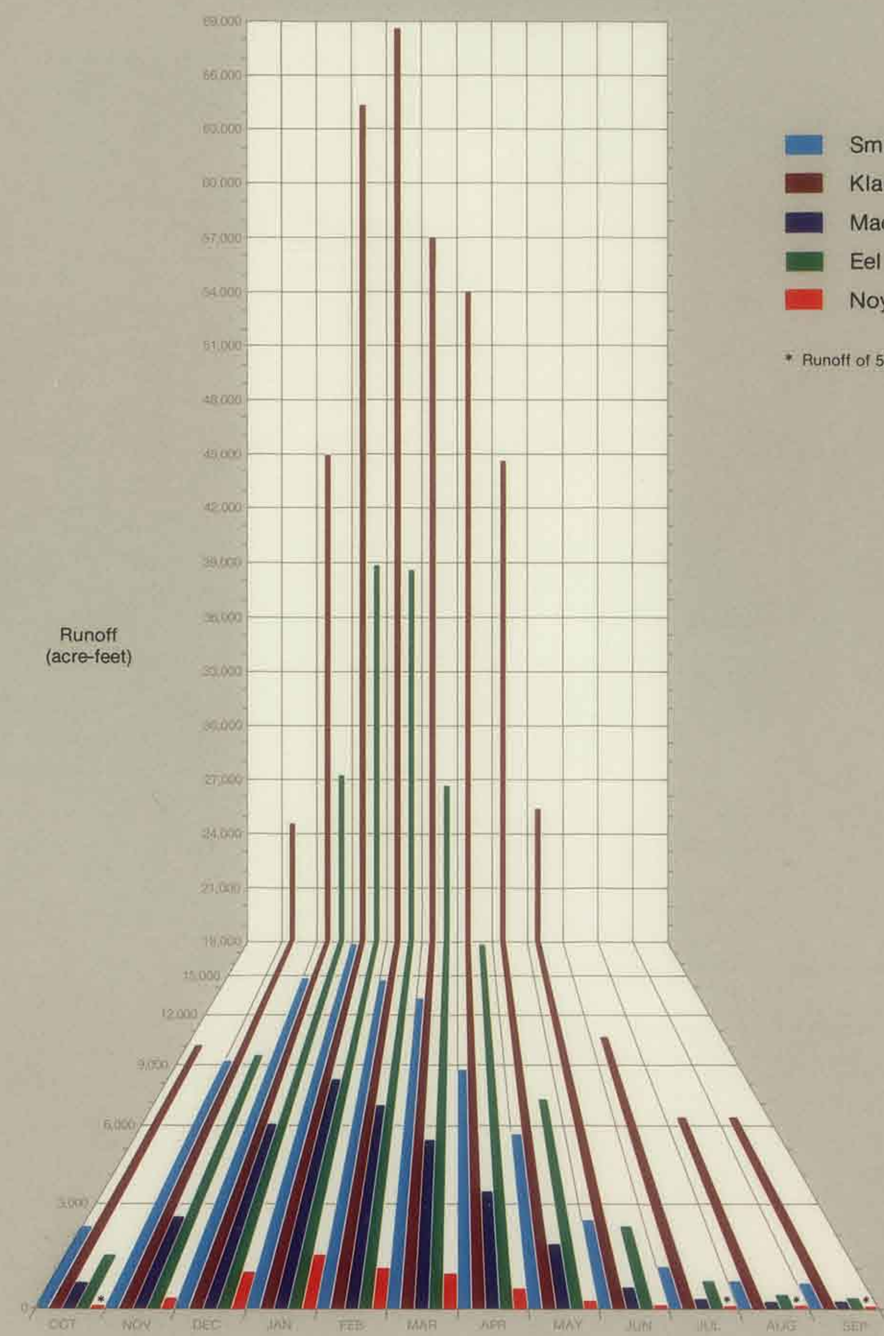
In the graphs below and to the right, runoff is the mean daily value for each month. Data for the period of record were used for all stations except the Pit and Sacramento rivers, which employ pre-regulation data only.



Area of Drainage Basins (sq. miles)

(1)	Smith River	609
(2)	Klamath River	12,000
(3)	Mad River	485
(4)	Eel River	3,113
(5)	Noyo River	106
(6)	McCloud River	604
(7)	Pit River	4,711
(8)	Stoney Creek	737
(9)	Sacramento River	8,900
(10)	Russian River	793
(11)	Napa River	81
(12)	Coyote Creek	196
(13)	Salinas River	3,563
(14)	Arroyo Seco	244
(15)	Feather River	3,624
(16)	Yuba River	1,108
(17)	American River	1,888
(18)	Putah Creek	574
(19)	Cosumnes River	536
(20)	Merced River	1,061
(21)	San Joaquin River	1,676
(22)	Kings River	1,545
(23)	Kern River	2,407
(24)	Truckee River	932
(25)	East Fork Carson River	341
(26)	East Walker River	467
(27)	Owens River	2,604
(28)	Salt Creek	—
(29)	Ventura River	188
(30)	Los Angeles River	827
(31)	Santa Ana River	209
(32)	San Diego River	377
(33)	Mojave River	514

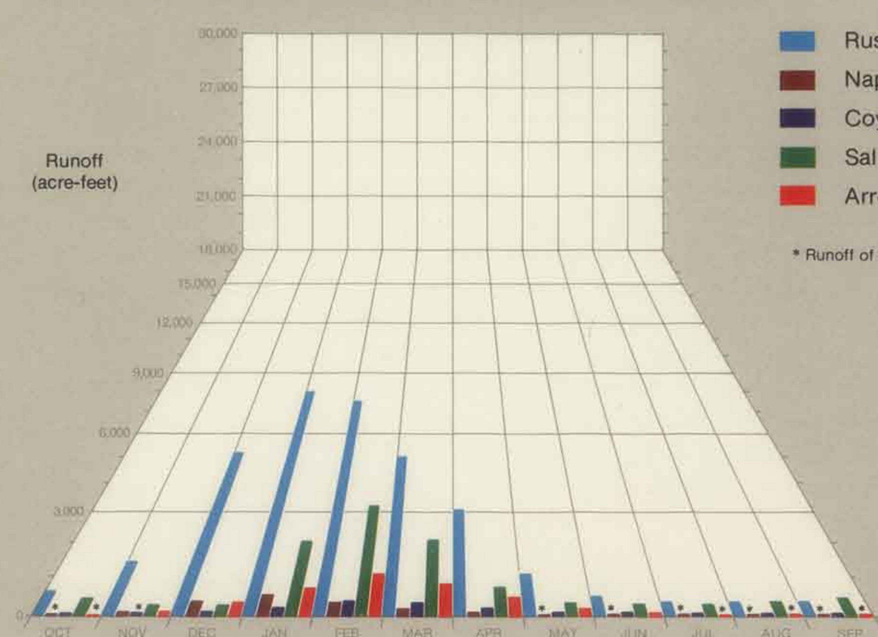
North Coast



- Smith River (1)
- Klamath River (2)
- Mad River (3)
- Eel River (4)
- Noyo River (5)

* Runoff of 50 acre-feet or less

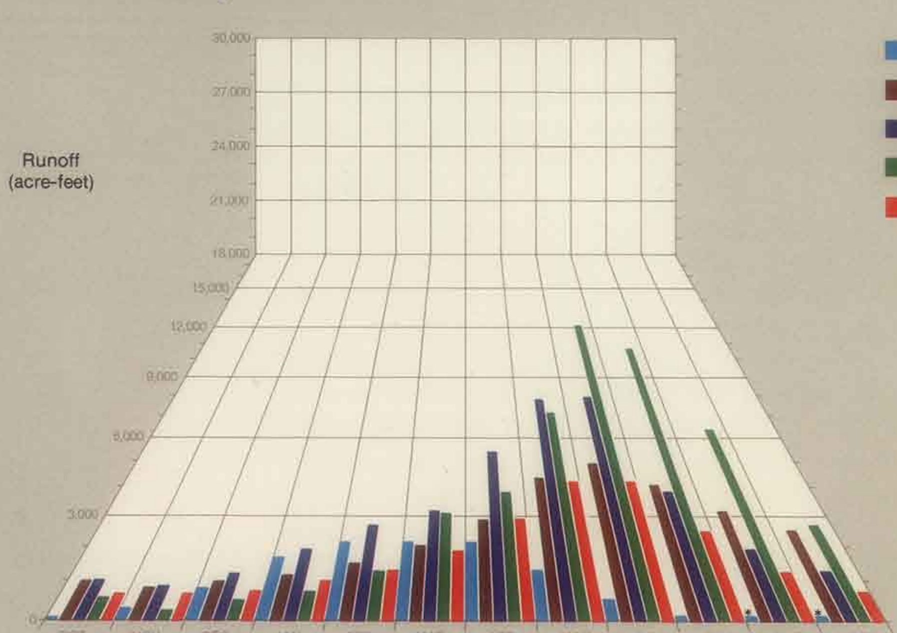
San Francisco Bay and Central Coast



- Russian River (10)
- Napa River (11)
- Coyote Creek (12)
- Salinas River (13)
- Arroyo Seco (14)

* Runoff of 50 acre-feet or less

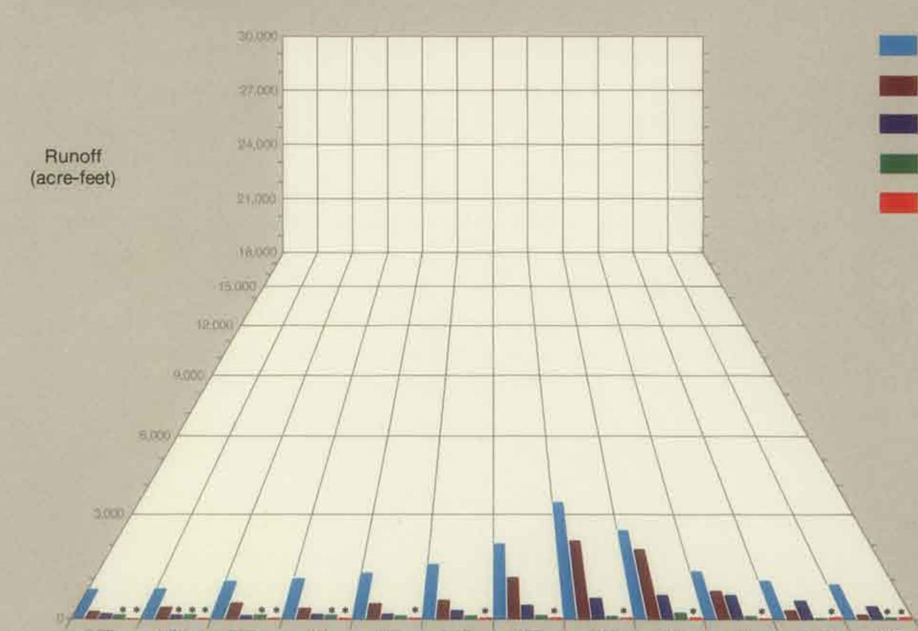
San Joaquin



- Cosumnes River (19)
- Merced River (20)
- San Joaquin River (21)
- Kings River (22)
- Kern River (23)

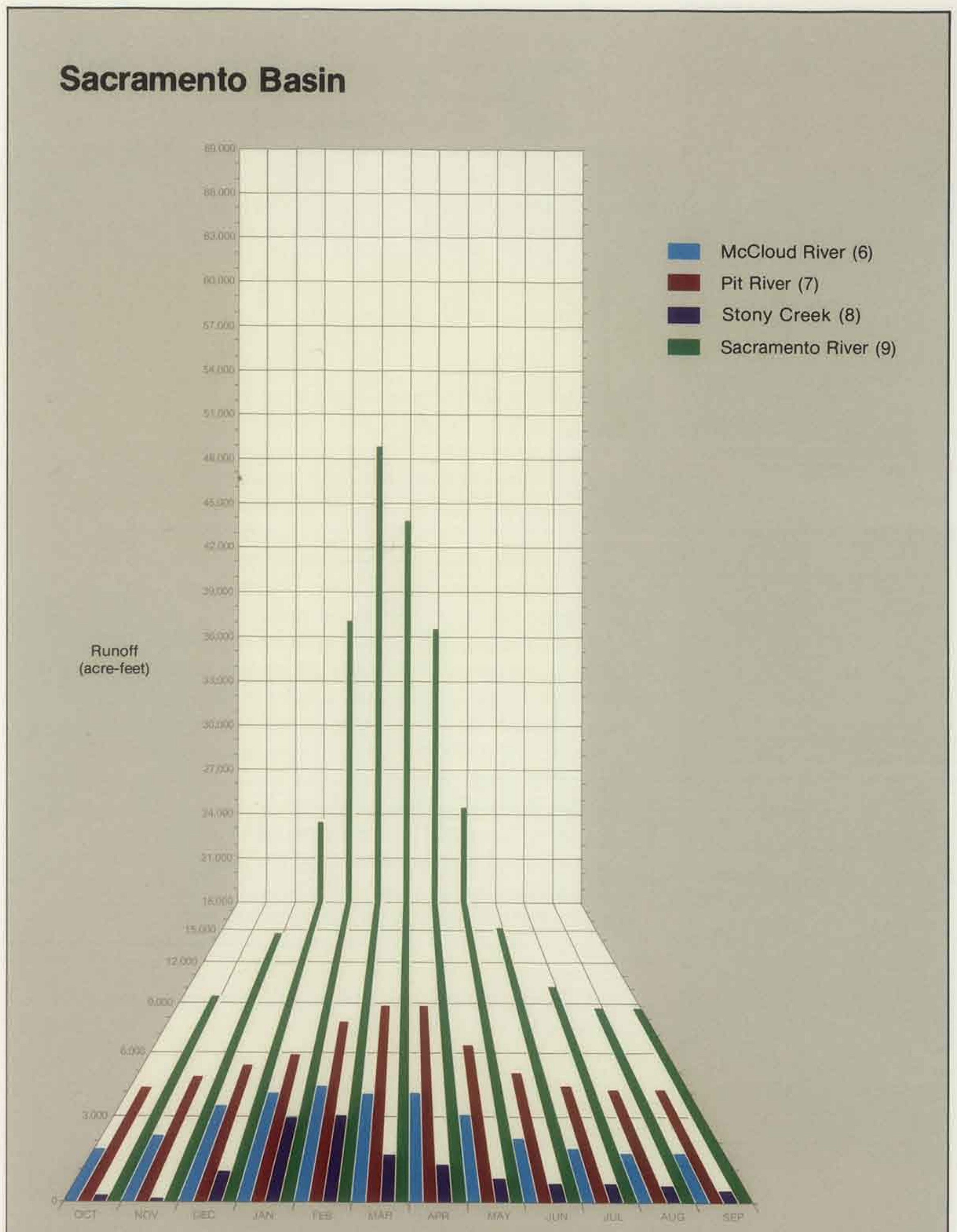
* Runoff of 50 acre-feet or less

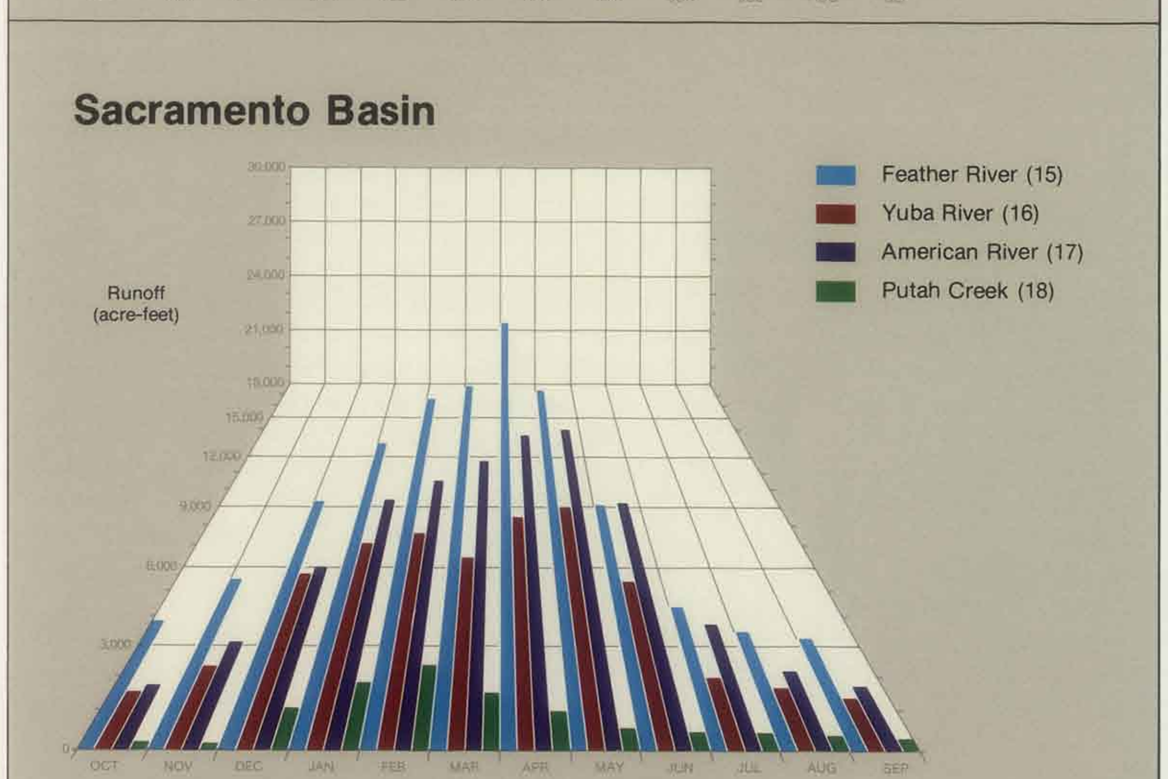
Lahontan

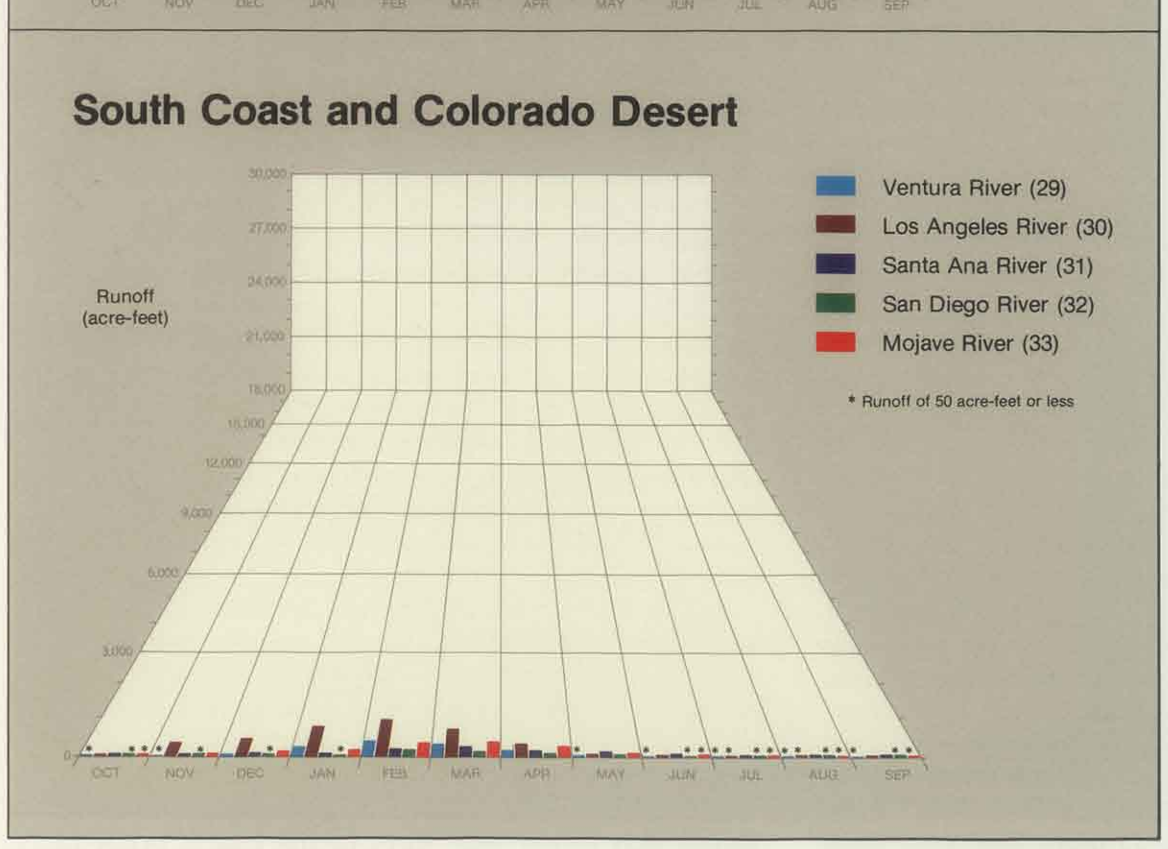


- Truckee River (24)
- East Fork Carson River (25)
- East Walker River (26)
- Owens River (27)
- Salt Creek (28)

* Runoff of 50 acre-feet or less







The dramatic contrast between the volumes of water carried by the major rivers of the North Coast as compared to the much smaller quantities of runoff available in the South Coast suggests one reason why water planners in Southern California have often looked to the north for assistance in meeting the water needs of their burgeoning population. In addition, this graphic comparison of the different points in the water year that maximum surface runoff occurs in each of the state's hydrologic basins helps to illustrate why simultaneous flooding throughout California is a rare event.

streams; or from water falling on impermeable rocks or roofs or pavements or ice. Runoff is downhill and down valley and it will eventually reach the ocean if not lost to the atmosphere or caught in a closed basin or other storage facility enroute. Flow to the ocean is achieved by a remarkable organization of river systems that ramify to the smallest tributaries. The incipient development of such systems can be seen on smooth slopes such as road cuts, spoil banks, or cultivated fields. Overland flow or sheet runoff may result from the first rainstorms, but rills and branching channels develop quickly by erosion that fashions their depth, cross section, and areal configuration. Natural channels of all sizes develop similarly.

Mean annual runoff throughout the state is eight inches, which is approximately 35 percent of mean annual precipitation. In most of California, however, variability is the keynote for all runoff, from time to time at any place as well as from place to place at any time. The direct runoff from rainfall reflects the varying intensities and durations of individual storms, which are separated by rainless intervals that may range from a few hours to many months. As a result, the mean monthly runoff in most California streams varies greatly throughout the year. During individual months of maximum flow, runoff is commonly more than 20 percent and may be as much as 35 percent of the annual mean. Minimum monthly runoff may be less than one percent of the annual runoff, and in some streams there is no flow at all for one or more months.

Precipitation on the Coast Ranges is generally rain or snow that melts within a few hours or days. Runoff from these areas increases soon after a storm begins, particularly if rain is intense, and dwindles after the storm ceases. The rocks that make up the Coast Ranges are generally relatively impermeable, and this may increase the rapidity and magnitude of storm runoff. In coastal streams generally 75 to 90 percent of the mean annual runoff has occurred by March 31, the end of the rainy season in most years.

By contrast, the temperatures in the Sierra Nevada are cold enough that most precipitation falls as snow and remains and accumulates on the ground until spring. As a result, more than 60 percent of the mean annual runoff may occur after March 31, probably reaching a peak in May but continuing through June and still significant in July. The graphic presentation of annual runoff and seasonality in this section shows the great difference that exists between the seasons of the rivers and the seasons of the heavens, as the time-delay effects of snow storage produce different periods of peak runoff for each of the hydrologic areas of California. The value of the winter accumulation of snow as a magnificent water-storage facility provided entirely by nature is further illustrated by the example of the Trinity River. The Trinity River has a drainage basin of 2,865 square miles and is tributary to the Klamath River, an interstate stream flowing to the Pacific Ocean. Much of the precipitation on the Trinity basin is rain, and 45 percent of the mean annual runoff occurs by March 31. But higher elevations within the basin receive considerable amounts of snow, which create a freshet during the spring that provides 50 percent of the annual runoff. Thus the Trinity maintains relatively high rates of runoff over a period of six months or more.

Mean annual runoff rises to more than 80 inches in the northwestern corner of the state but declines to less than 0.25 inch in the southeastern deserts and closed basins in the southern third of the Central Valley. Areas of such extreme water deficiency are a hostile environment to surface water whether flowing in streams or standing in lakes or reservoirs. The streams flowing in these desert areas are habitual losers to the unrelenting sun. Some streams are ephemeral or seasonal, others have broad sandy channels which, according to neighbors, "never" have water and do not deserve the name of river or rio. If there is perennial flow, it is limited to short reaches in mountainous headwaters or to areas of spring discharge. But such streams can flash into national prominence during once-in-a-lifetime or "hundred-year" floods. For example, rain beginning February 27, 1938, caused disastrous floods in Southern California: peak flows on March 2 reached 100,000 cfs in the Santa Ana River, 65,700 cfs in the San Gabriel River, and an estimated 67,000 cfs in the Los Angeles River at Main Street. In this flood 290,000 acres were inundated, 87 lives were lost, and estimated damage exceeded $78 million. And yet, most people regard the Los Angeles River as a dry channel.

Only one river, the Colorado, traverses the Southwest American Desert and discharges into the sea. It has done a magnificent job of carving canyons and transporting the debris therefrom to form a huge delta which separated the Gulf of California from the Salton Basin as it sank below sea level along the San Andreas Fault. As a result, the Imperial and Coachella valleys today are the only agricultural regions below sea level in North America. The Mojave River, with headwaters in the high San Bernardino Mountains, flows toward the Colorado River but gets lost in the Mojave Desert. In most years the water is lost before it reaches Barstow 50 miles east of the headwaters, but in flood years some water may reach and accumulate in Soda Lake, another 50 miles to the east. During the flood of March 1938, the Mojave River generated 150,000 acre-feet in its mountain headwaters, of which 120,000 acre-feet flowed past Barstow and discharged into erstwhile dry lakes.

The Owens River has several tributaries that drain the steep eastern slope of the Sierra Nevada, and has had enough water in the past to fill Owens Lake 250 feet deep and then overflow to form lakes in Indian Wells, Searles, Panamint, and Death Valley. But that was during the Ice Age which ended thousand of years ago. For many centuries the river has ended at Owens Lake, and most of its water is now diverted into reservoirs and pipelines before it gets near the former lake. Evidences of its former affluence—a fossil river system—are the high shore lines in Death Valley and Panamint Valley, and the brines of borax, potash, soda ash, and salt cake that have accumulated in Searles Lake.

The southern part of the Central Valley is currently a closed basin. Buena Vista Lake is the ultimate goal of the Kern River, southernmost of the Sierra rivers. Two smaller rivers, the Tule and Kaweah, flow toward a larger and lower depression farther north called Tulare Lake, and the Kings River still farther north turns southward toward the same depression. Although this southern end of the Central Valley has become isolated from the San Joaquin River System, early explorers noted that in 1853 the Tulare Basin contained a lake of about 450,000 acres extent, which overflowed to the San Joaquin River. In 1862 Tulare Lake reached a level six feet above the overflow line and covered an area of perhaps 500,000 acres. It may have been even higher in 1868 and overflows occurred in several subsequent years before ceasing in 1878. The lake dried up during the drought years 1894-1904, reappeared during the wet years 1906-16, and then disappeared during the drought of 1917-35. Thus, this area too has a fossil river system and a phantom lake.

The rivers and creeks that flow to the Pacific Ocean south of San Francisco generally have headwaters that are high enough to receive mean annual precipitation of 20 inches or more. This coastal belt experiences a winter surplus and summer deficiency of water, adding up to an overall annual deficiency generally less than 20 inches. Mean annual precipitation in the drainage basins of these coastal streams is generally in the range of 20 to 30 inches, and 10 to 30 percent of this becomes the mean annual runoff. Exceptionally high rainfall and runoff are recorded in some places: the 46-square-mile drainage basin of Big Sur River has mean annual precipitation of 51 inches of which 50 percent becomes runoff. Farther south and farther inland the mountainous Lytle Creek basin near San Bernardino has mean annual precipitation of 33 inches, of which 35 percent becomes runoff.

North of San Francisco Bay the evaporative demand is greater than rainfall most of the year, but the rainy season brings enough precipitation to provide a water surplus in a normal year. The rivers flowing westward have mean annual precipitation ranging from 50 to 80 inches on their drainage basins, of which 40 to 65 percent becomes runoff. The streams draining the east slopes of the Coast Range and tributary to the Sacramento River have drainage basins with mean annual rainfall of 25 to 40 inches, of which 35 to 45 percent becomes runoff.

Most of the water surpluses of the Sierra Nevada move westward into the Central Valley through tributaries of the San Joaquin-Sacramento river system, which flows to the Pacific Ocean via San Francisco Bay. From the San Joaquin River north, the major tributaries have mean annual precipitation exceeding 40 inches, and more than 50 inches in the basins of the Yuba River and the American River. The mean annual runoff in these tributaries generally ranges from 45 to 55 percent of precipitation. The principal streams draining the east slope of the Sierra Nevada—the Truckee, Carson, and Walker rivers which flow into Nevada—have somewhat less precipitation on their mountainous headwaters but about the same proportion of runoff.

The water stored as snow on the Sierra Nevada is the principal cause of the difference between the seasons of the heavens and the seasons of the rivers. The photograph at top shows one of the sources of the San Joaquin River. The photograph below displays a portion of the snowpack near Lake Tahoe.

The part of California north of Lake Tahoe and east of the Sierra Nevada has mean annual precipitation ranging from 30 inches down to less than four inches. The mean annual runoff is less than ten inches and generally less than five inches. This is Great Basin country, with Goose Lake severing itself from the Sacramento River system because of water deficiency, and several alkali lakes farther south near the Nevada border. It is also lava plateau country, high enough that much of the annual precipitation is snow, and with rocks permeable enough to absorb most of the water from snow melt or rain. In a typical stream such as Willow Creek near Susanville, 40 percent of the mean annual runoff occurs in spring with snow melt and the flow is well sustained throughout the rest of the year. Several other streams in the northeast part of the state have fairly uniform flow throughout the year because of groundwater inflow: examples are Fall Creek, tributary to the Klamath River; and Hat Creek, in the Sacramento River system. Such uniformity of streamflow throughout the year is rare in California, and the lava plateaux are the best place to find it.

Groundwater can thus provide an important adjunct to surface runoff. Although the mountains that catch most of the rain and snow are relatively impermeable, small valleys within these mountains, and larger valleys and plains that border, separate, or surround mountains generally contain unconsolidated sediments—clay, gravel, sand, and silt—which may be hundreds or even thousands of feet deep. These permeable sediments form aquifers that may yield moderate to large quantities of water to wells. The aquifers in these valleys and plains may be recharged by direct rainfall, melting snow, tributary streams, or by underground movement from adjacent mounain masses. A gauging station recording the runoff from such a mountain valley may show quick response to rain storms, slower response to melting snow, and a base flow representing continuous groundwater discharge into the stream. In successive dry years, these groundwater inflows can become the principal source of runoff for some streams.

NATURAL WATER STORAGE

Two-thirds of the precipitation upon California does not become runoff, but instead comes down to the land surface where it is measured, stored, or calculated, and then returns to California's atmosphere. This return step in the hydrologic cycle, however, only occurs after some delay, which may be a matter of hours, days, months, or years.

Some atmospheric water is intercepted by vegetation, or it is condensed directly from the atmosphere as dew or frost upon cold objects. The quantity of intercepted water is generally unmeasured, and presumably much of it is soon evaporated. Nevertheless, it is substantial in some coastal areas; special studies have shown it to be generally 5 to 15 percent of annual rainfall. Some forms of vegetation such as the redwood tree survive long rainless periods partly by interception of atmospheric water, particularly in the humid coastal areas. Like the individual cold rock or plant, the high mountains of California intercept atmospheric water, but they do it in a big way. All winter long these mountains receive and accumulate snow. On April 1 the depth and water content of the accumulated snow are measured by snow surveys, and these provide estimates of the natural storage of water that will contribute to freshets in the forthcoming rainless season.

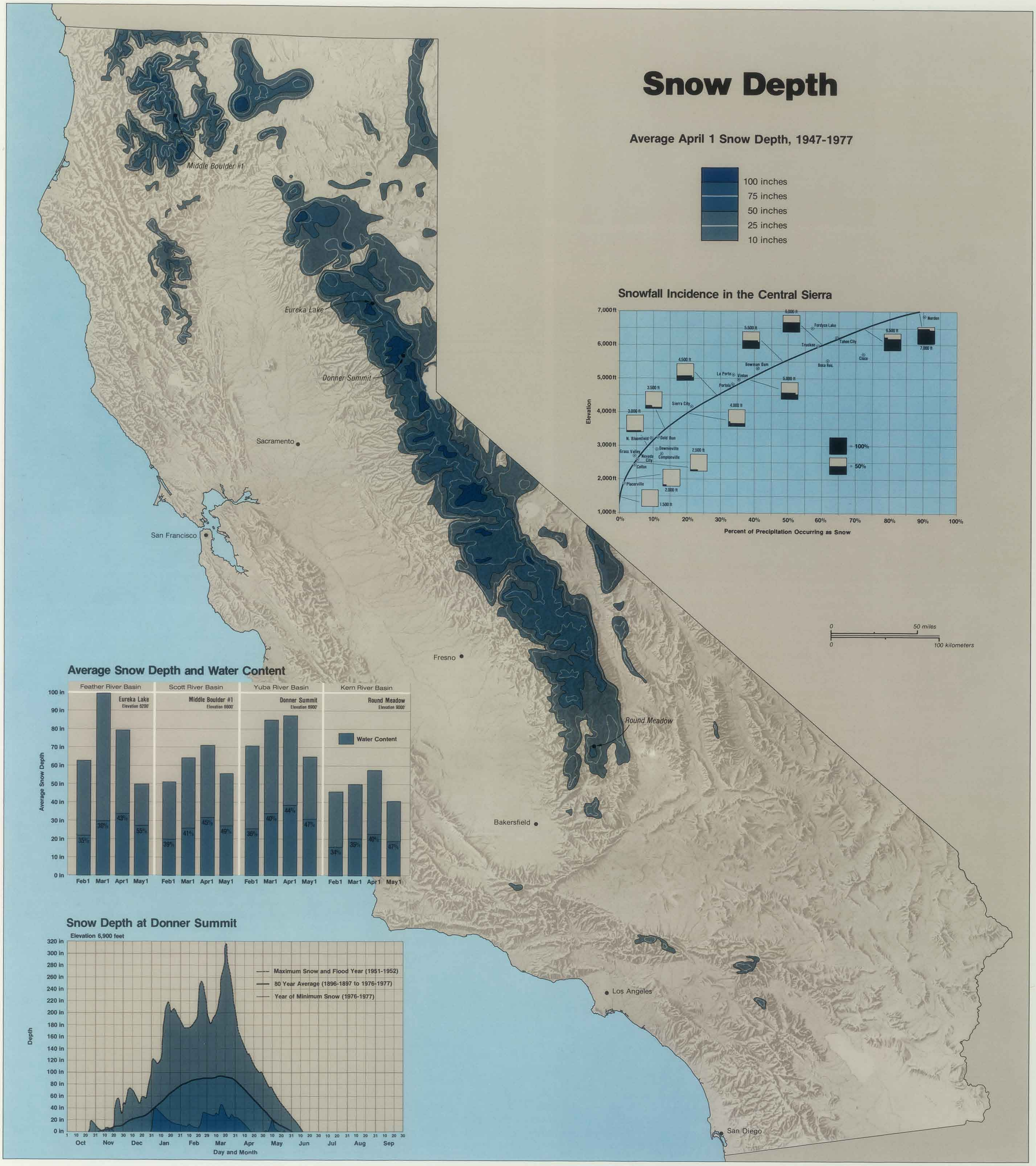
The land surface thus offers one of the first opportunities for delay in the circulation of water from the ocean through the atmosphere to earth and back again. Although some snow returns to the atmosphere by sublimation before it can be measured either as precipitation or runoff, rainfall on the land may be absorbed by infiltration. Some materials, such as dune sand, coarse gravel, talus, and some organic soils, are permeable enough to absorb all the water from storms of high intensity and long duration. Most soils have moderate to low permeability and can absorb some water, but the rate of infiltration decreases as the uppermost pores fill with water. The water that does not go underground but remains on the surface may accumulate to form puddles, pools, ponds, and lakes, thus filling depressions of all sizes and shapes. The depressions in which water accumulates are nature's surface water storage facilities, and as they fill to overflowing, the overflows become runoff, either overland or in a stream system.

Some water is retained as soil moisture in the unsaturated materials immediately beneath the land surface, where water occurs as vapor, liquid, or frost depending on the temperature. Soil moisture is estimated to be less than one-tenth of one percent of the fresh waters on earth and about three times as much as the average water content of the atmosphere. Like atmospheric water (and closely dependent on it) soil moisture is a very transient storage: yearly receipts and dispatches of water by the soil are doubtless several times as great as its average water content.

The seasonal availability of soil moisture dictates the growing season for many plants in California. Grasslands are commonly green in the winter, go to forage or hay or seed in early spring, and become golden fire-hazards in summer. Similarly, the first rains of winter reduce the summer pall of heat and increased soil moisture revitalizes the forests, chaparral, and brush lands. For much of California's native vegetation, summer is consequently the dormant season.

Soil moisture can be retained by molecular forces working against the force of gravity until it is reached by plant roots. Water storage is not the only mechanism, however, by which plants in California have adapted to summer drought conditions. Some plants form wax coatings to reduce evapotranspiration, small leaves to reduce the evaporative surface, or leaves that orient side ways to the sun in order to

Snow Depth



Average April 1 Snow Depth, 1947-1977
100 inches
75 inches
50 inches
25 inches
10 inches
Middle Boulder #1
Eureka Lake
Donner Summit
Sacramento
San Francisco
Fresno
Round Meadow
Bakersfield
Los Angeles
San Diego
0
50 miles
0
100 kilometers
Snowfall Incidence in the Central Sierra
Elevation
7,000 ft
6,000 ft
5,000 ft
4,000 ft
3,000 ft
2,000 ft
1,000 ft
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Precipitation Occurring as Snow
6,000 ft
5,500 ft
4,500 ft
3,500 ft
3,000 ft
4,000 ft
5,000 ft
6,500 ft
7,000 ft
2,500 ft
2,000 ft
1,500 ft
Norden
Fordyce Lake
Truckee
Tahoe City
Cisco
Boca Res.
Bowman Dam
La Porte
Vinton
Portola
Sierra City
N. Bloomfield
Gold Run
Downieville
Camptonville
Grass Valley
Nevada City
Colfax
Placerville
= 100%
= 50%
Average Snow Depth and Water Content
Average Snow Depth
Feather River Basin
Eureka Lake
Elevation 6200'
Scott River Basin
Middle Boulder #1
Elevation 6600'
Yuba River Basin
Donner Summit
Elevation 6900'
Kern River Basin
Round Meadow
Elevation 9000'
Water Content
100 in
90 in
80 in
70 in
60 in
50 in
40 in
30 in
20 in
10 in
0 in
35%
30%
43%
55%
39%
41%
45%
49%
36%
40%
44%
47%
34%
35%
40%
47%
Feb1 Mar1 Apr1 May1
Feb1 Mar1 Apr1 May1
Feb1 Mar1 Apr1 May1
Feb1 Mar1 Apr1 May1
Snow Depth at Donner Summit
Elevation 6,900 feet
Depth
320 in
300 in
280 in
260 in
240 in
220 in
200 in
180 in
160 in
140 in
120 in
100 in
80 in
60 in
40 in
20 in
0 in
Maximum Snow and Flood Year (1951-1952)
80 Year Average (1896-1897 to 1976-1977)
Year of Minimum Snow (1976-1977)
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Day and Month

North Palisades Glacier, a remnant of the great masses of ice which carved the face of California, appears as the densest concentration of white on the crest of the Sierra in the photograph at far right. The Middle Fork of the Kings River can be seen to the left of the glacier. Other forms of natural water storage are represented by the smaller photographs, which show a glacial tarn near Yosemite Valley and desert vegetation responding to a rainstorm.

avoid having their maximum surface area exposed. Other have green stems in order to reduce the use of leaves in photosynthesis, or close their breathing pores (stomata) at the onset of drought. And some adopt ephemeral life styles so that they grow only when the water supply is sufficient. Only the succulents, which are rare among California flora, use water storage as a major defense against drought.

Many California householders are more involved with soil moisture than they may realize. Roofs and pavements reduce infiltration and may create runoff instead, which may be a nuisance from the point of view of a neighbor. A septic tank increases soil moisture, as does any drain field. With a lawn a householder establishes a need for very shallow soil moisture which is frequently replenished, perhaps to the discomfiture of nearby trees and shrubs. Native vegetation may also suffer from so much water all summer long. Fortunately, soil moisture's movements are chiefly upward and downward, and not across property lines. Each man has a God-given right (Matthew 5:45) to both sun for evapotranspiration and rain for infiltration; so doubtless he has a perfect right to all soil moisture within his property, and its use, benefits, and problems.

If infiltration exceeds the retention capacity of the soil, some water may percolate downward until it reaches a zone where all pores are saturated. At this point it becomes groundwater and forms a part of the water-storage facilities widely distributed beneath the lands of California. The total groundwater on earth is more than 30 times as much as all the water in lakes and rivers plus all the moisture in soils and in the atmosphere. The relatively impermeable consolidated rocks that make up the mountains, canyons, slopes, and foothills of the Sierra Nevada and Coast and Basin ranges cover about half of California. More permeable sediments in these areas are restricted to narrow valleys and "flats".

In the southeastern deserts groundwater reservoirs occupy about ten percent of the state's area. They have been explored only enough to show that most of them contain some usable water, and some contain brines of economic value. Discharge from these groundwater reservoirs may come from springs or by evapotranspiration from wet playas, or through subsurface movement to a lower valley. Farther north in California and east of the crest of the Sierra Nevada, volcanic rocks on the Modoc Plateau and the Cascade Range include some excellent aquifers distributed over about 15 percent of the state's area. The groundwater here is discharged at numerous springs and streams throughout the year, and there are some very successful wells. But groundwater development has generally not been extensive. Thus the deserts and the volcanic rocks contain most of the groundwater reservoirs still undeveloped in California.

California's largest groundwater reservoir is in the Central Valley. It is composed largely of stream-borne sediments that now contain fresh water to depths ranging from 400 to 4,000 feet below sea level. These sediments include beds of sand and gravel, thickest near the canyons of the principal streams flowing from the mountains, which are the major aquifers, or bearers of water to wells. These aquifers are separated by less permeable beds of silt and clay which become thicker and more prevalent in the middle and western parts of the valley and in the intervals separating the major streams. Some deep aquifers are separated from shallow aquifers by extensive beds of clay, which have created artesian pressure sufficient for flowing wells. This Central Valley groundwater reservoir is a complex and heterogeneous mass, too large to consider conveniently as a unit and yet with sufficent unity that any division on the basis of groundwater characteristics is difficult. Taken as a unit, the Central Valley groundwater reservoir has a usable storage capacity estimated at 100 million acre-feet underlying a 15,000 square-mile area.

The Central Valley's groundwater reservoir is equivalent to the total area of the other 50 groundwater reservoirs from which significant volumes of water are pumped today. Approximately 40 of these developed groundwater reservoirs are in the drainage basins of streams rising in the Coast Range and flowing to the Pacific Ocean. These groundwater reservoirs are in alluvial sediments in structural valleys or coastal plains, or along streams that drain, traverse, or bypass various ranges as they flow toward the ocean. The northern coastal region has the greatest precipitation and runoff; its groundwater reservoirs are recharged each rainy season and maintain the perennial flow of streams in the rainless season. Water deficiency becomes increasingly prevalent to the south, where groundwater reservoirs are recharged in wet seasons but where the water may remain underground as it moves toward the ocean, appearing at the surface only where it encounters impermeable rocks, faults, or other barriers.

East of the Sierra Nevada and the Transverse Ranges farther south, several groundwater reservoirs have been developed and pumped chiefly for irrigation. Some of these are along perennial streams and receive recharge from those streams. Some are recharged chiefly during rare intense storms and flood runoff. And some give no evidence of replenishment at any time.

Natural lakes include all bodies of standing water, regardless of size, shape, or salinity. They are found in topographic depressions where water can, does, or used to flow and accumulate. Rivers and lakes do not get along well and tend to work against each other. When there is a sufficient surplus to fill the lake depression to overflowing, the river will try to destroy the lake by using its inflow to deposit sediment on the lake bed, and by using its outflow to erode its channel and lower the lake level. When, on the other hand, there is a deficiency of water, the outflow ceases, the lake takes all the water to meet evaporative demand, and the river dies.

Lake Tahoe is California's biggest natural lake. With an area of 191 square miles, it contains approximately 122 million acre-feet of water, about four times the total storage capacity of all the modern reservoirs in California. Its usable storage, however, is in a six-foot layer between altitudes 6,223 and 6,229 feet, containing 744,000 acre-feet, which is an amount nearly equal to the storage capacity of the three Hetch Hetchy reservoirs of today. Because its mean annual rate of evaporation of 36 inches exceeds its mean annual precipitation of 24 inches, however, Lake Tahoe may be losing more water to the atmosphere than Hetch Hetchy.

Mono Lake, east of the Sierra Nevada and south of Lake Tahoe at an altitude of about 6,400 feet, covers about half the area of Lake Tahoe and contains approximately four million acre-feet of saline water. Eagle Lake, north of Lake Tahoe and at about 5,100 feet altitude, is only half the area of Mono Lake and contains half a million acre-feet of water. Both are in areas of water deficiency where annual evaporation exceeds rainfall and neither has a natural outflow. In both lakes, levels increased after 1850 until about

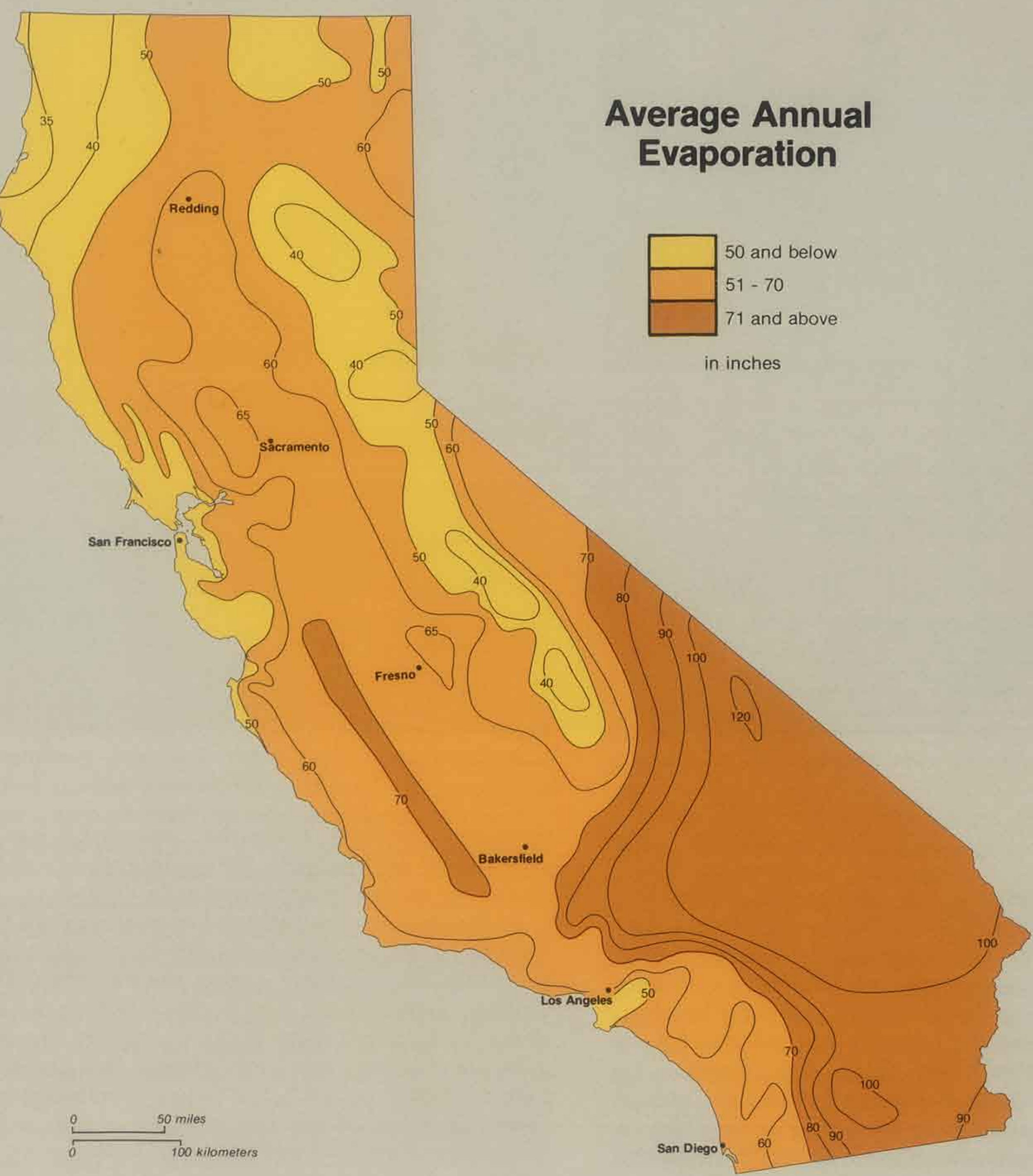
Natural Moisture Demand

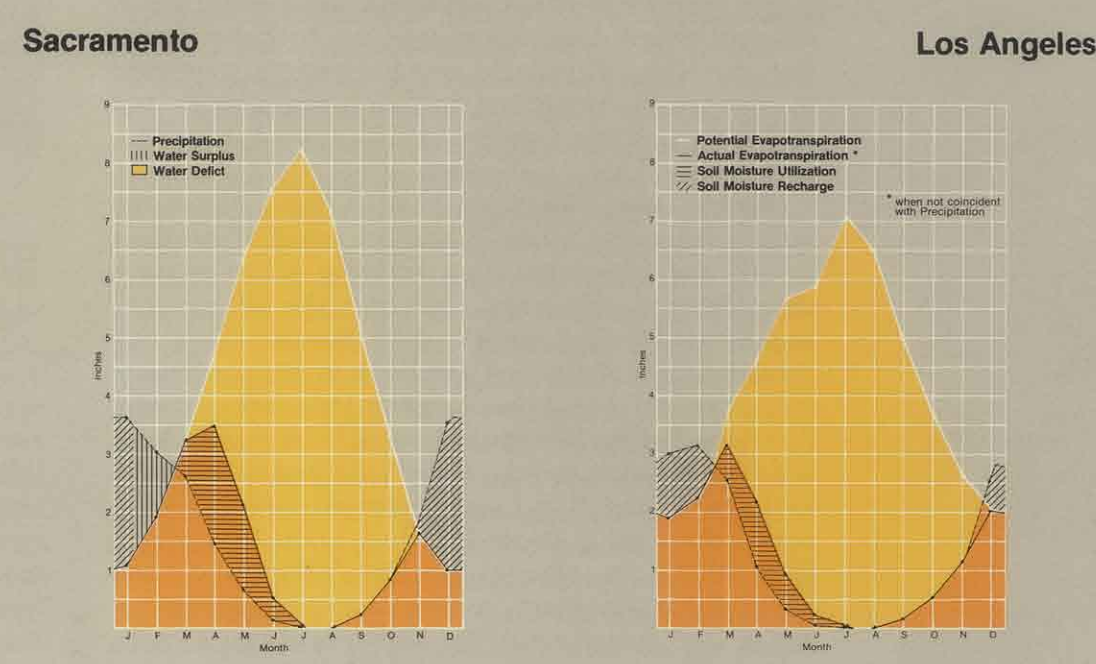
Natural Moisture Demand is the combination of processes by which water returns to the atmosphere through evaporation from land and water surfaces and through transpiration by plants. The statewide pattern of **Average Annual Evaporation** from water surfaces is limited principally by the amount of solar energy available in a given region or season of the year. Evaporation from land surfaces, however, is impeded by the cohesion of soil and water particles, while transpiration by plants is limited by the availability of soil moisture. As a result, the combined rate of these processes, called evapotranspiration, is usually less than the rate of average evaporation.

Evapotranspiration rates also vary with the season, as shown in the two maps below, which depict maximum potential evapotranspiration for moderately tall grasses.

In most areas of the state, there is a significant difference between potential and actual evapotranspiration at various times of the year. These differences are illustrated in the water balance charts for Los Angeles and Sacramento. In the rainy winter months, when soil moisture is the most abundant and solar energy levels are low, actual evapotranspiration rates approach their potential. As the seasons grow warmer, however, and soil moisture is depleted, the difference between potential and actual evapotranspiration increases and defícts consequently occur. When soil moisture is replenished and the natural demands of evapotranspiration are satisfied, as in the months of January and Febuary at Sacramento, surplus moisture may percolate downward as groundwater or move horizontally as runoff.

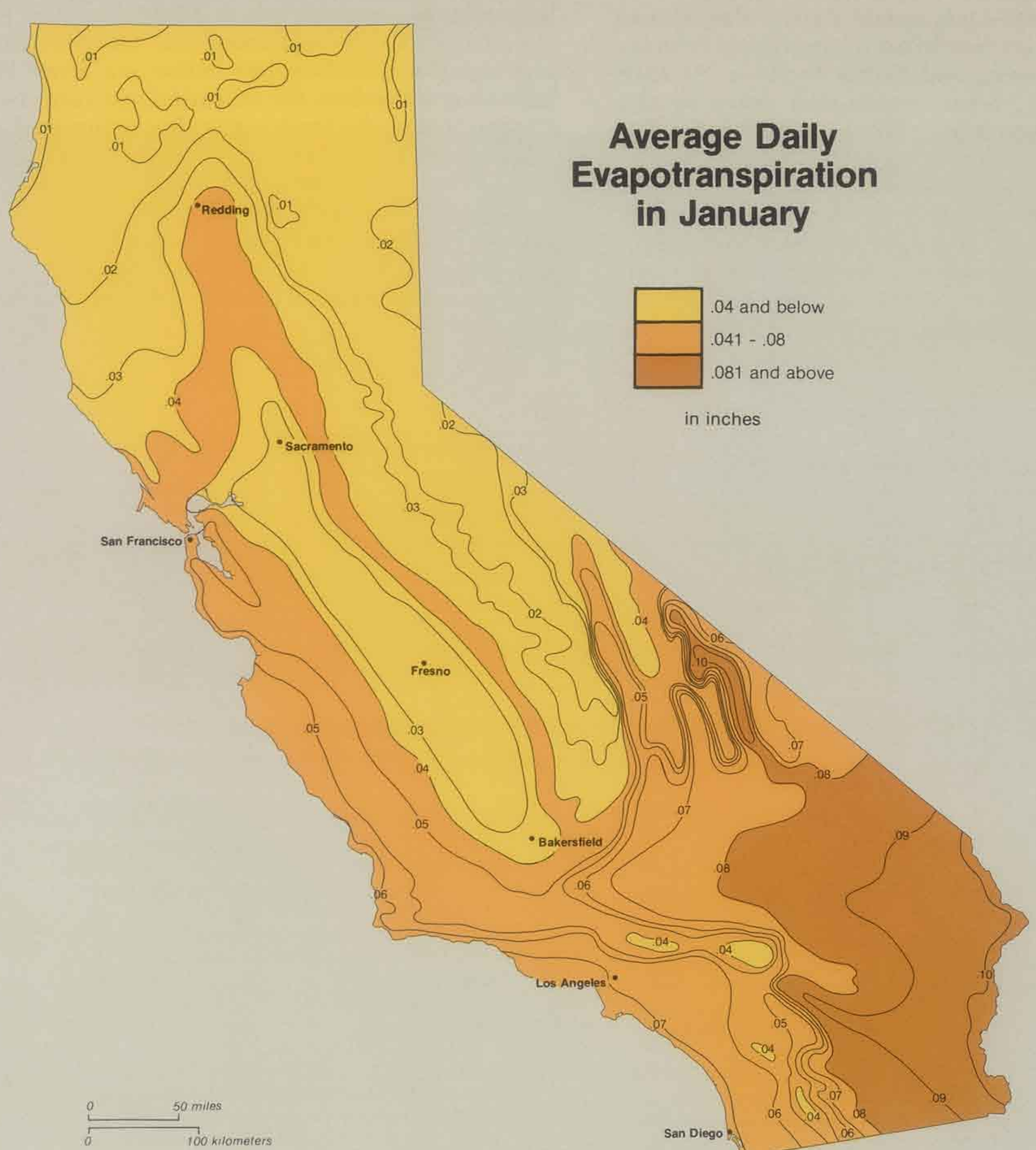
Average Annual Evaporation



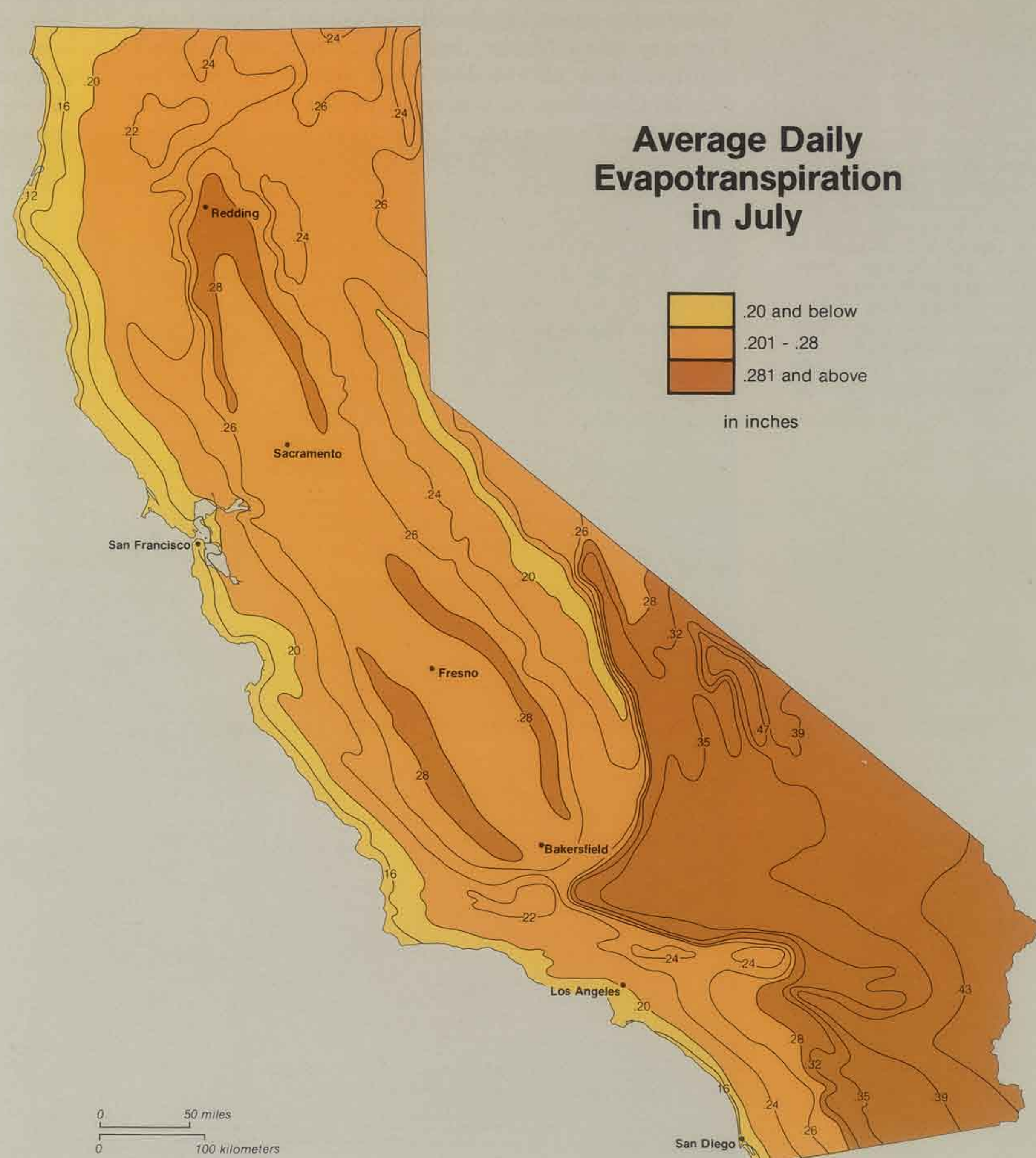


legends refer to both graphs

Average Daily Evapotranspiration in January



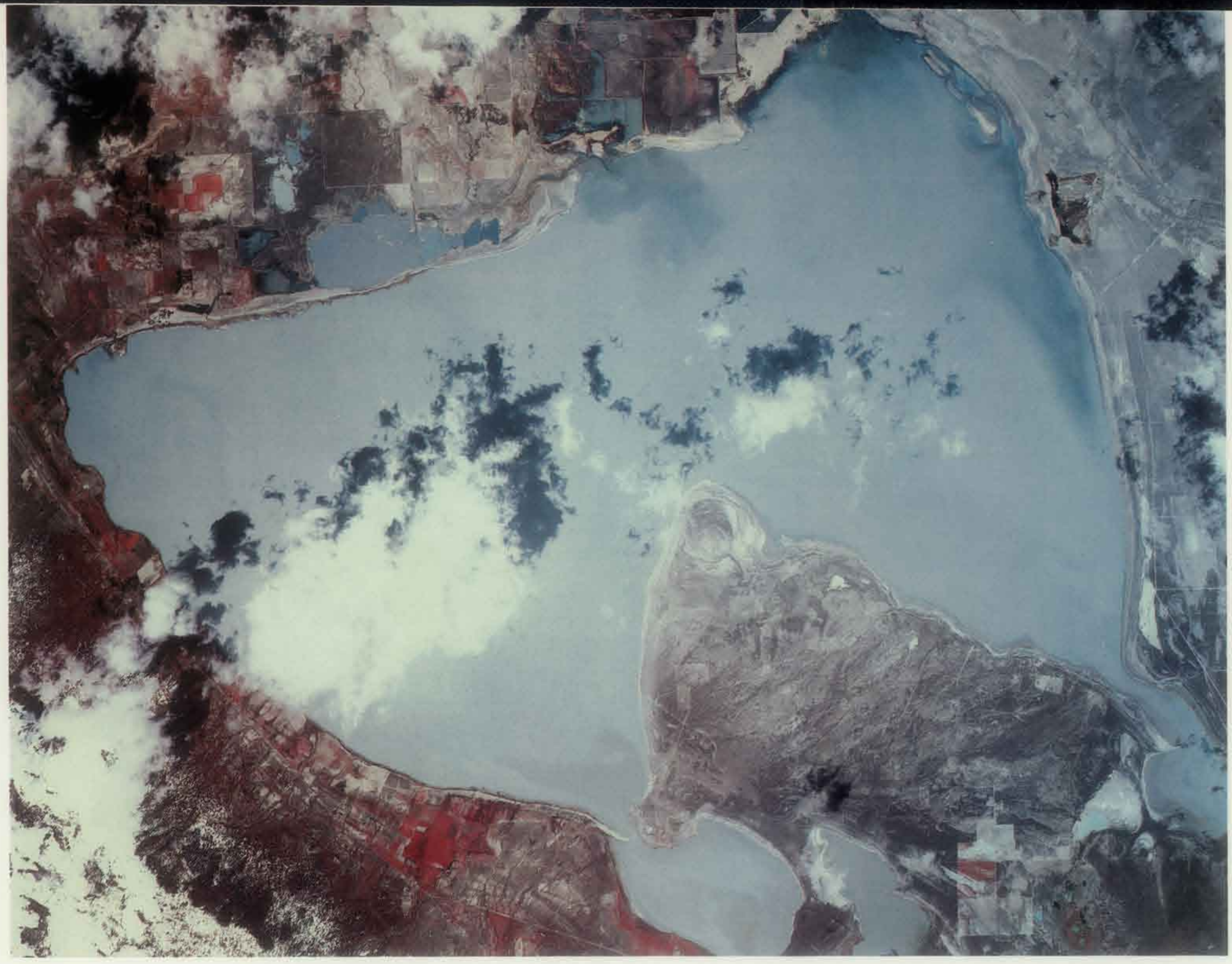
Average Daily Evapotranspiration in July



1915. Because of diversions via tunnel from its tributaries, however, Mono Lake no longer mirrors climatic fluctuations. Clear Lake, with inflows from the east flank of the Coast Ranges north of San Francisco Bay, is the largest fresh-water lake entirely in California. It appears to be in an area of perennial water surplus and it has a perennial outflow which is today regulated.

Goose Lake, in the northeast corner of California, is in a closed basin during droughts, but overflows southward into the North Fork of the Pit River in wetter years. This has not occurred, however, since the nineteenth century. Thus its relations to the Central Valley are tenuous and ephemeral, like those of Tulare Lake at the south end of the San Joaquin Valley. Tulare Lake is now confined because its natural variable bed is too valuable to be inundated at the whim of tributary rivers. As a result, there is a water-disposal problem during wet years. The Kern River in flood directs its flows toward Buena Vista Lake, some 60 miles southeast of Tulare and 100 feet higher. The Tulare Lake area would receive the overflow from Buena Vista plus the flood flows of Tule and Kaweah rivers. The Kings River, generally larger than these three combined, has a major channel southward down its alluvial fan to Tulare Lake. But the Kings River can also flow north westward via the Fresno Slough to the San Joaquin River, and this is the preferred course today to prevent inundation of the Tulare Lake bed.

Honey Lake, north of Lake Tahoe, has some inflow from the Susan River: in years of greatest runoff the lake level rises and the water surface expands until evaporation balances the inflow; and, as inflows decrease the lake does likewise. Thus it is similar to the playas and dry lakes in the southeastern part of the state. Rogers Dry Lake in the Antelope Valley, Searles Lake, and Bristol Lake have dry lake beds larger than Clear Lake and three times as large as the San Luis Reservoir, which is in a similarly dry area in the San Joaquin Valley. Rosamond Lake, also in Antelope Valley, and Soda Lake, which sometimes receives water of the Mojave River, are larger than the Oroville Reservoir. In these areas of greatest water deficiency, where annual precipitation is far less than the evaporative demand, these water bodies do not act as reservoirs but as evaporating ponds. Their principal products are residual salts, which are of sufficient economic value to be mined at Searles Lake and Owens Lake. The dry lakes of the desert thus provide nature's confirmation of the law first stated in 1946 by Harold Conkling, an employee of the State Division of Water Resources: "No matter how large the reservoir capacity, streams of erratic annual and cyclic flow will yield for useful purposes no more than 50 or 60 percent of the annual average discharge because the remainder will be lost, over the years, by evaporation from the excessive water surface of the reservoirs necessary to impound the water of the infrequent years of large discharge."



Honey Lake

THE OCEAN

The Pacific Ocean is the ultimate goal of all the rain and snow that falls on California, unless it is wafted toward heaven sooner by solar energy. Along the California coast there are hundreds of places where permeable materials—sand or pebble beaches, sand spits and bars, sand dunes—extend both inland and offshore. Beneath the surface similar permeable materials may occur to depths of tens or hundreds of feet. In these permeable sediments there will be an interface between fresh and salt water. Because the groundwater is flowing toward the ocean, this interface should naturally be close to the coast, and in many places fresh water does indeed come to the surface close to the strand line. Surely the ocean knows its place—below sea level—and stays there most of the time. Only rarely does it rise up and wreak damage on beachfront structures, vehicles and people, shipping and harbor facilities. At such times, however, ocean water may move up the numerous streams and infiltrate into channel and flood plain sediments.

Seawater intrusion can occur where the natural hydraulic gradient is changed so that conditions become favorable to landward or upward movement of sea water. Such conditions develop where groundwater levels are drawn below sea level by pumping from wells. This could happen in a groundwater reservoir anywhere along the coast but it has happened more noticeably in the southland, where fresh water is seasonally or perennially deficient.

By far the greatest influx of seawater into California occurs in the San Francisco Bay. Every day at high tides ocean water enters the bay through the Golden Gate and the bay is characteristically saline as far as 30 miles inland at the Carquinez Straits. As a rare exception, however, during the greatest of historic floods in 1862, the flow of fresh water was continuous out of the bay into the ocean, and San Francisco Bay had freshwater fish for several months. In Suisun Bay, east of the Carquinez Straits, the water flowing from the Central Valley during the nineteenth century was naturally fresh enough to drink in some years, although never in summer. Under natural conditions the Delta would be wetlands through which about half the total runoff from California flowed in a maze of channels and sloughs with bottoms below sea level. With increasing diversions for irrigation upstream in the Central Valley, the fresh water flow diminished, and saline water moved up the channels and sloughs of the Delta. The preservation of the Delta has consequently become a central issue in the formulation of modern water policy. That the issue has arisen at all, however, is a measure of how far California has come in remaking the natural water endowment.

CALIFORNIA AS IT WAS

The following accounts by early explorers and settlers of California describe aspects of the water environment that no longer exist and some that never were.

In 38 deg.30.min. we fell with a convenient and fit harborough, and June 17. came to anchor therein: where we continued till the 23. day of July following. During all which time, notwithstanding it was in the height of Summer, and so neere the Sunne; yet were wee continually visited with like nipping colds, as we had felt before: insomuch that if violent exercises of our bodies, and busie imployment about our necessarie labours, had not sometimes compeld us to the contrary, we could very well have beene contented to have kept about us still our Winter clothes. . . . Besides how unhandsome and deformed appeared the face of the earth it selfe! Shewing trees without leaves, and the ground without greennes in those moneths of June and July. The poore birds and soules not daring (as we had great experience to observe it) not daring so much as once to arise from their nests, after the first egge layed, till it with all the rest be hatched, and brought to some strength of nature, able to helpe itselfe.... The inland we found to be farre different from the shoare, a goodly country, and fruitfull soyle, stored with many blessings fit for the use of man: infinite was the company of very large and fat Deere, which there we sawe by thousands, as we supposed, in a heard.

Sir Francis Drake Expedition, 1579

Through the interpreters that accompanied them, they received reports from the Indian residents...that on an island in the middle of the sea there is a famous settlement governed by a queen, a very tall woman who, as they demonstrated, is as tall as a giant and who wears many strings, joined together like necklaces, of these large pearls around her neck and that they cover her breasts.... According to this report and that which I explored and saw up to thirty-four degrees north latitude, this land did not join, and thus California is a very large island.... The said land of California, along the interior coast, is composed of large mountain ranges, barren and rugged and without forests. They seem burned for they are composed of silver-bearing rock.... Along the sea coast of the interior region, over a distance of one hundred leagues, all that one sees are heaps of pearl oysters.... They are the size of a small plate, and full and complete they would weigh from one to two pounds.

Report of Nicolas de Cardona, 1632

The soil is as variable as the face of the country. On the coast range of hills there is little to invite the agriculturist, except in some vales of no great extent. These hills are, however, admirably adapted for raising herds and flocks, and are at present the feeding-grounds of numerous deer, elk, &c., to which the short sweet grass and wild oats that are spread over them, afford a plentiful supply of food.... The valleys of the Sacramento, and that of San Juan, are the most fruitful parts of California, particularly the latter, which is capable of producing wheat, Indian corn, rye, oats, &c., with all the fruits of the temperate and many of the tropical climates. It likewise offers fine pasture-grounds for cattle.... we find great aridity throughout the rest of California, and Oregon also. All agree that the middle and extensive portion of this country is destitute of the requisites for supplying the wants of man.

Charles Wilkes Expedition, 1839-1842

From Tulare Lake come the turtles that make the rich turtle soups and stews of San Francisco hotels and restaurants. It is the western pond turtle common in the fresh water ponds. The Italians call it *Ella-chick*. These turtles are sent in sacks to San Francisco. During the season more than 180 dozen found a ready sale at the bay.

History of Kern County, 1883

It is well to state some of the wonderful properties of the water, that for bathing, shampooing, and general cleansing powers it has no equal among artificial productions. It is believed by many to be a specific for catarrhal and lung affections.... Though mild and agreeable for a short time, yet it will leave no vestige of bones or flesh of man or beast put in it for a few hours.... No living thing abides the surface of this water, perfectly clear as ever it is, neither fish nor reptile nor anything save millions of small white worms from which spring other myriads of a peculiar kind of fly.... Legions upon legions of a so-called duck ...lived on the lake.... They are web-footed but have a bill like a common chicken ...they have no real wings or feathers and consequently cannot fly.... It is the reasoned conviction of parties who have observed the facts for years that these birds migrate from other regions, alighting on the Lake perfect birds, only soon to become bereft of feathers and even the physical power to prevent themselves from drowning whenever the surface of the water becomes ruffled by a continuous breeze.

"Owens Lake in 1885" T. E. Jones.

CHAPTER 3

The Advent of Human Settlement

The first Europeans to come to California found it settled by a numerous people of many tribes and tongues who lived in so simple and elementary a relationship with nature that they had neither need nor facility to manipulate its resources. The Indians, as the Europeans called them, harvested such food as the environment provided: the salmon which annually crowded up the rivers; the acorns of the great oak forests which covered the land; and the deer, tule elk, and antelope which grazed in the hills and flatlands by the tens of thousands. Although there is evidence that some tribes along the lower Colorado River and in the Owens Valley diverted water to flood natural areas of vegetation, these native Californians for the most part had no tradition of raising crops. They made no effort to gather and transport water; rather, they went where the water was, and lived beside it.

The Spaniards who came to Alta California in 1769 to establish permanent settlements brought with them, however, a profoundly different culture. Their arrival utterly transformed the Indian world, setting in motion a process which would bring about its virtual obliteration within the brief span of a century. At the same time, the Spanish also transformed the relationship between the natural environment and humankind, for in their European homeland they had been for centuries a farming people living on an arid landscape. From the ancient civilizations of Rome and the eastern Mediterranean they had inherited the skills and attitudes of hydraulic engineering. From their perspective, water was a raw material to be gathered where it was in surplus and transported, often over great distances, to irrigate dry but fertile farmlands and quench the thirst of distant settlements.

When Father Francisco Palou stood at the site where Mission San Gabriel was to be founded, he noted in 1771 that there was not only good soil for farming, but "an abundance of water that runs [nearby]...in ditches that form the river. [There are] ...facilities for taking out the water in order to irrigate the land." In 1773, the fathers and their Indian laborers built a dam six miles from Mission San Diego, and an aqueduct to supply the settlement with the water thus impounded. When the metropolis of San Diego, with its many hundreds of thousands of people, drew most of its water two centuries later from the Colorado River through an aqueduct system hundreds of miles long, constructed and managed by public authority, only the scale of the enterprise was different from that of the padres. Its essential principle was the same.

The Spanish and Mexican periods brought little modification of the California waterscape, for the European population was tiny, scattered thinly along the coastline and around the bay of San Francisco, and its needs were few and simple. The arrival in 1839 of an enterprising Swiss, John August Sutter, began a new chain of events. Given a large rancho grant in the relatively unoccupied Sacramento Valley, his fort and thriving settlement beside the American River near its juncture with the Sacramento soon developed needs for lumber and other commodities. Sutter determined to make a large-scale industrial use of waterpower, causing a sawmill to be constructed on the upper reaches of the American, where it was flowing rapidly in the Sierra foothills. When his foreman, James Marshall, discovered gold in the mill's tailrace, California would never be the same again.

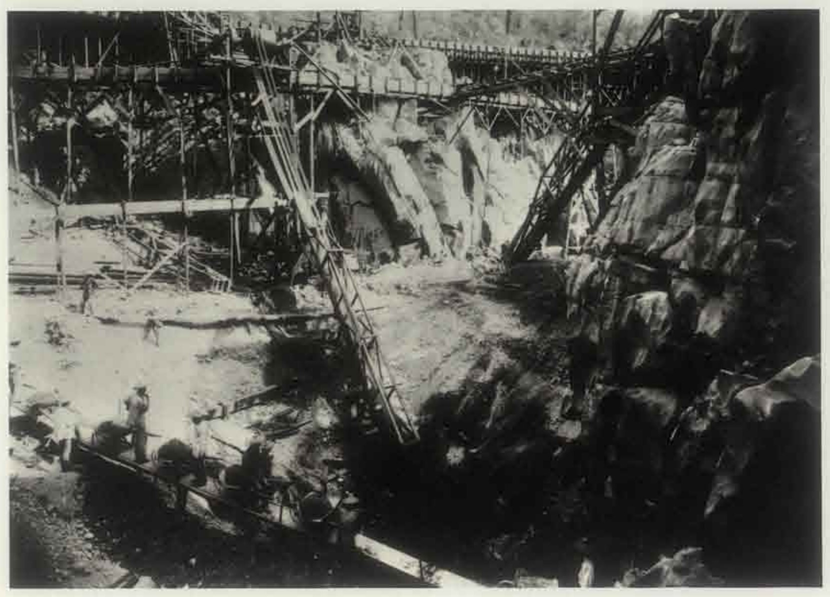
Now a civilization inundated the new American state of California that made massive and complex demands upon its water resources. It was, moreover, an essentially Anglo-American civilization which lacked Spain's concept of a strong and centralized public authority. In Britain and America, the social center of gravity had long since shifted not only toward the supremacy of elected legislative bodies and away from powerful executives, but also toward an assertion of greater freedom for individuals to enrich themselves as they saw fit. In resource-rich America, this laissez-faire mentality fostered a belief

This view of San Francisco in 1873 emphasizes the importance the waterfront once had for the city as the focus of the commercial activity the Gold Rush brought to California. Virtually every type of ship crowds the wharves—steam and sail for both inland and oceanic navigation. A few years earlier, the bay itself was filled with empty vessels, abandoned by their crews who left for the gold fields.

The map on the facing page displays the natural configuration of lakes, rivers, and related vegetation which confronted the earliest European and Anglo-American settlers upon their arrival in California. Urban and agricultural developments have today replaced the inland marshes and riparian forests shown here, while the construction of the modern water system has created the Salton Sea and all but eliminated Tulare and Owens lakes. This map does not, however, show the virgin waterscape as it existed at any single point in time. The levels of many of the natural lakes and marshes fluctuated from year to year, and the map itself has been reconstructed from several historic maps drawn of various parts of California between 1843 and 1878, a period when some areas of the state remained largely unexplored.

that the continent's resources were open for the strong-minded and the enterprising to seize and use in whatever way would most profit them individually. Out of this economic anarchy, in which government was to stand aside and remain small and inactive, would come, it was confidently asserted, the enrichment of all.

The Spanish notion of "public property in water," developed in an arid land culture where waterworks had to be publicly managed to ensure their most efficient and equitable use, thus gave way to the Anglo-American concept of unrestrained private enterprise. Coming from lands of water abundance, the Anglo-Americans, Germans, and Irish who made up most of the white population of California during the nineteenth century were disposed to think of water as a free commodity to be used without restraint in any industrial or other enterprise that came to hand.



Hydraulic mining in the Sierra Nevada brought the first major man-made alterations in the natural waterscape. In the photograph at left, great streams of water under pressure are used at the Malakoff Diggings to break down walls of gold-bearing river gravel. In the photograph below, water drives a sawmill preparing timber for the construction of flumes and diversion works. The photograph at bottom left illustrates a different type of mining which became popular during the 1860s and 1870s. Here an entire river has been diverted from its course at the Golden Feather Mining Claim to provide access to the streambed. Works of this magnitude required the development of a structured work force of paid laborers. The Chinese workers seen here thus began to replace the independent miners who first opened the mountains to exploitation.

THE FALL AND RISE OF THE SACRAMENTO

With the discovery of gold, the Sierra Nevada swiftly became the seat of a teeming industrial system devoted to the extraction of the precious metal. In 1853, great deposits of gold-bearing gravels were discovered in the high ridges overlooking the northern mines in and around Nevada County. The miners soon learned to work these deposits by directing heavy streams of water onto the hillsides, washing them down so that the flowing mud, sand, and gravel passed through long sluice boxes, where the heavy gold flakes could be recovered. The torrent of water and mining debris pouring out of the sluice boxes was discharged into nearby streambeds, its subsequent destination not a matter of concern to the miners. The miners' need, however, for more and more water led to the excavation of ditches to adjacent streams, then to the building of a network of reservoirs and flumes leading down from the higher mountain regions.

Thus the first large hydraulic engineering works in California were constructed entirely through the application of private enterprise and capital, outside the realm of public supervision. At the same time, a cadre of professional engineers skilled in the building of such works was forming, along with a community of capitalists confident through direct experience that they could transport rivers of water great distances at great profit. By 1857, in Nevada County alone there were 700 miles of ditches feeding water to the hydraulic miners. The hydraulic mining industry, however, passed rapidly through a complex technological progression which required heavier capitalization and the concentration of scores of individual mines into a few large operations. In 1871, the California Water Company began operations in El Dorado County with a capitalization of $10 million and the ownership of 24 lakes. Some operators, as in the case of the North Bloomfield Mine, which used a hundred million gallons of water a day, built their own water systems. In other situations, ditch firms like the Eureka Lake and Yuba Canal Company grew so large that they acquired their own mines. By 1879, when the hydraulic mining industry was operating full bore, Nevada County was laced by more than a thousand miles of ditches and flumes.

Meanwhile, thousands of farmers began breaking the soil of the Central Valley floor to raise crops for California's burgeoning markets. Before the 1850s were out, however, the farmers and townspeople living along the Sacramento learned that they were residing on what was essentially a flood plain. The rivers crossing the flat valley floor could never contain within their banks the great volumes of water that almost annually surged out of the mountain canyons during winter storms. Flowing over river banks for many miles, flood waters inundated the surrounding countryside, forming an inland sea in the Sacramento Valley which took months to drain away when the rains had ended. For this reason, a tule swamp many miles across occupied the Central Valley floor, paralleling the rivers. In 1850, the City of Sacramento was flooded for a mile back from the river and, when the water subsided, the community's response set the course for valley development over the next several generations. Sacramento immediately began throwing up levees, which were soon overtopped, so that the embankments had to be built higher and higher in succeeding years. Marysville, sitting at the juncture of the Yuba and Feather rivers, had a similar experience, so that by the mid-1870s it had made itself a walled city.

In the cities, flood control was a relatively simple undertaking, although arduous and costly, because the area involved was small and compact. In the countryside, however, the problem was more complicated. At first, there were efforts at central coordination. Under the Arkansas Act of 1850 the federal government granted to the states all swamp and overflow lands within their borders, on condition that these lands be drained and reclaimed. California eventually received a total of 2,191,000 acres of such land, more than 500,000 acres of which lay in the Sacramento Valley. A Board of Reclamation Commissioners was established in 1861 to oversee the reclamation process and careful plans were drawn up to ensure that all levees would be constructed along natural drainage lines.

The slow progress and ill-success of the first state-directed leveeing projects, however, produced a clamor from impatient enterprisers and in 1868 the State Legislature passed the Green Act, freeing the reclamation process of all controls. Property owners could throw up levees along any alignment they chose, even along the rectangular pattern of property lines. Thereafter, the drainage system of the valley was utterly fragmented, a crazy-quilt stitchery of levees marching across sloughs and other natural drainways, choking channels and producing ponds where formerly the water had flowed easily away. Out of this flood control anarchy came the popular observation, "Of all the variable things in Creation, the most uncertain are the action of a jury, the state of a woman's mind, and the condition of the Sacramento. The crookedness you see ain't but half the crookedness there is."

In an ever-escalating spiral, landowners regularly raised their levees higher than those put up by farmers on the opposite side of the river, hoping to force the stream to overflow upon their adversaries and thereby leave their own land dry. But, since every acre protected from flood was therefore unavailable for overflow, and no one was compensating for this by building channels which ensured general valley drainage, the rivers in floodtimes got higher and higher. The first levees were three feet high because the river overflowed its banks in thin sheets. Eventually, the valley's levees would become great walls up to 25 feet high and 200 feet wide at their base.

Such undertakings went far beyond purely individual resources and, in the late 1860s, the Legislature began authorizing the formation of levee and reclamation districts which could raise revenues to pay for these works by taxing the land protected. Soon, the flatlands became a patchwork of such districts. But since no one knew how large the rivers were, huge sums were expended in many projects which failed, and after 40 years of such efforts, Sacramento valley farmers were still subject to frequent and disastrous flooding.

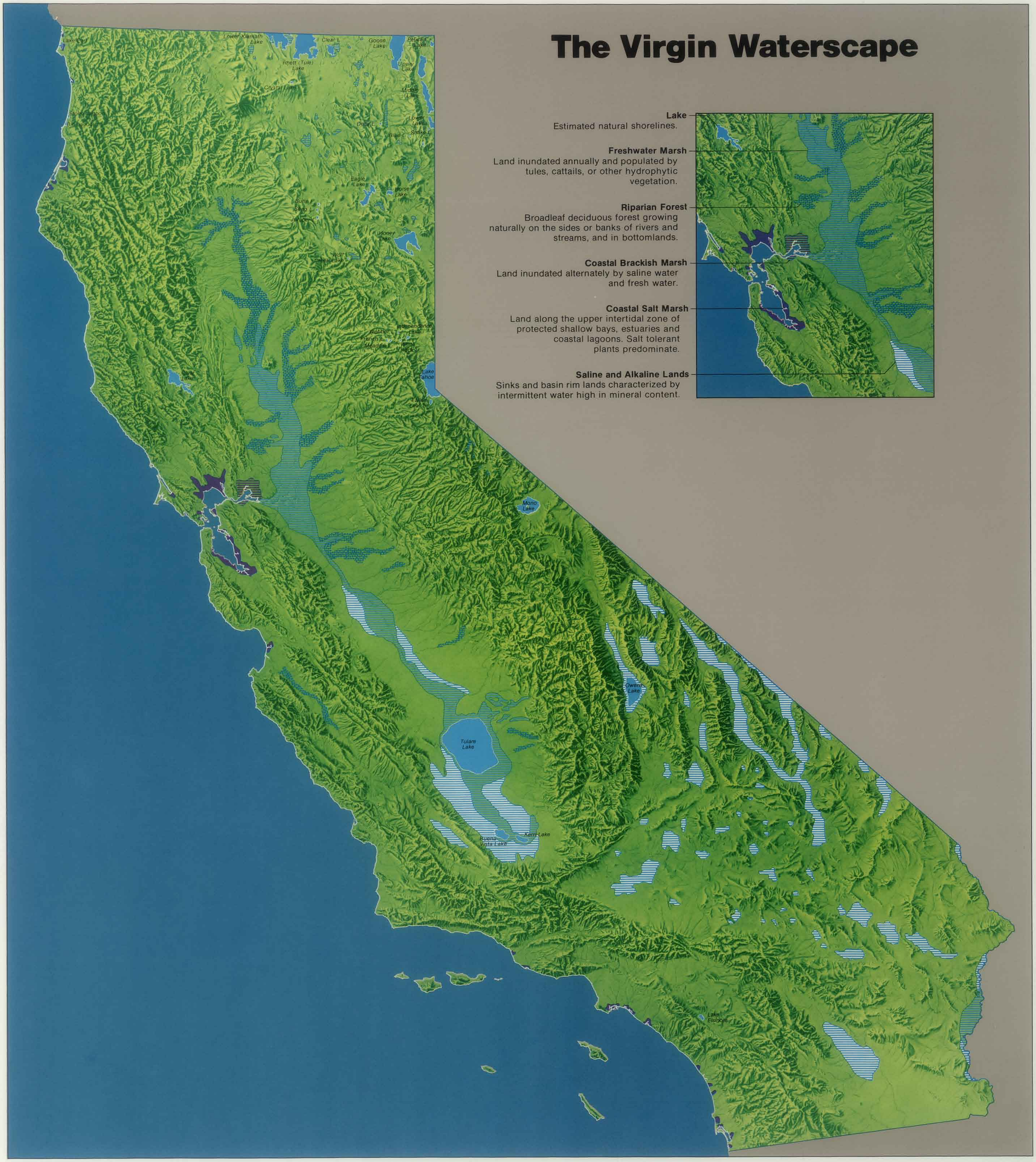
Making the situation far worse, and in some parts of the valley absolutely hopeless, an enormous mass of hydraulic mining debris began issuing from the mountain canyons to spread out on the valley floor. Since the finest sediments in the mud, sand, and gravel which composed the mining debris were carried by the river system to San Francisco Bay almost as soon as hydraulic mining began, the riverbeds had in fact been filling in for some years.

Canals and Water Ditches for Mining Purposes - 1867

County	Identifiable Ditch Systems	Total Length of Ditches (miles)	Total Cost ($)
Amador	27	412.75	1,154,500
Butte	11	64.5	60,700
Calaveras[1]	15	272	754,000
Del Norte	13	35	59,700
El Dorado	24	786.25	1,365,500
Inyo	1	15	30,000
Klammath	5	18.25	23,100
Lassen	4	18.25	25,000
Mariposa	2	25	10,800
Mono	1	20	75,000
Nevada[1]	12	577	1,771,500
Placer	26	699.5	1,673,000
Plumas	20	132	361,050
Sacramento	4	58	948,000
Shasta	15	201	297,000
Sierra	26	115.5	491,000
Siskiyou	20	201	296,000
Stanislaus	5	43	170,000
Trinity	42	158	199,000
Tulare	17	70.5	32,800
Tuolumne[1]	6	142	1,765,000
Yuba[2]	26	150	591,400

[1]cost missing for one system
[2]mileage for one system only

The Virgin Waterscape



Sacramento Flood Control System

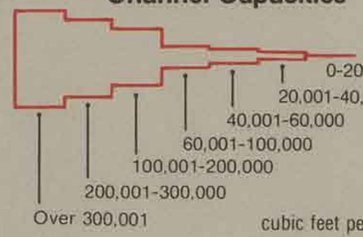
Flood Hazard Area
Subject to 100 year flood

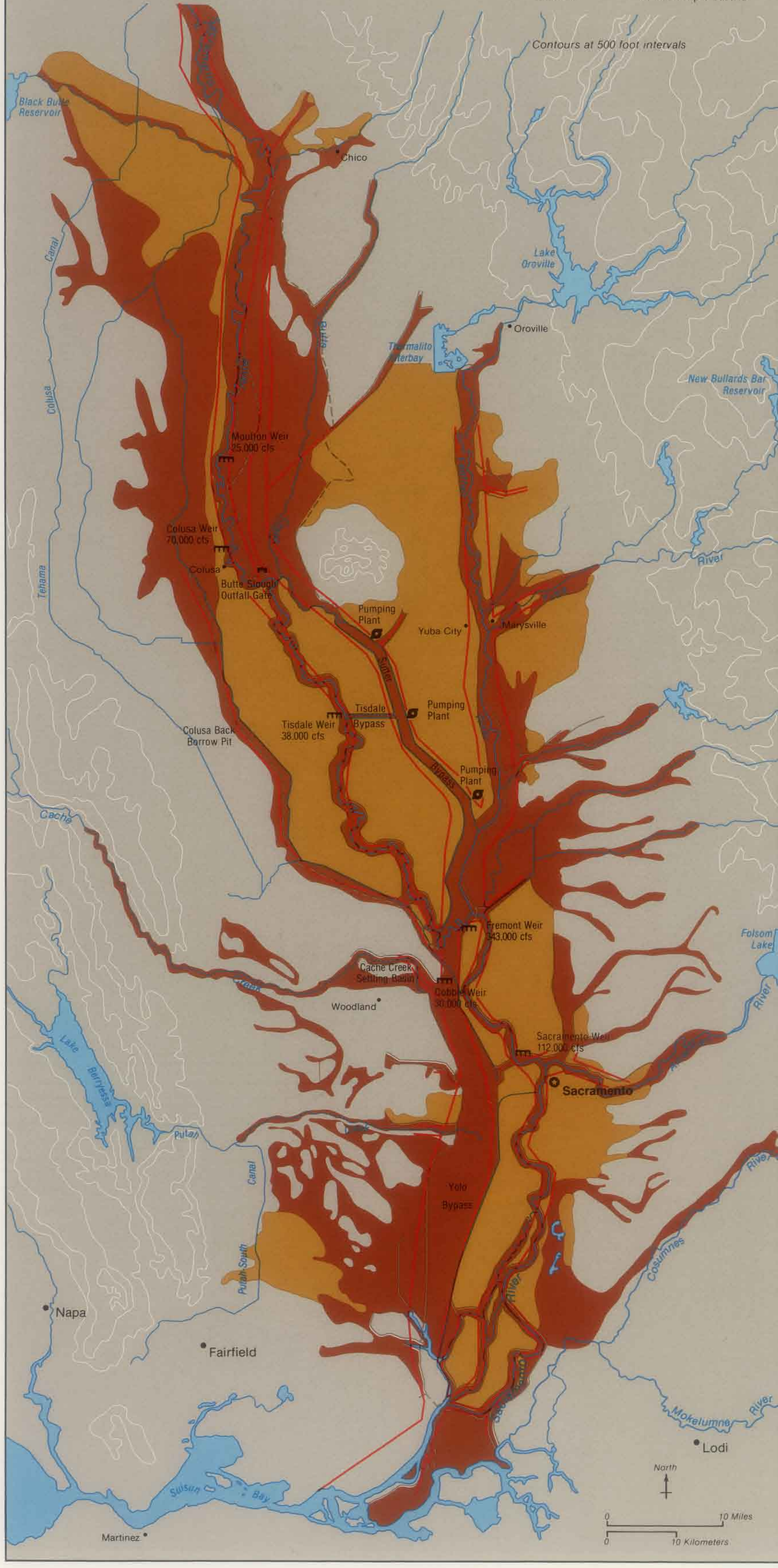
Protected Area
Subject to inundation by 100 year flood in absence of flood control devices

Bypass Boundary

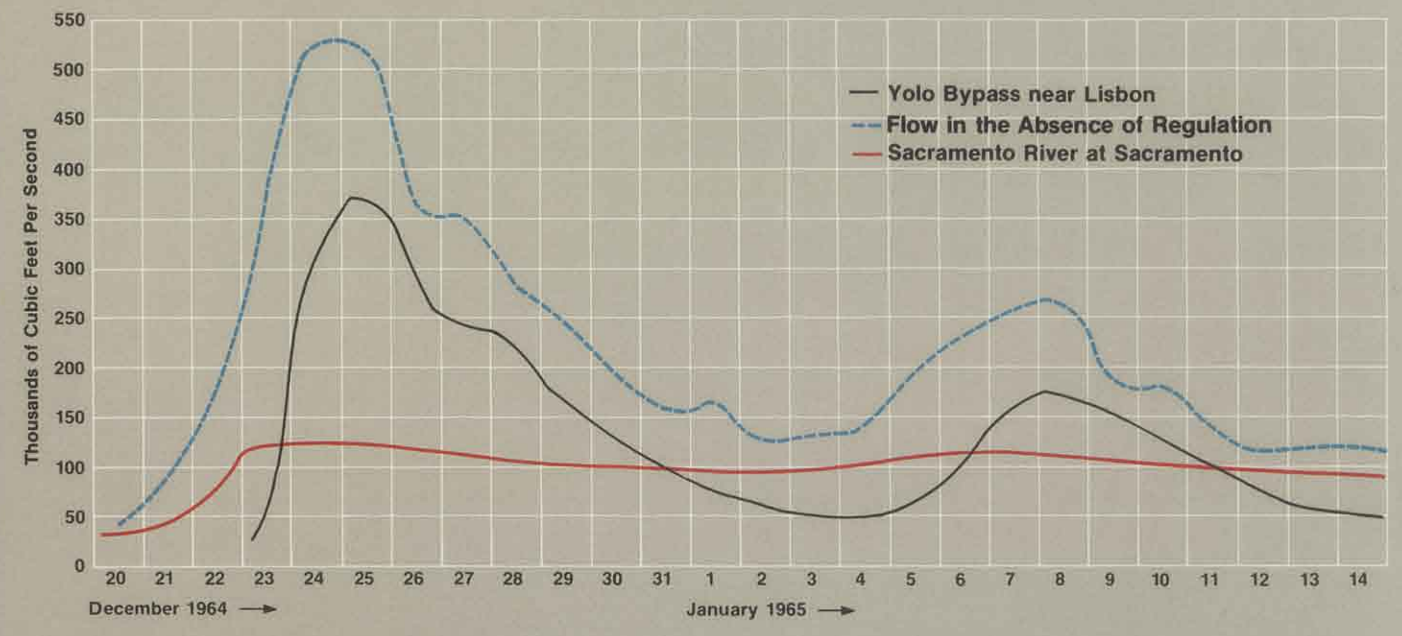
Levee Boundary

Channel Capacities

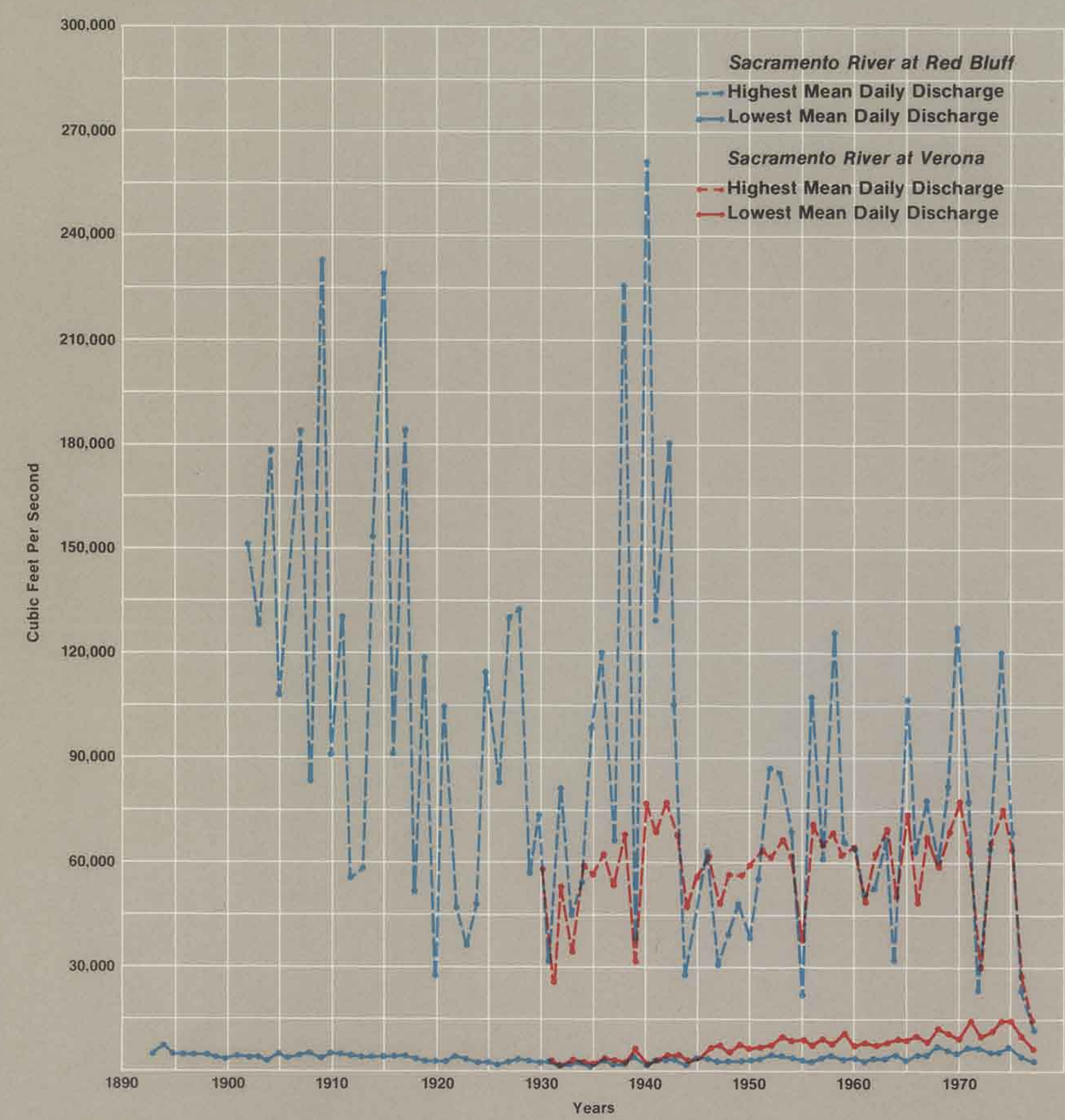




Flow Past the Latitude of Sacramento During Flood Event

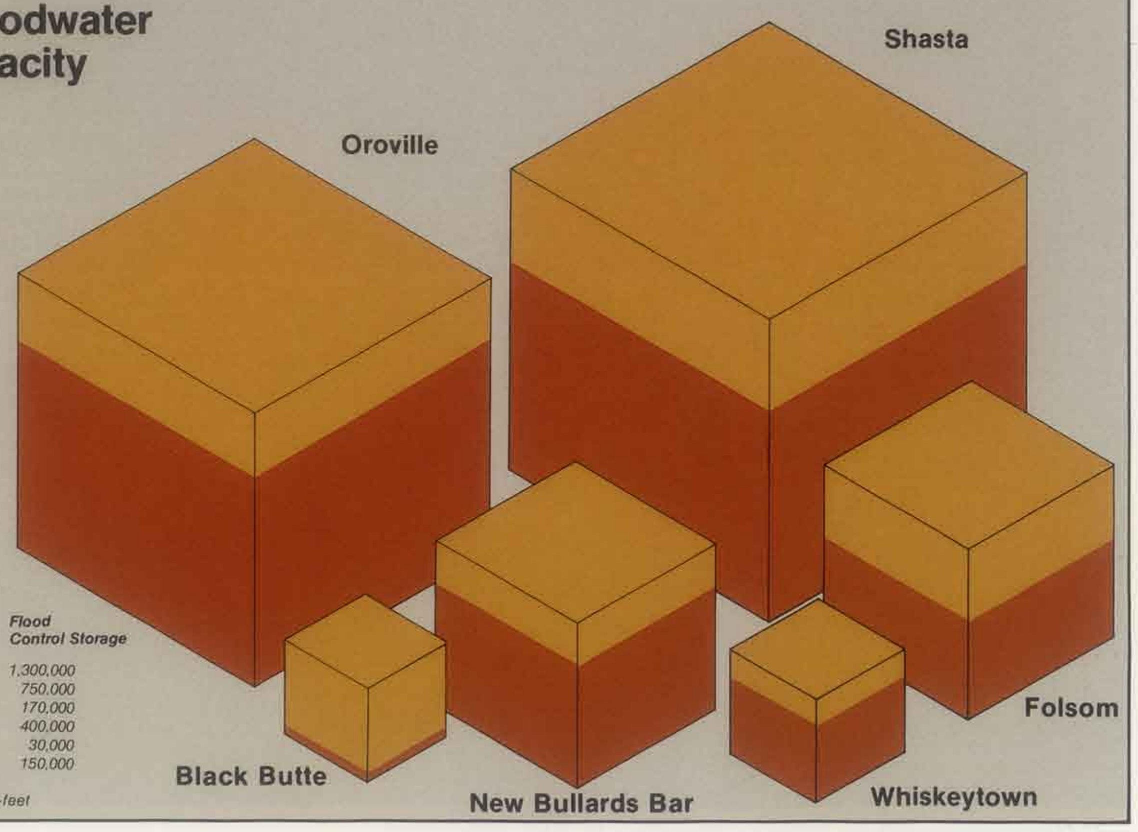


Maximum/Minimum Discharge



Reservoir Floodwater Storage Capacity

The cubes depict the total capacity of the major, multi-purpose reservoirs on the Sacramento. The upper portion of each cube represents that part of the total capacity which is available for flood-water storage.



Reservoir	*Total Storage*	*Flood Control Storage*
Shasta	4,500,000	1,300,000
Oroville	3,484,000	750,000
New Bullards Bar	969,600	170,000
Folsom	1,010,000	400,000
Whiskeytown	241,000	30,000
Black Butte	160,000	150,000

in acre-feet

This type of sedimentation first affected navigation. Steamboats which had regularly called at Sacramento, Colusa, Chico Landing, Marysville, and Oroville, soon were having difficulty in reaching even Sacramento. While navigation upstream on the Sacramento and Feather rivers was dying, the many channels flowing through the Sacramento-San Joaquin Delta became choked and narrowed by debris and the beds of these tidal reaches were raised as much as 15 feet for long stretches.

By the 1860s, heavier sediments began coming out of the mountains. Farmers noticed that each flood left wide deposits of glaring white mud and sand on their property. By the 1870s, many thousands of acres along the Feather, Yuba, and Bear rivers were buried so deeply by mining debris that orchards, houses, and barns were swallowed up. The bed of the Yuba, between Marysville and the mountains, spread to a two-mile width, the stream wandering at random over the obliterated farmlands. Where the Yuba and Feather met at Marysville, their beds eventually rose 20 feet, making them much higher than the adjacent city streets. Debris pouring out of the mouth of the Feather, where it joined the Sacramento, pushed an underwater dam across the Sacramento's bed which sharply raised flood levels far up that stream to Colusa and beyond. The entire central part of the valley was under siege.

A bitter controversy consequently sprang up in the mid-1870s between the flatland farmers and the mountain miners. At first, farmers and townsmen of the valley floor sought relief in the courts, asking for damages and injunctions. It was impossible, however, to establish which mine or company was responsible for the mud and sand flowing upon given farms. Then both miners and farmers, to quiet and resolve the controversy, asked the Legislature to assume responsibility. A valley-wide program of flood control, based upon the first systematic survey of the river system, was launched in the Drainage Act of 1880. The basic objective of this act was to erect an integrated system of levees which would constrict the rivers within narrow channels, create a heavy and concentrated flow, and thereby induce the rivers to scour out their own beds and carry the mining debris down to the bay for deposit. Flood control, navigation, and reclamation would all be served by this system. The Drainage Act relied upon statewide taxation, however, and an avalanche of protest soon poured in upon the Legislature. Residents of other areas argued that the Sacramento Valley should solve its own problems; flood control was not a state but a local responsibility. In 1881, the California Supreme Court threw out the Drainage Act as an unconstitutional assumption by the state of an essentially private concern.

The federal Circuit Court resolved the impasse in 1884, in the case of *Woodruff v. North Bloomfield, et al.*, by issuing a perpetual injunction against the discharging of hydraulic mining debris into California's rivers. Judge Lorenzo Sawyer held that the discharge of such debris created irremediable and uncontrollable damage in the community at large and that the general welfare therefore required the termination of such discharges, whether of fine or coarse debris. Thus, in one of the nation's first environmentally-conscious judicial decisions, an entire industry was closed down. Mining, which had formed the basis for prosperity in the new state of California, was forced to give way to the needs of agriculture and commerce.

Although John Sutter built his fort on high ground at some distance from the river, the city that grew up around the fort soon extended its borders to the river banks. The photographs above show the consequences of this development in two views of Sacramento during the flood of 1862. Agricultural development on the valley lands below the gold fields brought an end to hydraulic mining, but great fields of spoils left over from gold dredging still dot the banks of the American River above Nimbus Dam as shown in the photograph at left.

THE SACRAMENTO FLOOD CONTROL SYSTEM

There still remained, however, an enormous volume of mining debris already lodged in the mountain canyons which continued over many years to wash down upon the valley floor and create more destruction. Not until 1905 would the peak of the debris wave pass the City of Marysville and move down the Feather. And once again, it was the federal government which provided the impetus for a resolution of the Sacramento River's continuing flood control problems.

The involvement of the federal government in California water affairs began as early as 1868, when the United States Army Corps of Engineers responded to local requests by making the first of its many studies of harbor sites and needs in the Los Angeles region. In the 1870s, the Corps began a regular program of pulling snags in the rivers of the Central Valley in aid of navigation. In 1873 its engineers conducted a study of irrigation possibilities in the state, and during the hydraulic mining controversy of the 1870s and 1880s, the Corps made numerous technical examinations of the problem and a series of proposals for dams and drainage works which were not funded.

The first plan for flood control in the Sacramento Valley was developed in 1880 by State Engineer William Hammond Hall who called for constricting the rivers within strong levees in order to induce a vigorous current which would thereby force them to scour out their own beds and wash the mining debris down into the bay. He warned, however, that even the highest levees could never hold the giant floods which occasionally strike the valley. Hall argued therefore that there should be weirs and drainways at a few locations to allow excess water to flow out, as it had always done, to pond in the basins beside the rivers. Little was done to carry out Hall's plan, but in his painstaking studies of the river system he had laid down the first reliable body of hydraulic information concerning its performance, and his fundamental concept endured.

In 1892, Congress created the California Debris Commission, composed of Army Corps of Engineers officers, to clear the rivers of mining debris and restore a navigable channel. A third mission, to restore hydraulic mining through the erection of restraining dams, quickly demonstrated its futility. For its part in the broader question of flood control, the State of California in 1894 established the office of Commissioner of Public Works, staffed by two of Hall's former assistants, Marsden Manson and C.E. Grunsky. They took Hall's plan one step further and proposed that the flow of the Sacramento in floodtime be divided by constructing a leveed bypass channel. This channel would lead out from overflow weirs in the east bank of the main river levees, and down through the Sutter Basin between the Feather and Sacramento rivers and the Yolo Basin, which parallels the lower course of the Sacramento on its west side. This would force the river to carry all of the water it could safely contain, inducing scour, while allowing controlled overflows. It would also free most of the lands in the basins for agriculture by keeping the overflow within leveed bypass channels and preventing it from ponding.

To build such a system, however, would take millions of dollars and many years of steady construction. Neither Congress nor the State of California was yet ready to take up the plan and thereby accept the responsibility for flood control with its large potential costs. After 1900, however, the national mood swung more strongly under the leadership of President Theodore Roosevelt toward the use of public authority to conserve and manage the nation's natural resources. At the same time, beginning in 1902 and occurring again in 1904, 1906, 1907, and 1909, a series of increasingly violent floods washed over the Sacramento Valley, demonstrating the utter futility of fragmented, locally managed flood control. In addition a new breed of entrepreneurs, college-trained and ready to rely upon the expertise of engineers, replaced the older generation of reclamation leaders who had distrusted centralized regulation and expert professionals.

By 1905, the California Debris Commission recognized that it could not control debris along the Yuba River, where it had been concentrating its attention, without developing a project for valley-wide flood control. In 1907, the commission asked Congress for funds to purchase two very large dredges of a type only recently perfected with which the commission proposed to widen the debris-choked channels at the mouth of the Sacramento so that the river could accommodate an overflow of 600,000 cubic feet per second. The dredges began their work in 1913 but so large was their task that by 1924 they had succeeded in opening the river's mouth only enough to accommodate a flow of 400,000 cubic feet per second. The improved outflow, however, was so successful in scouring out immense quantities of mining debris that by 1927 the bed of the Sacramento had been restored to its original elevation (before the impact of mining debris) at the City of Sacramento. The clearing of river channels was eventually extended up the Feather, where a seven-foot lowering at the mouth of the Yuba still left the river 13 feet higher than it had been in the days before mining began.

In 1911, the commission's chief engineer, Captain Thomas Jackson, announced his plan for the Sacramento Flood Control Project. Based upon the bypass concept, it would let water flow eastward out of the Sacramento River over weirs in the Colusa vicinity about a hundred miles north of the river's outlet; this excess water would be guided through the Sutter Basin within a leveed channel; then across the Sacramento into the Yolo Basin at a point just above the juncture of the Sacramento and the Feather by means of the Fremont Weir; finally, the water would be allowed to move through a bypass in the Yolo Basin to empty back into the main channel of the river just above its mouth. Along the course of the bypass channel, which in effect formed an additional river bed to be brought into use during floodtimes but farmed during the dry months, additional inflows would be received from other weir points, and the bypass levees would grow progressively wider apart.

Congress took six years to fund the federal aspects of Jackson's plan, which were limited to those elements regarded as being concerned primarily with maintaining a navigable channel. The State of California and local landowners, however, moved swiftly to carry out their part of the project. A Reclamation Board was created in 1911 with the power to regulate all private levee-building so as finally to bring order and efficiency to the system. The levees of the Sutter Bypass were constructed by the state to help meet the heavy demands for food production during World War One. Many large private reclamation schemes were launched, resulting in the construction of hundreds of miles of levees and the repair of other, existing embankments.

There were about 300,000 acres of land in the valley in a relatively complete state of reclamation in 1910. By 1918 this figure had risen to 700,000, thanks to a total of 350 miles of levees. In one of the more

The modern Sacramento Flood Control System in operation during 1975. The Yolo Bypass is shown at the left of the photograph with the Sacramento Ship Channel running next to it. The Sacramento River can be seen entering from the left and curling down through the center. The American River entering at right appears here to have a distinctly darker color than the Sacramento because the American carries less silt.

striking projects, the entire American Basin east of the Sacramento River and north of the American was ringed with levees, creating an enclosed area of 80,000 acres. As the Reclamation Board observed, "The sea of flood waters was replaced by a sea of waving grain." Furthermore, holdings formerly used only for field crops could be transformed into orchards, once the danger of flooding had been reduced. With this agricultural activity came a new transportation system. Railroads and electric interurban lines were built throughout the valley, and the Sacramento, its navigation largely halted for many years because of mining debris, quickly became one of the major river routes of commerce in the United States. Hundreds of boats passed up and down the rivers and navigated across the bay to San Francisco, where they transferred their cargoes directly to ocean-going vessels. By 1916, 90 percent of the freight between Sacramento and San Francisco was carried by boat, and many thousands of passengers relied upon the large paddle-wheeled river steamers.

After World War One, farm prices slumped, bonds floated to construct levees could not be paid off, and bankruptcy was widespread. Under the Flood Control Act of 1928, the federal government therefore assumed most of the costs of the project, which was still being built. When the United States Bureau of Reclamation took on the construction and management of the Central Valley Project in the 1930s, Washington's commitment to the Sacramento Valley deepened. Soon, the era of high dams around the Central Valley was well launched, greatly easing the flood control burden, and an enhanced inflow of federal funds for all purposes allowed the Sacramento Flood Control Project to move toward completion. Largely in place by 1944, it included 980 miles of levees; 7 weirs or control structures; 3 drainage pumping plants; 438 miles of channels and canals; 7 bypasses, 95 miles in length, encompassing an area of 101,000 acres; 5 low-water check dams; 31 bridges; 50 miles of collecting canals and seepage ditches; 91 gauging stations; and 8 automatic short-wave-radio water-stage transmitters.

The Sacramento Flood Control Project was the pioneer flood control plan in the nation for a complete valley, and it has stood as a model for similar projects elsewhere. One of the least visible great systems of public works in California, it also embodies one of the state's most extensive rearrangements of the natural waterscape. Still subject to occasional levee breaks and overtoppings—William Hammond Hall's warning about giant floods can never be safely forgotten—its effect has been to transform a moribund, gravely afflicted valley into one that is extraordinarily active, productive, and prosperous.

IRRIGATION AND THE WATER COLONIES

From the 1860s onward, the Sacramento-San Joaquin Delta saw rearrangements of the natural waterscape nearly as striking as those occurring in the Sacramento Valley. Almost three-fifths of the Delta's half million acres had originally been subject to daily inundations by ordinary tides. The higher tides of spring covered the entire Delta except in those areas where natural levees of somewhat higher land had accumulated around individual islands. Floodwaters coming down the Sacramento River also overflowed the Delta, especially when met by westerly winds and high tides surging in from San Francisco Bay. Utterly flat, the Delta's most elevated locations were no more than ten feet above sea level.

Where crops could be raised, however, the deep peat soils of the Delta islands proved to be marvelously fertile. Following the passage of the Green Act in 1868, the Delta came under determined assault by imaginative entrepreneurs who were ready to take heavy risks and had purchased Delta properties from the state under the swampland legislation. Levees crept first along the upstream edges of the easternmost islands. It was here that the Sacramento and San Joaquin rivers entered the Delta, flood overflows occurred earliest, and rivers tended to drop the most silt as they spread out and slowed down so that the land was highest and most easily protected. In later years, reclamation districts were formed encompassing entire islands, and heavy investments in levee-building accelerated, subject always to trial and error, massive failure, and long years of suspended efforts. By 1880 the reclaimed area topped 100,000 acres; by 1900, it was approaching 250,000, or about half of the Delta's total area. And in the next 30 years, the acreage enclosed rose to almost 450,000.

As the islands dried out and were repeatedly plowed, however, their peaty soils subsided below sea level. Immense drainage works with large pumps had to work harder to keep these saucer-like depressions dry. Since the area available for overflow in the Delta had been drastically reduced from a mean tidal basin area of about 325,000 acres to only 39,000 acres, levees had to be exceptionally high and broad. But because the levees themselves were composed of peaty soils and were therefore subject to wash and failure, they made for a precarious defense against flood. In addition, the Delta lost much of its capacity for keeping out salt water from San Francisco Bay because its fresh water ran into the bay faster and was much less in volume than in pre-reclamation times.

The Delta was affected, too, by influences arising far upstream. From the north, hydraulic mining debris came down to fill in the tidal channels. And from the south—and eventually from the north as well—came the cumulative effects of another great human rearrangement of the natural waterscape: irrigation. As each year passed, more and more water was drawn out upstream to irrigate the fertile plains of the Central Valley during the dry months, when the Delta most needed a steady flow of fresh water to prevent saltwater intrusion.

The dominating natural fact in the San Joaquin Valley was not water abundance and overflow, but water scarcity. In its natural condition the valley, from the Delta to its southern terminus at the Tehachapi mountains, was a spacious dry grassland hundreds of miles long, a Kansas in California. Just as the grasslands of the eastern Great Plains were grazed by huge herds of buffalo, so the San Joaquin Valley had its own large animal herbivora which roamed the flatlands by the thousands, the tule elk and pronghorn antelope. Early settlers of the Central Valley consequently turned these vast grasslands to cattle ranching, which seemed to offer a surer means to profit than the uncertainties of farming in a land of rainless summers. Between 1846 and 1860, the state's cattle population grew from an estimated 400,000 to more than three million.

Two years of disastrous drought from 1862 to 1864, however, devastated the herds and encouraged the ranchers to turn to other products. Although the state government offered cash bounties to farmers who experimented with the cultivation of exotic

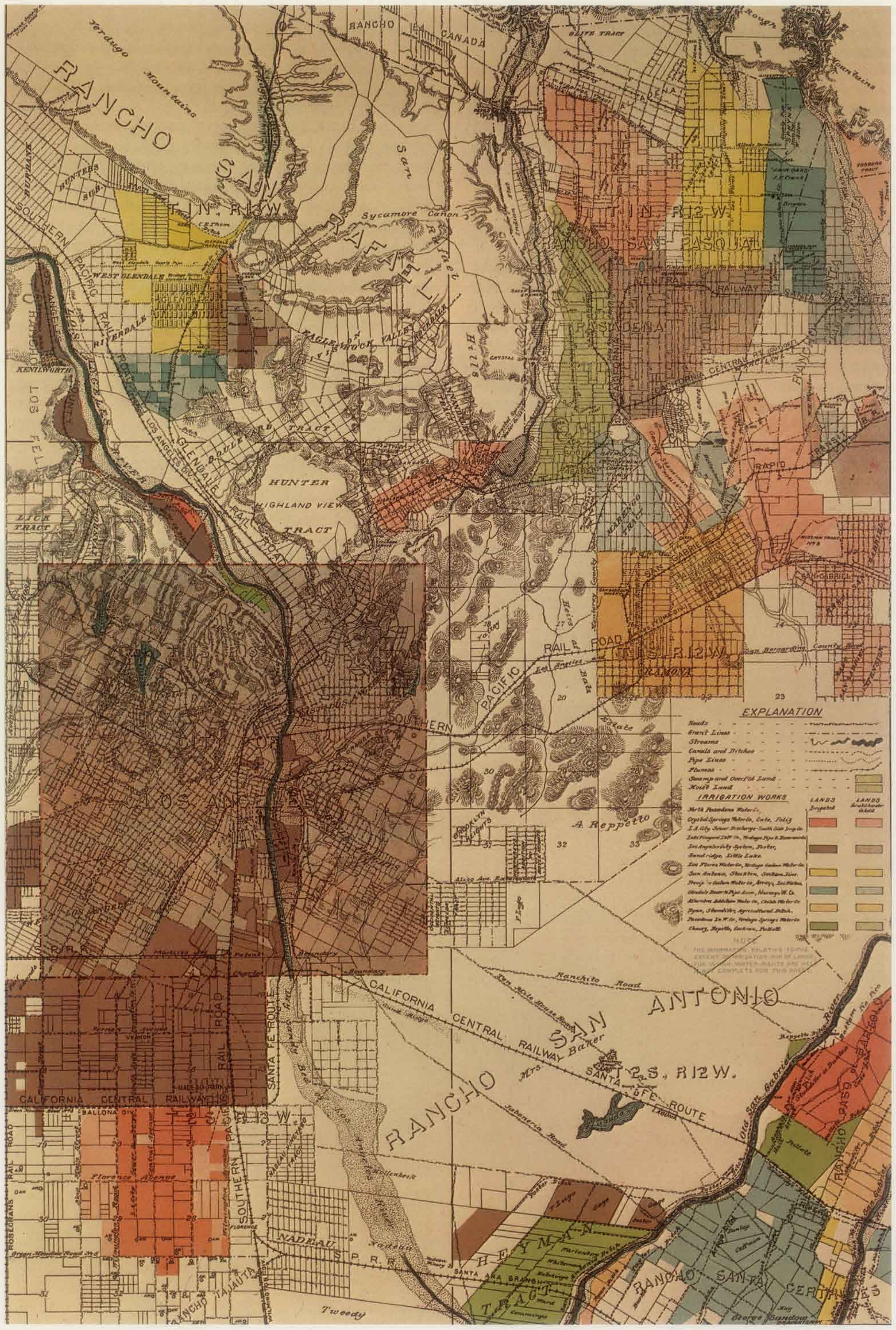
The rich soils of the Delta, which appear here as red tones, contrast dramatically with the nonirrigated croplands on the Montezuma Hills at left. The Delta, however, remains a highly vulnerable center of agricultural activity, as seen in this view of the Rio Vista-Isleton flood July 27, 1972. The Sacramento River is at the left and the San Joaquin River enters from the lower right corner. Brannan Island is the large inundated area at the center of the photograph and the top of the levee at Rio Vista can be seen as a thin line on the west side of the island running beside the Sacramento. The inundated area in the lower right quarter of the photograph marks the site of Franks Tract which was flooded in 1937.

crops such as flax and hemp, cotton, tobacco, raw silk, tea, coffee, and indigo, it was Dr. Hugh J. Glenn's success with the growing of non-irrigated wheat on the west bank of the Sacramento River which pointed the way to future prosperity. A series of rainy winters that began with the crop year 1866-67 opened the Sacramento and San Joaquin valleys to large-scale wheat production. Grain rapidly replaced beef as the state's principal agricultural commodity and the state laws which in the 1850s had denied a farmer compensation for crops damaged by a neighbor's cattle were reversed as the political power of the cattlemen declined.

Railroads also greatly modified California's agricultural economy. For 20 years navigation had bound the course of settlement in California to its coasts and rivers. But, with the completion of the first transcontinental railroad in 1869, a revolution in transportation technology swept over the state. Tracks were laid between existing river cities, undermining the very shipping that had made those places important. As the network of tracks extended inland, small villages that had languished because of their remoteness were transformed into bustling trade centers, and virgin land was broken and planted to wheat. From north and south the grain harvest was hauled to the Carquinez Strait where it was loaded onto ships bound for Europe.

Railroads cut the cost of overland freight sufficiently to allow the intrastate shipment of grain, but not so far as to permit its shipment over the transcontinental routes. Only the highest valued agricultural products could be carried great distances, and those only with difficulty. The development of refrigerated cars, however, combined with the rapid growth of eastern cities to create urban markets for California's early ripening deciduous fruit and its exotic citrus. Entire districts were planted in vines and trees introduced from the far corners of the world. Oranges, grown at Mission San Gabriel since 1804, were made a viable commercial crop with the introduction of the navel orange to Riverside from Brazil in 1873 and the Valencia from the Azores in 1876. Grape stock was brought in from France to supplement the vines introduced by the Spanish missionaries, lemons arrived from Australia and Sicily, and figs came from the Levant. Most of these vine and tree crops shared one important characteristic: they required irrigation in California's drier summer climates.

By the time the railroads were built, water management had already been a principal concern of Southern Californians for more than a century. From San Diego to Santa Barbara the Franciscan padres employed Indian labor to build sometimes elaborate systems for the conservation and delivery of the precious liquid. The availability of arable land and water was the basic requirement for successful settlement, ecclesiastical or civil. So it was that when Spanish authorities determined to establish a pueblo in the south, they chose a low-lying alluvial terrace adjacent to that portion of the Los Angeles River through which water flowed year round. With its founding on September 4, 1781, the *Pueblo de los Angeles* began its enduring relationship with the stream. The first settlers erected a brush diversion dam and excavated a *zanja madre* (main ditch) along the base of the hills past the northeast corner of the plaza. Equally important, a ditch master was appointed and a system of rules established for the operation of the system.

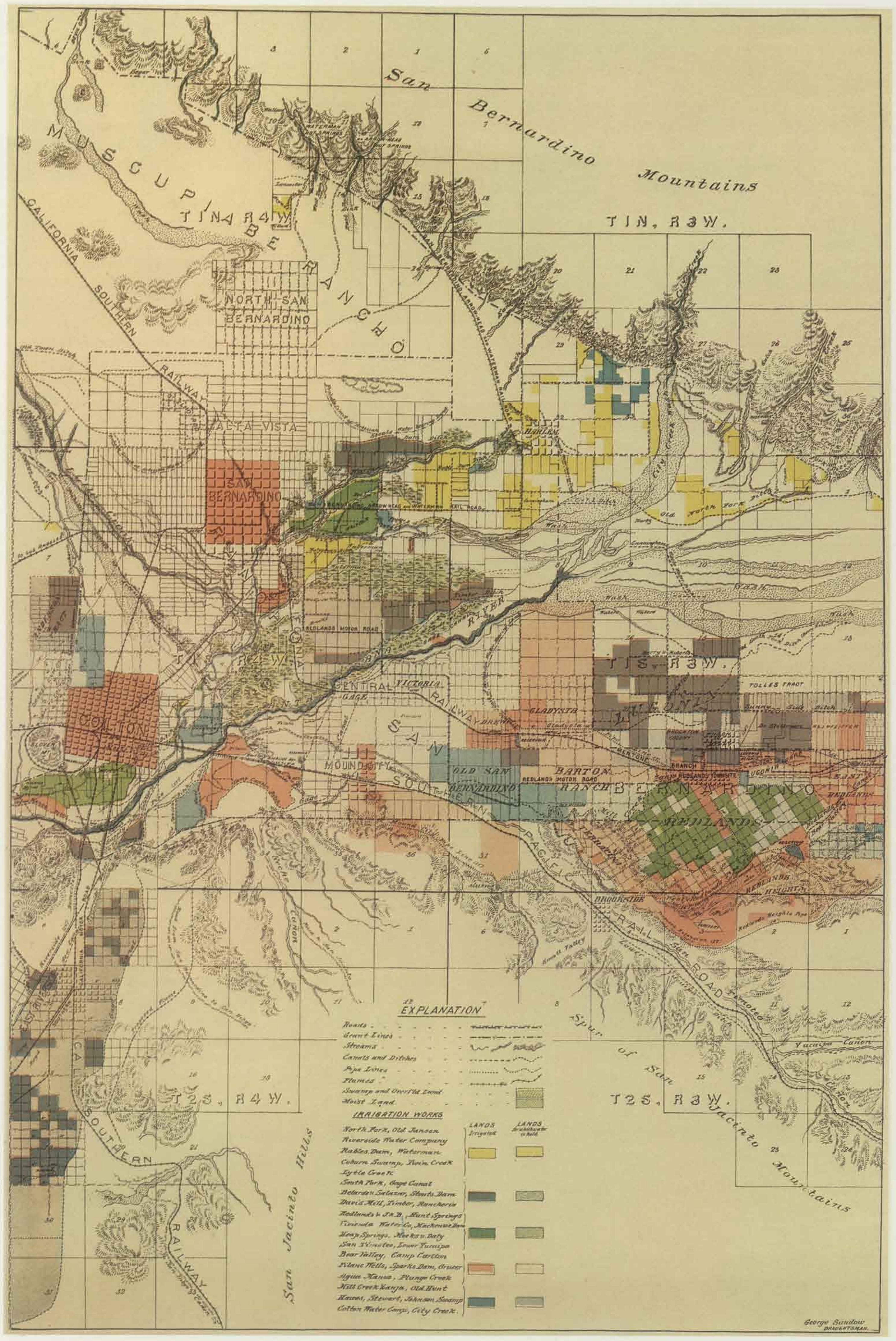


Los Angeles' water colony endured the administrations of three national governments. That it did so is a testament to the importance of Spanish colonial policy, which gave to California's pueblos the exclusive right to their rivers. In a land of little rain, this provision for the community's exclusive use of the Los Angeles River became the legal basis by which citizens held their vital resource inviolate, guaranteeing a reliable source of water for domestic and agricultural purposes. Only within the confines of the muncipality did both an incontestable right to water and a political organization for its distribution exist. As a result, only there had water development continued uninterrupted for more than a century. By 1888 almost 3,000 acres of irrigated farmland lay within the town's borders. The adobe village had grown to a city of almost 50,000 persons, the state's second largest urban place.

The pueblo's survival and the resulting continuity of water rights and management under Spanish, Mexican, and American rule contrasted sharply with conditions elsewhere in Southern California. The Franciscan missions, the only other institution with resources sufficient to construct and maintain elaborate water systems, were secularized and dismantled during the 1830s. Their dams, canals, and extensively irrigated fields were abandoned and rapidly fell into disrepair. Irrigation did not disappear entirely; at scattered locations along the perennial streams, water was diverted for gardens and other small plots. But in most cases these were individual enterprises, limited in scope by an absence of suitable organization, inadequate markets, and ill-defined land and water titles.

Although numerous persons participated in bringing water to the land during ensuing years, it was never so much individual personalities as organizations that dominated irrigation development—organizations that would capture and manage the scarce resource through their ability to concentrate money, labor, and political power. The first institution to succeed in such a venture after the American conquest was the Church of Jesus Christ of Latter-Day Saints, which established a Mormon colony at San Bernardino in 1851. This officially sponsored settlement was meant to be a strategic outpost on the route to Salt Lake City, a community which would help secure a protected Mormon corridor to the sea. It was in many respects a theocracy; wherever necessary the church provided the organizational structure and required leadership. Its authority was immense in all secular matters and, partially as a result of this, the enterprise succeeded for awhile.

Under the direction of the religious leaders, 35,500 acres of *Rancho del San Bernardino* were purchased and a community laid out on the south bank of the Santa Ana River. Fields were planted and an irrigation ditch was dug by communal effort. But in 1857, federal troops marched on Utah, and central church authorities ordered the colony to be abandoned by its 500 residents. Thus ended the first church-sponsored irrigation colony of the American period. Others, such as the Presbyterians at Westminster and the Quakers at Earlham, would attempt to build New Jerusalems among the vineyards and groves of Southern California; none, however, were more ambitious or by experience and doctrine better pre-



WILLIAM "HAM" HALL

The nineteenth century maps of early water systems in this section are part of the priceless legacy of California's first state engineer, William Hammond Hall. Born in Maryland in 1846, "Ham" Hall's early dreams of training as an engineer at West Point were dashed by the Civil War. He worked instead as a field engineer, draftsman, and hydrographer for the Army Corps of Engineers, and his surveys in this connection of the sand dunes south of Lands End in San Francisco led to his appointment as San Francisco's Engineer and Superintendent of Parks in 1870. After six years spent supervising the development of what is now Golden Gate Park, Hall devoted two years to studies for a canal on the west side of the San Joaquin Valley.

When the menace of hydraulic mining debris resulted in passage of the Drainage Act of 1878, Governor William Irwin appointed Hall to head the newly created Office of the State Engineer, which was charged under the act with the responsibility for determining the extent of debris damage and developing a program of relief. Hall's work measuring the capacities and discharge of the Sacramento and San Joaquin rivers quickly expanded to include comprehensive study of all California's water resources. The meticulous reports and maps which Hall and his teams of assistants assembled thus came to constitute the earliest overall survey of California's hydrologic system.

Hall kept the Legislature steadily supplied with reports on his progress and recommendations for new irrigation and drainage projects. Where irrigation was involved, however, controversy was sure to follow. Charges were repeatedly made but never proved that Hall's assistants were supplying the results of their surveys to aid private interests such as the Miller and Lux Land and Cattle Company, and Hall's repeated appeals for greater governmental control over the development of the state's water resources met with little favor in the Legislature. When the Legislature refused in 1888 to provide funding for the completion of the third volume of his irrigation studies and the printing of the first complete map of the state's water system, Hall resigned and his office was abolished. Although portions of Hall's work were used by the State Mineralogist to produce a statewide map in 1890, the bulk of Hall's vast accumulation of data lay unpublished and little used by state officials for decades.

Hall thereafter pursued a lucrative private practice until his death in 1934. From 1890 to 1898, he acted as a consulting engineer for the mines of South Africa, and in 1899 he developed a series of reports on irrigation and canal projects for the Transcaucasus of Russia. He returned to California in 1900 and was almost immediately the center of controversy once again as a result of his activities as an agent for a syndicate of New York investors buying up water and power rights in the Lake Eleanor and Cherry Creek watersheds. Lake Eleanor was the key to San Francisco's plans to tap these waters for the Hetch Hetchy project. Hall's desire to retain the right for private development of a power project in the area ran directly counter to the insistence of the United States Department of the Interior that the Hetch Hetchy system be entirely public. After ten years of bickering over price, Hall ultimately sold the holdings he had acquired for approximately $100,000 to the City of San Francisco for a total price in excess of one million dollars.

The two maps on these pages are part of Ham Hall's detailed inventory of irrigated lands in California in 1888. In the map of Los Angeles on the facing page the flows of the Los Angeles River are shown to disappear temporarily into a "dry sandy bed" south of the California Central Railway's Santa Fe line. The map on this page displays agricultural development in San Bernardino along the Santa Ana River. On both maps, principal colors have been used to distinguish the service areas of various water works and the darker shades of each color identify the areas that are actually irrigated.

pared than these first Mormon irrigators. Their successes in the Intermountain West became legendary and their settlements the prototype for later federal developments.

Even as the Mormons abandoned San Bernardino another type of colony, one organized along ethnic lines, began operations on the *Rancho Juan y Cajon de Santa Ana*. The group in this case consisted of Germans from San Francisco, who decided to purchase 1,165 acres south of Los Angeles, subdivide the parcel into small farms, and plant vineyards. Since none of the 50 subscribers was conversant with the operation of water systems, they wisely decided to remain at their urban occupations, employing a resident manager to prepare the colony for their eventual settlement. The manager divided the area into 20-acre farms with houseplots grouped together in a village where land was set aside for a school and other public buildings. On each 20-acre parcel were planted eight acres of vines and some fruit trees. Local laborers built a water system and planted a 45-mile-long living fence of willow trees around the perimeter and between individual plots to keep out livestock. The manager maintained the whole place until 1860, by which time each stockholder had paid $1200 in assessments. Lots were assigned by lottery, and a dividend was paid to the owners from the sale of the company's tools and other assets. When most of the original San Francisco subscribers finally took possession of their properties, they named their town Anaheim and set about the business of raising grapes and pressing wine. These settlers were merchants, blacksmiths, and watchmakers—people with little or no experience in agriculture. That they sought to escape their occupations in an urban society seems remarkable, that they should succeed even more so. Their accomplishment testified to the importance of community action and the potential for small-scale, intensive irrigated agriculture in Southern California.

In subsequent decades the Anaheim colony and its organization would be popularized by writers and social reformers as a model of economic planning and the proof of one method by which people of modest means could acquire a small share of Southern California's pastoral utopia. As the residents of other colonies patterned after Anaheim soon found out, however, development costs were high, and so too was the price of colony land. Local residents and the poor were not easily persuaded to join such expensive enterprises. Instead, most of the colonists were drawn from the newly mobile middle classes of the Middle West and Northeast. Like Anaheim's Germans they were recruited from distant places and often settled together at their chosen destinations. These new developments sometimes took their names from the origins of their promoters or inhabitants, as in the case of the Indiana Colony at Pasadena and the Kansas Colony at Rialto.

As interst in irrigation increased, companies were formed by investors to offer prospective settlers the same services San Bernardino's and Anaheim's colonists had attempted to provide for themselves. Neither religious nor ethnic affiliations were so common in these enterprises as to make them viable organizations for most immigrants. Reclamation became a business to be pursued for speculative gain.

The photographs below depict aspects of agricultural development in the nineteenth century. Chaffey's colony at Ontario, shown here looking northward along Euclid Avenue toward the San Gabriel Mountains, established the mutual water company as the model for building successful planned communities in an era of private water development. Below at right, grapes are harvested in the San Gabriel Valley. At lower left is an example of the artesian wells which were developed in the last decades of the nineteenth century as a way of tapping the groundwater basins of the lower lying alluvial plains of the South Coast and Central Valley.

Vast acreages were purchased, dams built, and canals dug in expectation of realizing huge returns on land and water sales. Many of these ventures prospered for awhile, but the continuing corporate ownership of water frequently led to grave legal problems. A few companies, not the small farmers, controlled the resource upon which the entire economy depended. Competing firms diverting from the same stream sued each other over water rights, jeopardizing the improvements of their colonist clients. And, once the lands had been sold, the canal owners often attempted to maintain high profits by exercising their monopolistic control over water rates.

Along the Santa Ana River, the largest Southern California stream open to claimants, the problems were especially complex. At Riverside, for instance, the conflict between irrigators and the Riverside Canal Company became so great that the citizens sought redress through state legislation which attempted to fix the water rates and compel the company to furnish water to all customers at the same rate for as long as the colonists wished. The company replied by reducing service and suing. Years of acrimonious litigation passed before the irrigators settled the matter by purchasing their antagonist's property.

Riverside's situation was not unusual. Throughout the state, the very corporate structure which permitted extensive systems to be built usually led to a conflict of interest between suppliers and consumers. Perhaps the most famous solution to the problem was devised by George B. Chaffey, a Canadian often credited with successfully applying the concept of a modern mutual water company to the California scene. In April 1882, Chaffey and his associates began developing a "Model Colony" on 6,216 acres of land which they had purchased from the Cucamonga Grant together with all conflicting claims to the water of San Antonio Creek along the east bank. The property was surveyed and subdivided into rural parcels of ten and twenty acres, suburban lots of two and a half acres, and town lots adjoining the Southern Pacific Railroad. In honor of his home, Chaffey named the colony Ontario.

Every aspect of the scheme was thoroughly planned and executed. Chaffey built a modern water system that conveyed water through more than 60 miles of cement and iron pipe to every holding. For public betterment he established an agricultural college and outlawed saloons. To beautify the community he laid out Euclid Avenue, a 200-foot-wide boulevard planted with shade trees stretching seven miles from the railroad station up to the base of the San Gabriel Mountains. Even public transportation was provided by the construction of a streetcar line that ran the entire length of this principal thoroughfare. The most important part of the development, however, could not be seen. Chaffey organized the San Antonio Water Company for the purpose of constructing and operating the necessary water system. Unlike other companies, however, this one was organized in such a manner as to vest in the land purchasers control over water rights and deliveries.

Chaffey's success at Ontario depended in part upon the fact that his company had bought out a significant portion of any conflicting claims to its principal water supply. These conditions did not obtain, however, in other parts of the state, where irrigators often found themselves in bitter conflict with one another for the limited flows of nearby streams. Irrigation in the delta of the Kings River, near the present site of Fresno, for example, began as early as 1858. Following enactment of the Green Act in 1868, these efforts were greatly expanded. The water seemed freely available to all, and public authorities made no attempt to control its appropriation. Irrigators would simply file a claim with the county clerk, saying they were taking a certain volume of water out of the river, and nail a copy of their claim to a tree near their ditch's headgate. People were ignorant of how much water the Kings River actually carried; their units of measurement as to water volumes varied widely; claims overlapped; and the basis for years of lawsuits was quickly laid. In this way, ditches were dug through the flatlands, forming an intricate tracery of water courses, and by 1878, more than a thousand miles of irrigation canals were in operation in Fresno County.

A serious drought in 1876, however, set off the inevitable warfare of lawsuits that had been long in preparation between upstream and downstream appropriators of the Kings' flow. The owners of a large rancho in the Kings delta, the *Laguna de Tache*, initiated no less than 135 lawsuits against upstream irrigation companies to protect their claim to an undiminished flow of the river through the rancho's lands. At the heart of these and similar conflicts throughout the state lay a series of important questions about the meaning and suitability of the system of riparian water rights, which was part of the English common law adopted by the State Legislature in its first sitting in 1850 as the basic legal system for California.

THE CONFLICT OVER RIGHTS

The word rival is derived from the Latin word *rivalis*, which originally meant a person living on the opposite bank of a river. The word riparian, which is used to refer to land, persons, or anything else along a river bank, has a related derivation. The perception that the owners of riparian lands, by the nature of their situation on a common stream, should be perpetual rivals constituted a fundamental aspect of water development in California throughout the latter half of the nineteenth century and the early decades of the twentieth. As a result, the Chief Justice of California noted in 1922 that there were more California Supreme Court decisions on the law of waters than on any other subject.

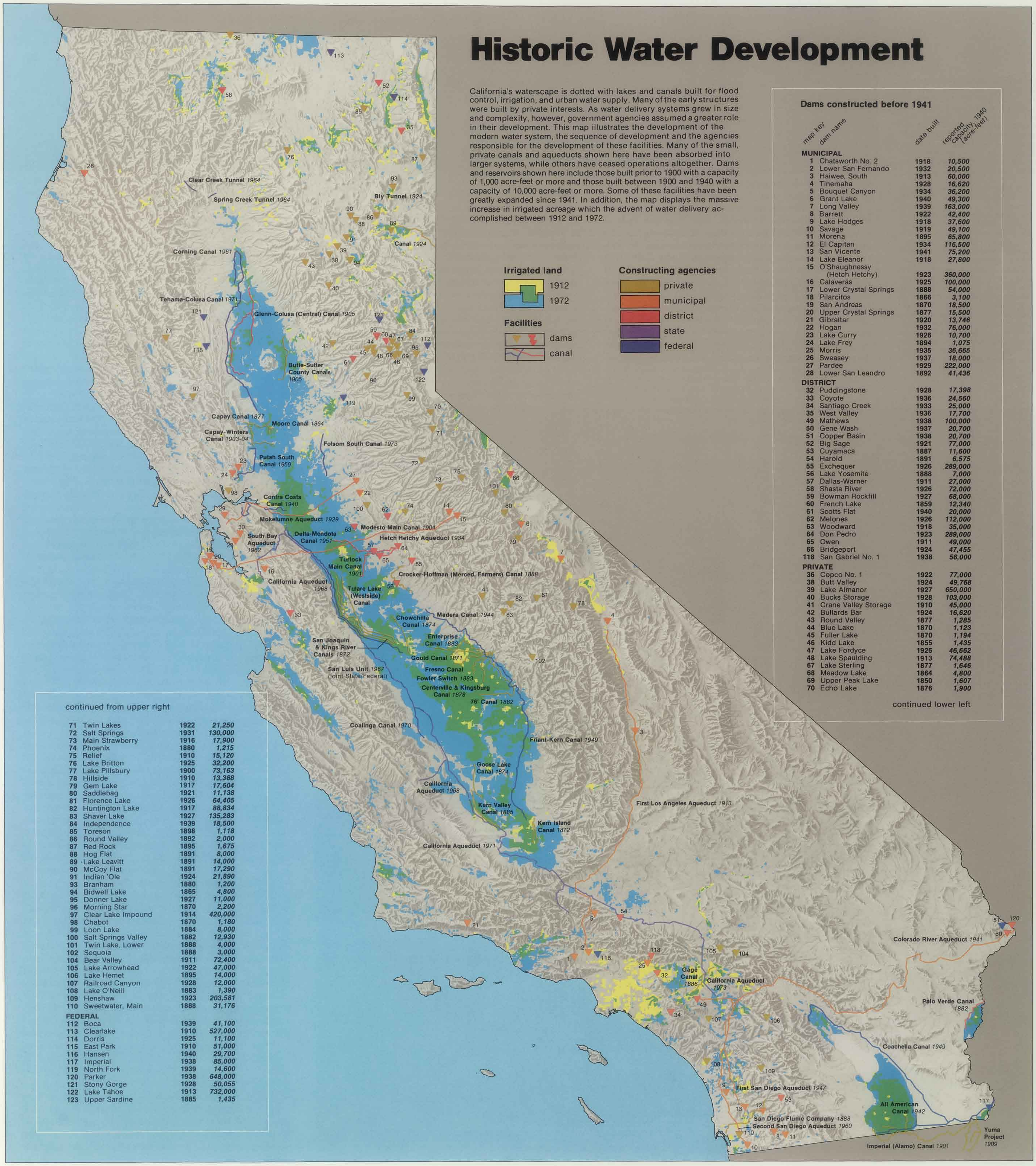
Before California's admission to the Union in 1850, the doctrine of riparian rights had been recognized in both England and the eastern United States. Under that doctrine, the owners of lands adjoining a stream were held to share the right to the waters of the stream for use on those adjoining lands to the exclusion of use on other lands. When the first California Legislature adopted the English common law as the basis of the state's legal system, the doctrine of riparian rights became the ultimate legal test for resolving all disputes on water use. But a doctrine developed in foggy, rain-soaked England, where the earliest problems of water development involved the use of streams and rivers to drain bogs and marshes from the land, seemed ill-suited to the arid southwestern United States. And the story of California water rights is consequently in large part a history of the continued assault upon the riparian doctrine by the adherents of the competing doctrine of appropriation. Under this doctrine, the right to water is awarded to the first person who puts its to a beneficial use, regardless of whether that individual in fact uses the water on land abutting the stream from which it is taken.

As the western states formed and established their individual systems of law, they divided almost equally on the question of which doctrine to follow. Oregon, Washington, Oklahoma, Nebraska, the Dakotas, and Kansas all followed the lead of Texas and California in granting primacy to the riparian doctrine with its emphasis upon land ownership and physical proximity to a water source. In contrast, Montana, Idaho, Wyoming, Utah, New Mexico, and Arizona followed Nevada and Colorado in adopting appropriative principles which encouraged the development of beneficial uses for water. Although these two major branches of western water law have come to be described as the California and Colorado doctrines, the ideas essential to both riparian and appropriative doctrines appeared early in California. The critical legal difference was that California recognized an appropriative right as superior to a riparian right only if the appropriation was made while the riparian land was in the public domain, whereas Colorado recognized appropriative rights to the complete exclusion of riparian rights.

The appropriative doctrine was first applied in the California goldfields where it became a recognized principle among the miners that whoever first extracted and used a certain quantity of water from a stream would be allowed to continue to extract and use that

Historic Water Development

California's waterscape is dotted with lakes and canals built for flood control, irrigation, and urban water supply. Many of the early structures were built by private interests. As water delivery systems grew in size and complexity, however, government agencies assumed a greater role in their development. This map illustrates the development of the modern water system, the sequence of development and the agencies responsible for the development of these facilities. Many of the small, private canals and aqueducts shown here have been absorbed into larger systems, while others have ceased operations altogether. Dams and reservoirs shown here include those built prior to 1900 with a capacity of 1,000 acre-feet or more and those built between 1900 and 1940 with a capacity of 10,000 acre-feet or more. Some of these facilities have been greatly expanded since 1941. In addition, the map displays the massive increase in irrigated acreage which the advent of water delivery accomplished between 1912 and 1972.



Dams constructed before 1941

map key	dam name	date built	reported capacity, 1940 (acre-feet)
MUNICIPAL			
1	Chatsworth No. 2	1918	*10,500*
2	Lower San Fernando	1932	*20,500*
3	Haiwee, South	1913	*60,000*
4	Tinemaha	1928	*16,620*
5	Bouquet Canyon	1934	*36,200*
6	Grant Lake	1940	*49,300*
7	Long Valley	1939	*163,000*
8	Barrett	1922	*42,400*
9	Lake Hodges	1918	*37,600*
10	Savage	1919	*49,100*
11	Morena	1895	*65,800*
12	El Capitan	1934	*116,500*
13	San Vicente	1941	*75,200*
14	Lake Eleanor	1918	*27,800*
15	O'Shaughnessy (Hetch Hetchy)	1923	*360,000*
16	Calaveras	1925	*100,000*
17	Lower Crystal Springs	1888	*54,000*
18	Pilarcitos	1866	*3,100*
19	San Andreas	1870	*18,500*
20	Upper Crystal Springs	1877	*15,500*
21	Gibraltar	1920	*13,746*
22	Hogan	1932	*76,000*
23	Lake Curry	1926	*10,700*
24	Lake Frey	1894	*1,075*
25	Morris	1935	*36,665*
26	Sweasey	1937	*18,000*
27	Pardee	1929	*222,000*
28	Lower San Leandro	1892	*41,436*
DISTRICT			
32	Puddingstone	1928	*17,398*
33	Coyote	1936	*24,560*
34	Santiago Creek	1933	*25,000*
35	West Valley	1936	*17,700*
49	Mathews	1938	*100,000*
50	Gene Wash	1937	*20,700*
51	Copper Basin	1938	*20,700*
52	Big Sage	1921	*77,000*
53	Cuyamaca	1887	*11,600*
54	Harold	1891	*6,575*
55	Exchequer	1926	*289,000*
56	Lake Yosemite	1888	*7,000*
57	Dallas-Warner	1911	*27,000*
58	Shasta River	1926	*72,000*
59	Bowman Rockfill	1927	*68,000*
60	French Lake	1859	*12,340*
61	Scotts Flat	1940	*20,000*
62	Melones	1926	*112,000*
63	Woodward	1918	*35,000*
64	Don Pedro	1923	*289,000*
65	Owen	1911	*49,000*
66	Bridgeport	1924	*47,455*
118	San Gabriel No. 1	1938	*56,000*
PRIVATE			
36	Copco No. 1	1922	*77,000*
38	Butt Valley	1924	*49,768*
39	Lake Almanor	1927	*650,000*
40	Bucks Storage	1928	*103,000*
41	Crane Valley Storage	1910	*45,000*
42	Bullards Bar	1924	*16,620*
43	Round Valley	1877	*1,285*
44	Blue Lake	1870	*1,123*
45	Fuller Lake	1870	*1,194*
46	Kidd Lake	1855	*1,435*
47	Lake Fordyce	1926	*46,662*
48	Lake Spaulding	1913	*74,488*
67	Lake Sterling	1877	*1,646*
68	Meadow Lake	1864	*4,800*
69	Upper Peak Lake	1850	*1,607*
70	Echo Lake	1876	*1,900*

continued lower left

continued from upper right

71	Twin Lakes	1922	*21,250*
72	Salt Springs	1931	*130,000*
73	Main Strawberry	1916	*17,900*
74	Phoenix	1880	*1,215*
75	Relief	1910	*15,120*
76	Lake Britton	1925	*32,200*
77	Lake Pillsbury	1900	*73,163*
78	Hillside	1910	*13,368*
79	Gem Lake	1917	*17,604*
80	Saddlebag	1921	*11,138*
81	Florence Lake	1926	*64,405*
82	Huntington Lake	1917	*88,834*
83	Shaver Lake	1927	*135,283*
84	Independence	1939	*18,500*
85	Toreson	1898	*1,118*
86	Round Valley	1892	*2,000*
87	Red Rock	1895	*1,675*
88	Hog Flat	1891	*8,000*
89	Lake Leavitt	1891	*14,000*
90	McCoy Flat	1891	*17,290*
91	Indian 'Ole	1924	*21,890*
93	Branham	1880	*1,200*
94	Bidwell Lake	1865	*4,800*
95	Donner Lake	1927	*11,000*
96	Morning Star	1870	*2,200*
97	Clear Lake Impound	1914	*420,000*
98	Chabot	1870	*1,180*
99	Loon Lake	1884	*8,000*
100	Salt Springs Valley	1882	*12,930*
101	Twin Lake, Lower	1888	*4,000*
102	Sequoia	1888	*3,000*
104	Bear Valley	1911	*72,400*
105	Lake Arrowhead	1922	*47,000*
106	Lake Hemet	1895	*14,000*
107	Railroad Canyon	1928	*12,000*
108	Lake O'Neill	1883	*1,390*
109	Henshaw	1923	*203,581*
110	Sweetwater, Main	1888	*31,176*
FEDERAL			
112	Boca	1939	*41,100*
113	Clearlake	1910	*527,000*
114	Dorris	1925	*11,100*
115	East Park	1910	*51,000*
116	Hansen	1940	*29,700*
117	Imperial	1938	*85,000*
119	North Fork	1939	*14,600*
120	Parker	1938	*648,000*
121	Stony Gorge	1928	*50,055*
122	Lake Tahoe	1913	*732,000*
123	Upper Sardine	1885	*1,435*

This map by Ham Hall displays the northern end of the San Joaquin Valley in the vicinity of the watersheds of the Kings and Kaweah rivers, site of some of the most intense court battles over water rights in the nineteenth century. The Fresno colony appears at the top left and the northern tip of Tulare Lake can be seen directly below the colony. The blue tones on the map depict the extent of irrigated lands in 1886; the green areas identify swamp and bottom lands; and the vast fields of pink mark the lands that Hall argued might someday be developed for agriculture through the construction of irrigation systems.

quantity as against any later user. This principle was followed notwithstanding the fact that the land on which the stream flowed, in almost every case, was actually public land owned by the United States; under familiar common law principles, neither private party to a given controversy was in a position to assert the rights of the true owner, the United States. There were exceptional cases in which the land in question was not owned by the federal government, and in these cases the California Supreme Court made its critical policy determination as early as 1857 in the case of *Crandall v. Woods*. The riparian rights of land which was in private ownership at the time an appropriation was made were held to be superior to the rights of the appropriator; the common law rule of riparian rights was thus approved.

The uncertain element in every early appropriative right in California, however, was that the federal government, either as sovereign or as owner of the public land, might repudiate the whole idea. In particular, the common law approach of the California Supreme Court necessarily reserved the question of the rights of the United States as the proprietor of the land on which almost all appropriations had occurred. In a remarkable post-Civil War legislative battle, Congress resolved the question in 1866. An effort to recover for the United States the value of gold mined on public land without congressional authority was defeated, and western members of Congress went on to win not only the right to mine on public land but also federal acquiescence in all water appropriations which had been made on the public domain, or which might be made in the future. The exact meaning of this legislation was much debated, but in the end the Congressional waiver of water rights of the public domain was recognized. Indeed, the ultimate controversy was not whether Congress had given up the proprietary rights of the United States but rather whether, in the process, it had established a national policy in favor of appropriation as against private riparian rights.

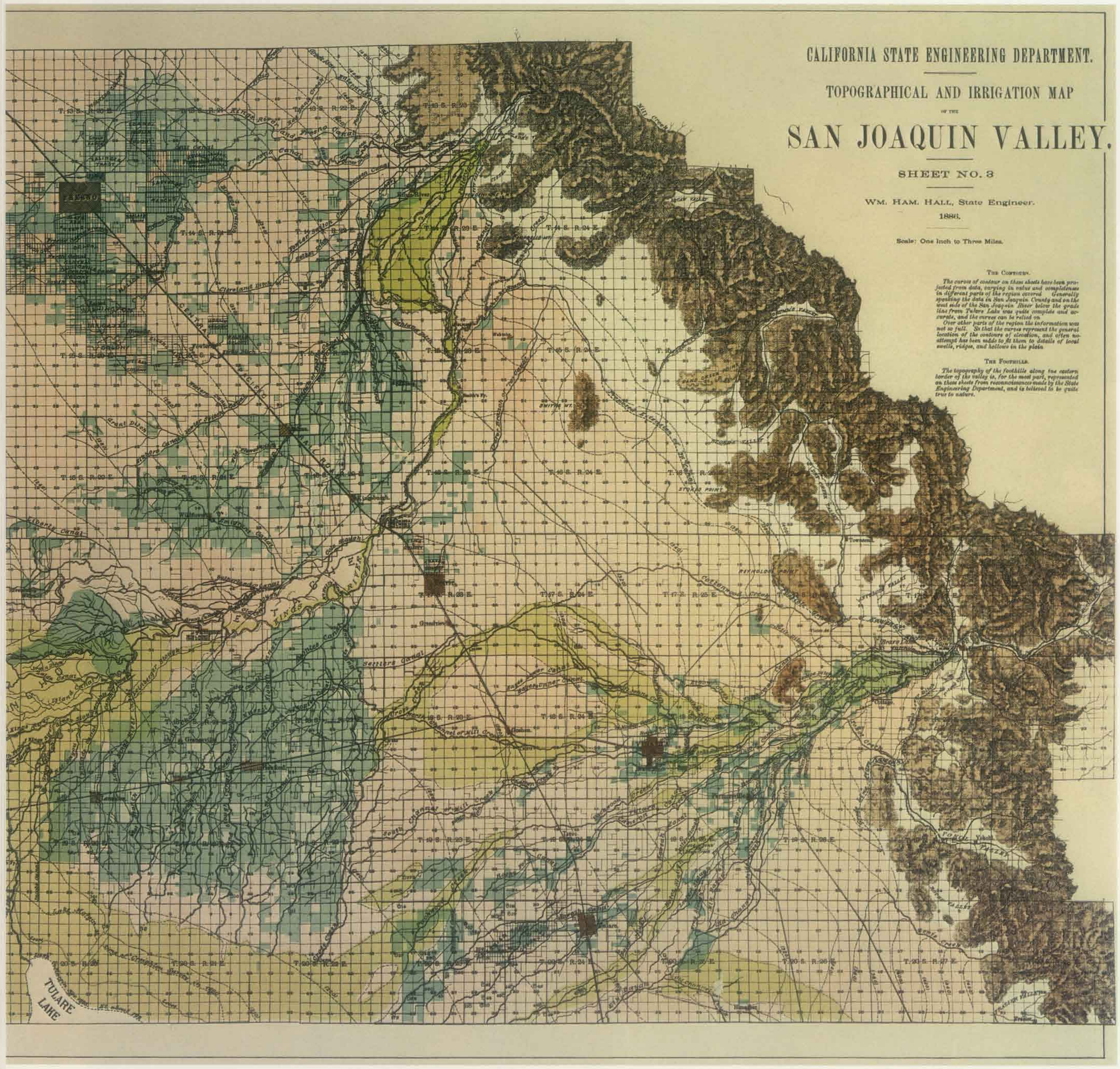
In the generation following the decision in *Crandall v. Woods* in 1857, the California doctrine of riparian rights on private land drew increasing criticism for a number of reasons. First, whatever any individual member of Congress may have thought when voting for the act in 1866, the appearance of federal approval of the idea of appropriation thereafter carried considerable weight. Second, as mining decreased in importance in California and agricultural activity increased, and as a larger and larger portion of California land was transferred to private ownership, the practical consequences of the riparian doctrine grew more obvious. In terms of the number of acres affected, the doctrine constituted an increasingly significant barrier to any land development dependent on appropriation. In addition, the decision by Colorado and other western states in the years after *Crandall v. Woods* to opt for the impetus to development, stability, and flexibility which the appropriation doctrine offered, spurred efforts in California for a reexamination of the early California decisions.

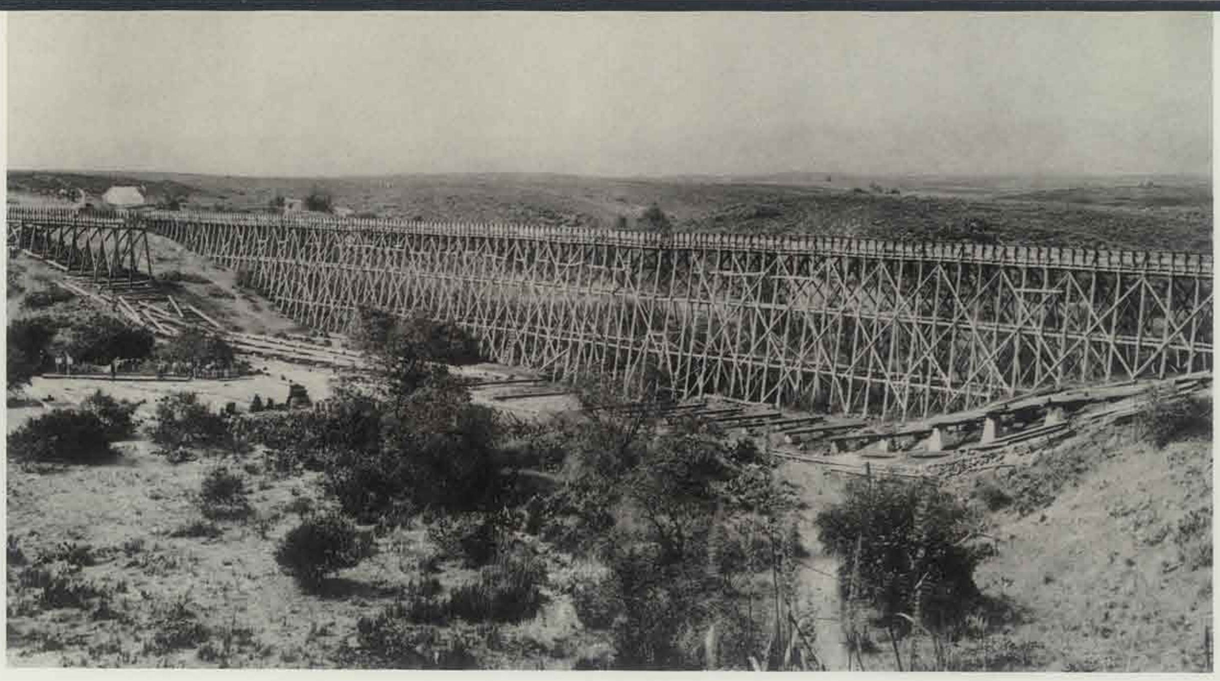
The issue was joined in the case of *Lux v. Haggin*, which reached the California Supreme Court in the middle of the 1880s. Henry Miller and his partner Charles Lux bought up vast amounts of acreage in the San Joaquin Valley under the state's program for disposing of federal swamp and overflow lands during the 1850s. The holdings of the Miller and Lux Land and Cattle Company embraced both banks of the San Joaquin River for a stretch of 100 miles from Modesto to Madera, and 50 miles of the Kern River. Ultimately, the company laid claim to more than a million acres in California, Nevada, and Oregon and Miller boasted that he could ride from Mexico to Oregon and sleep every night in a ranch house of his own. Although Miller and Lux claimed they were cattlemen, their critics charged that they were manipulating their vast riparian holdings for purposes of land speculation by keeping their properties undeveloped and delaying subdivision so as to drive up the value of the land. Their riparian right to the undiminshed flow of the Kern River, moreover, interfered with the intention of another firm owned by James Haggin and Lloyd Tevis to appropriate water upstream for the purpose of irrigating lands lying at some distance from the river.

By a four to three vote, the California Supreme Court in 1886 reaffirmed the doctrine of riparian rights and denied Haggin's appropriative use of the streamflows of the Kern River. The majority opinion in the case is the longest in the history of the court, and the decision had important effects not only for California but for all the states which followed the California approach. In part, the decision was political. While the case was pending in the Supreme Court, the conflicting rules of riparian and appropriative rights were much debated in the election of 1884, and in those days, Supreme Court justices were directly elected. Although the riparian estate involved in this case was very large, it was argued that appropriation generally favored the well-financed promoter or public utility as opposed to the ordinary farmers and the owners of Spanish land grants who made their living by working the land riparian to California's streams. On the other hand, many irrigation projects were absolutely dependent on the right of appropriation. The controversy became so heated in Kern County, where the case arose, that at the next judicial election the trial judge, who had decided in favor of appropriation, was defeated by an opponent who campaigned on the doctrine of riparian rights. The Supreme Court's decision in this case did not write new law; it simply reaffirmed the principles it had recognized earlier. But the effect of the decision was to delay for 40 years the advance of the appropriative doctrine in California.

Irrigationists, angered by the outcome of the case, were successful in obtaining a special session of the Legislature to take up irrigation legislation that same year. Although this special session failed to achieve any reforms, the Legislature did respond to the crisis the next year by passing the Wright Irrigation Act of 1887. Declaring for the first time that the use of water for irrigation was a "public use," the Legislature by this enactment authorized the formation of local public irrigation districts which had the power to bring condemnation suits against the existing works of private irrigation companies, take them over, and build extensions by issuing bonds and levying taxes upon the landowners who would be benefited. Enactment of the Wright Act prompted the formation of dozens of public irrigation districts in southern and central California. Although 50 districts were ultimately created under this act, the Modesto and Turlock districts proved most successful, while others floundered and failed. The Legislature repeatedly tinkered with the law to try to make it work. But each proposal for a new district stirred intense local controversies; few districts understood how properly to design and manage an irrigation system; fraud was a persistent phenomenon in connection with land sales; litigation flourished luxuriantly; and drought conditions in some parts of California during the mid-1890s drove many districts into bankruptcy.

By the turn of the century, some advocates of irrigation began to despair that California would ever enjoy what they regarded as the civilizing influence of irrigated agriculture. "Until quite recent years, the people living in the greater part of the State regarded





Two of the greatest waterworks of the nineteenth century no longer exist. On the right, the Anaheim Flume with a parallel line under construction. The Sweetwater Dam at far left was built entirely with private capital in 1883 to serve the San Diego and National City areas. Until its collapse in 1916, it was one of the largest dams in the West.

irrigation in the same light that eastern people generally view it, *viz.* that it is a grievous hardship imposed by nature upon the inhabitants of certain ill-favored regions of the earth," commented a report of the United States Department of Agriculture in 1900. The federal investigators who prepared the report attributed this prejudice against irrigation in part to a fear that it would spread malaria but also to a basic flaw in the character of Californians: "The cowboy on horseback was an aristocrat; the irrigator on foot . . . a groveling wretch. In cowboy land, the irrigation ditch has always been regarded with disfavor because it is the badge and symbol of a despised occupation."

Nonetheless, irrigation pushed ahead persistently. The 150,000 acres in Southern California which were brought into irrigation districts in 1889 eventually became spreading orange and lemon orchards in the fertile southern valleys. Vast water importation projects described in succeeding sections of this volume brought agricultural prosperity to the barren wastes of the Imperial, Coachella, and San Fernando valleys. The development of efficient, motor-driven pumps opened sections of the San Joaquin Valley to irrigation by enhancing access to the Central Valley's groundwater reservoirs. Establishment of a Bond Certification Commission at the state level in 1911 brought a much-needed measure of stability to the fiscal affairs of the irrigation districts. And, with the advent of a cycle of wet years beginning in 1908, 66 new districts were formed in the dozen years between 1909 and 1921.

All of this activity proceeded in the absence of a definitive system of appropriative water rights. Although it is difficult to understand today, the California Supreme Court appears to have flirted throughout this period with a dog-in-the-manger principle whereby a riparian owner could obtain an injunction against an appropriative use of water even though the riparian owner himself was not using it. This was sometimes called the rocking chair theory of water rights because it allowed a riparian owner to sit in his rocking chair and watch the water flow unused to the ocean. The California cases were in conflict. One line of decisions held that no injunctive relief should be allowed, for the obvious reason that a waste of water would result. Another line of cases granted injunctions on the ground that the plaintiff would otherwise lose his riparian right by prescription. It bears noting, however, that this latter line of decisions began at a time when the law did not yet recognize declaratory relief, and it was not until 1921 that a California statute authorizing declaratory actions eliminated the reason for those decisions.

The Legislature attempted to bring order to the condition of appropriative rights through the Water Commission Act of 1913 which created a state agency to determine whether a proposed appropriation should be allowed. Other provisions in the act, however, which constituted a direct assault upon the doctrine of riparian rights, were declared unconstitutional. One of these provided for the termination of unexercised riparian rights, while another would have limited the beneficial use of water on uncultivated land to 2.5 acre-feet per acre.

One effect of the riparian doctrine was to give special prominence to the so-called theory of the long purse. So long as litigation was the principal means of protecting water rights, anyone setting out to make use of California's water supplies had to add to the ordinary risks of his enterprise an often large and continuing outlay for the support of litigation to maintain his right to water. Thus, critics of the riparian doctrine complained, those with the longest purse could harass other water users into submission through frequent suits.

The crisis finally came in 1926, when the California Supreme Court again confirmed the supremacy of riparian rights in the case of *Herminghaus v. Southern California Edison Company*. The company proposed to store water for hydroelectric purposes, but the plaintiffs sought an injunction on the ground that this use would interfere with the natural irrigation of their riparian lands. The critical circumstance in the case was that the plaintiffs' lands were watered by the river only in periods of extremely high flow, during the spring and summer melting of the snow in the Sierra Nevada when the river water was lifted up to remote areas which at other times did not even touch the river. Thus, a large volume of water was necessary to confer a small benefit—the issue was not that the plaintiffs wasted water by not using it at all, but rather that the plaintiffs wasted water by making an unreasonable use of it.

As in *Lux v. Haggin*, the case stirred great public controversy and there were numerous briefs filed on both sides. Although the law was settled that appropriators could make only a reasonable use of water, and that one riparian owner was required to act reasonably with respect to other riparian owners, the court quoted approvingly from an earlier decision to the effect that the law did not require riparian owners to act reasonably as against an appropriator. The court did not concede that the plaintiffs' use was unreasonable, and again, the vote was close. Although the opinion appears to have a five-to-one majority, with one justice abstaining, there were changes in the membership of the court within a few days after the decision was issued, and the vote on the petition for rehearing was four to three.

Public reaction was immediate and critical. With the collaboration of the author of the dissenting opinion, a state constitutional amendment was drafted which required all uses of water to be reasonable. The amendment was adopted in 1928 and, in several decisions immediately following, notably *Peabody v. City of Vallejo* in 1935, the California Supreme Court carried out the mandate of the amendment. For some time it was believed that the change in law may have affected only the remedy of injunction and that a riparian owner might obtain damages from an appropriator who interfered with the riparian owner's right to make an unreasonable use of water. But in 1967, the right to obtain damages for such use was held to have been terminated by the amendment in the case of *Joslin v. Marin Municipal Water District*.

The 1928 constitutional amendment did not, of course, abolish riparian rights in California. Where they survive they are still important and, except for riparian land which was still in the public domain when a given appropriation was made, riparian rights have priority over appropriative rights. But the amendment did bind together the competing principles of riparian and appropriative doctrines, which had been tangled throughout the early years of California's settlement, under a system which recognized the interest of all the people of California in the promotion of the "reasonable and beneficial use" of all the waters of the state.

The passage of the constitutional amendment in 1928 and the assumption that same year of federal responsibility for the construction of the major facilities of the Sacramento Flood Control Project mark the end of an era which depended upon individualism, local control, and private enterprise for the development of California's water resources. The new era, characterized by cooperation, centralized supervision, and the use of public funds and authority, was already well advanced by this time, however, thanks in large part to the pressing needs of California's cities, which by 1900 had become critical.

PARKS DAM CONTROVERSY

Rather than resolving private conflicts over water use through systematic programs of reclamation and development, the early statutes authorizing the formation of public districts in some instances simply provided competing water users with another means to wage war. Such was the case in a controversy of the 1870s involving two of the largest landowners in the Sutter Basin near Colusa, William H. Parks and L. F. Moulton.

Parks, the owner of extensive swamplands in the basin, formed a levee district in 1871 to implement a plan to drain his lands and reduce the risk of floods by constructing a dam shutting off natural overflows into Butte Slough. Although the plan sparked local controversy because it would require taxing farmers who would not benefit from flood control while flooding other lands downstream, Parks completed his dam on December 6, 1871.

Moulton owned land along the east side of Butte Slough which was protected from floods by a levee system Moulton had constructed through the formation of a reclamation district. As the water began to back up behind Parks Dam, flooding lands that had never before been endangered, a band of masked men on December 27, 1871, seized the dam and destroyed a part of it.

The Sutter County Board of Supervisors initially supported Parks' efforts to maintain the dam, which had to be repeatedly repaired to compensate for floods which washed away portions of the dam in 1874 and 1875. Moulton meanwhile resorted to litigation to prevent reconstruction of the dam and obtain compensation for his losses. In the initial phases of his suit, however, Moulton met with no success in the courts.

In 1875 the county required modifications to the dam which should have alleviated some of the problems it had caused in earlier years. Parks, however, circumvented these requirements by placing the dam under the authority of a swampland district whose operations would not be subject to county approval. On January 3, 1876, Moulton's suit came before Judge Phil Keyser in Colusa. As if to support his case, floodwaters diverted by the dam washed out the levees in another reclamation district and the affected landowners raided Parks Dam in retaliation, destroying a large segment of it. Judge Keyser ruled against reconstruction on the evidence of the damage the dam had already caused, and despite numerous appeals by Parks, this decision was upheld.

CHAPTER 4

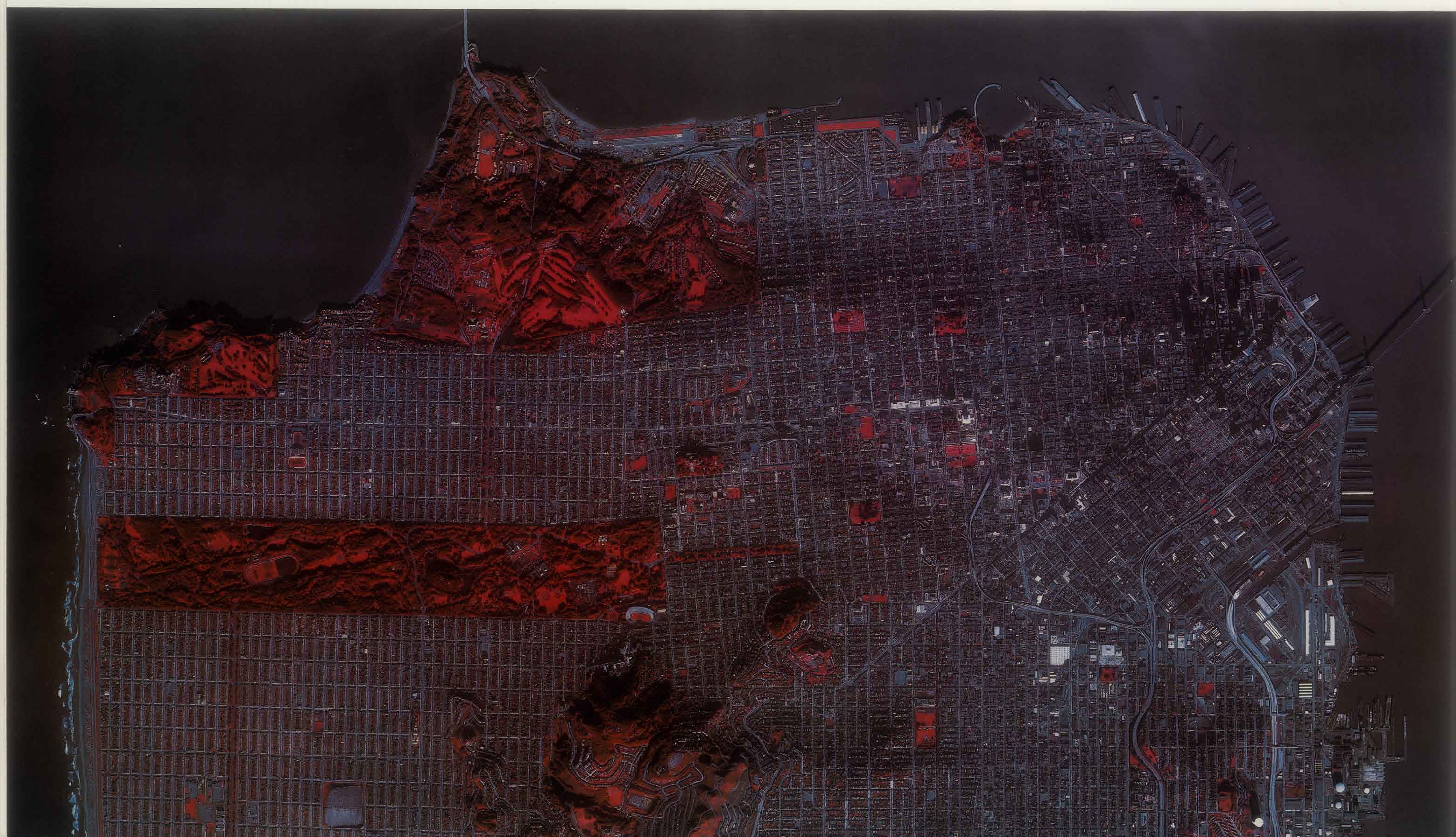
Urban Development and the Rise of Public Control

The most densely populated city in California today derives its water supply almost entirely from external sources. From above, the only evidence of the water delivery system of San Francisco are the great flat roofs enclosing the reservoirs perched high on the slopes of Twin Peaks and Sunset Reservoir south of Golden Gate Park.

In the early days, the patterns of settlement within California followed traditional lines of civilization, centering upon areas of natural water supply. Missions, towns, and villages consequently grew up along the river courses which provided them with the means of life and commerce. The great wave of immigration that followed the discovery of gold in 1849 and the opening of the transcontinental railroad soon after, however, concentrated the centers of human settlement not in areas of abundant natural supply but instead in those regions which lacked a natural endowment of water capable of sustaining large urban populations. The body of law and practice which grew out of the conflict between mining and agriculture in the nineteenth century established a framework for the organization of irrigation districts and the protection of the urban trading centers which served these newly developing agricultural regions. But little attention has been paid to the problem of urban water supply itself. Even the federal Reclamation Act, which did more than any other governmental program to remake the western waterscape, made no provision in its original form for the supply of domestic water needs. By 1900 the spectacular rate of California's population growth had rendered these shortcomings critical, and the problem of urban water supply emerged as the principal obstacle to California's future prosperity in the new century.

The aberration of California's growth away from the areas of natural water supply was in part the consequence of the state's appeal. The great wave of new Californians who began to arrive in the 1850s did not bring with them families to open up the land as had happened in the settlement of the Midwestern and Plains states. They were instead a predominantly male, predominantly young population who came for the gold and the fortunes to be made in the mining camps. Initially, they came from New England and the mid-Atlantic states, and the skills they brought with them were not in husbandry but in trade and merchant shipping. As their hopes of success in the gold camps dwindled and the mines played out, they returned to the great port cities along the coast, not to the inland farms. Despite its success in securing protection for agriculture from the threat of hydraulic mining, Sacramento's rate of growth slowed as the mines closed, while San Francisco's population continued to swell. Even as the great wheat empires formed in the Central Valley, the proportion of California's rural population steadily shrank from 79 percent of the total population in 1860 to 63 percent, 57 percent, and 51 percent in each succeeding decade until 1890. For America as a whole, the long process of transition from a predominantly rural to an urban society extended from the latter half of the nineteenth century to the 1920s; in California, however, the transformation began almost immediately and proceeded with remarkable speed.

Although the flow of new population was initially directed toward the water-abundant areas of Northern California, the opening of the railroads changed all that. From 1860 to 1880, 83 percent of California's population growth continued to concentrate in the



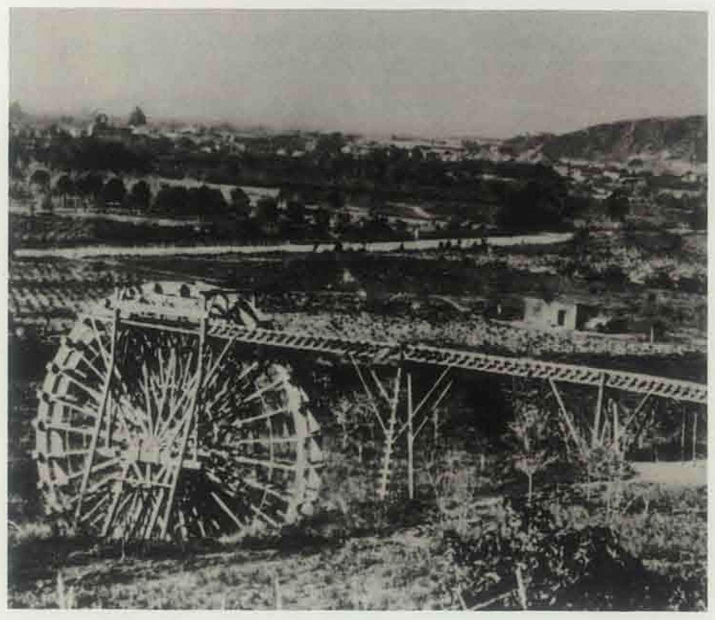
northern sections of the state. An early sign of change, however, occurred in 1870, only one year after the golden spike was driven at Promontory Point, when the rate of growth in Southern California for the first time surpassed that of the north. The opening of the railroad did not bring the immediate prosperity its backers had imagined; rather than opening new markets to California's products, it introduced competition from the East and thereby ushered in a sustained recession for California's economy. But the Southern Pacific had over ten million acres of land to dispose of and it turned its mighty promotional engines to the selling of California. Handbills and pamphlets flooded the eastern states touting the health benefits of life in Southern California and the profits to be made in land speculation. *Sunset* and *Out West* magazines were founded to promote the Mediterranean qualities of the Southern California climate and, in keeping with this theme, new towns sprang up with names like Hesperia, Tarragona, Terracina, and Verona, while San Diego and Long Beach tousled for the opportunity to be identified as the "Naples of California." Land prices in the Los Angeles area spiraled upward for a brief period in the late 1880s but plummeted again before the decade was out. Despite these setbacks, however, despite the bank failures and bread lines that came with the Panic of 1893, the closing of the railroads during the Pullman strike of 1894, and the three years of drought that descended upon Southern California in the mid-1890s, the people kept right on coming. By 1900, 30 percent of the state's population was concentrated in the semi-arid South Coast.

The rapid growth of San Francisco and Los Angeles during the latter decades of the nineteenth century brought both cities up against the limits of their natural water endowment. Continued prosperity could not be assured without an additional source of supply. But neither city possessed in 1900 an organizational structure capable of undertaking the kind of development project required to tap a distant water resource because the business of water supply in both cities was at that time a private, not a municipal, enterprise.

Just as Californians were slow to accept the principles of systematic irrigation, so too did the state lag far behind the rest of the nation by 1900 in the development and distribution of urban water supplies. The first American municipal waterworks system was installed at Bethlehem, Pennsylvania, in 1754. The success of the major municipal systems that were subsequently constructed in Philadelphia and Cincinnati assured that by the middle of the nineteenth century private water systems, with few exceptions, were characteristic only of the smaller cities. California was one of those exceptions. Of the 16 largest cities in the United States in 1860, San Francisco was one of only four that still lacked a municipally owned water system. Los Angeles went still further in 1868, when it leased its entire local water supply for private exploitation, a monopoly which the water company fought vigorously to retain for four years after the expiration of the lease in 1898. The Los Angeles City Council would, in fact, have sold the water supply outright if Mayor Christobal Aquilar had not vetoed the proposal.

Water was not uniquely treated in this regard; virtually the full panoply of utility services—gas, electricity, telephone service, and urban transit—were delivered by private companies in California's cities at the turn of the century. This confidence in the private sector stemmed from a profound faith in the free-enterprise system and an even deeper distrust of politicians. As one Los Angeles city councilman remarked as he prepared to sign over the city's water rights in 1868, "It is well known by past experience that cities and towns can never manage enterprises of that nature as economically as individuals can, and besides, it is a continual source of annoyance." Water, under California's riparian laws, was treated as a private resource, and the success of the water colonies at Pasadena, Anaheim, and elsewhere seemed to offer proof of what private capital could accomplish in the way of community development.

The example of the water colonies, however, had little application to the plight Los Angeles and San Francisco faced in 1900. The colonies' success, after all, involved the development of already-available water resources. But the delivery of a supplemental supply from distant watersheds required capital investments which lay beyond the capacity of any private water company to make. Municipalization of the urban water supply, as a means of securing access to the far greater amounts of capital which government



Hilly terrain and the absence of municipal waterworks made the water carrier at top a common sight in early San Francisco. The flatlands of the south coastal plain, on the other hand, made the water wheel below the principal method of delivering water to residents of Los Angeles for many years after its construction in 1859. The wheel lifted water from the Los Angeles River to a sufficient height to enable it to flow by gravity into the city.

can raise through taxation and bond sales, thus came to be regarded as the essential first step toward the development of a water supply sufficient to sustain the dreams of Northern and Southern California's city builders. The movement toward municipalization in San Francisco and Los Angeles was not founded on politically partisan principles or an early urge toward progressive reform. Instead, it rapidly attained the standing of a principle above politics which promised better service and lower rates, and assured continued prosperity for all. Thus, San Francisco and Los Angeles, confronting a common problem but acting independently and exclusively in their own interests, began a process of water development through massive public projects which would eventually remake the entire California waterscape.

HETCH HETCHY

The first decade of the twentieth century was a time of reform throughout the United States, a movement which blended an earlier generation's quest for opportunity and the new age's preoccupation with efficiency. In California especially, problems of land and resource management became the focus of reformers' efforts to overhaul city and state government and guard the public interest against exploitation by private interests. While Los Angeles, traditionally a business-oriented city, was establishing total municipal ownership of its water supply system, San Francisco, by reputation a more liberal community, approached the question of public ownership with hesitation.

Ever since the 1860s the bulk of San Francisco's water supply had been provided by a private corporation, the Spring Valley Water Company. When William Chapman Ralston, elegant founder of the Bank of California, offered to sell the company to the city in 1875 in an effort to save his toppling financial empire, San Francisco rejected the notion. From that time forward, the company worked resolutely to continue expanding its system to meet the steadily increasing needs of the Bay Area. When the city's water planners proposed the purchase of Calaveras Valley in southern Alameda County as a future source of the city's supply, for example, Spring Valley rapidly bought up the area to head off any renewed threat of municipal ownership. By the turn of the century, the company was delivering water to the city from wells near Pleasanton and from the Sunol and Alameda Creek watersheds through a pipeline running around the southern end of the Bay and up the Peninsula.

By 1900, however, the city's population was approaching 350,000 and that total was expected to triple within the next 50 years. The new city charter that year therefore directed San Francisco's public officials to plan for a public water supply system capable of meeting these future needs, not to replace but to supplement the Spring Valley system. Surveys conducted over the preceding 20 years had identified 14 new water sources the city might consider in distant watersheds ranging from Plumas to Mariposa. But the city engineer, Marsden Manson, considered the Tuolumne superior to all the rest. If the Hetch Hetchy Valley and neighboring Lake Eleanor were used to store the waters of the Tuolumne River, he told the city government, a system could be built for $70 million that would deliver 60 million gallons a day through pipelines to the city's reservoir nearly 160 miles away. Moreover, the fall of water from the ruggedly beautiful Hetch Hetchy Valley at an elevation of 3,800 feet down to the San Joaquin foothills could be used to generate electric power for the city. Best of all, because Hetch Hetchy lay within the public domain as part of Yosemite National Park, its water supply could be secured at virtually no cost.

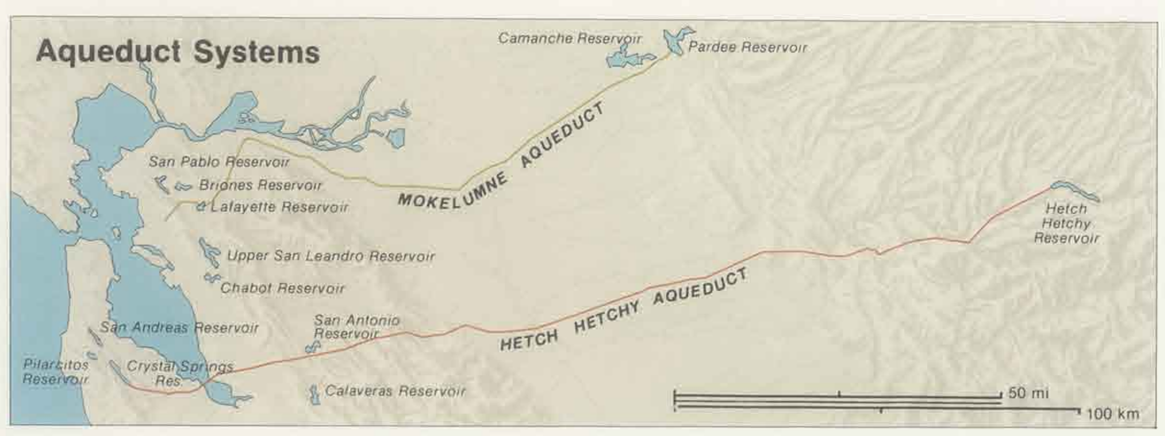
The practicality of Manson's recommendation seemed assured when Congress passed the Right of Way Act in 1901, authorizing the Secretary of the Interior to grant public access to federal reserved lands in the state, including Yosemite. But the Secretary of the Interior, Ethan A. Hitchcock, rejected San Francisco's application for access to the Hetch Hetchy in 1903, arguing that several alternative sites—many of them much closer to the city—could be used instead. The area was at this time the focus of national attention as a result of John Muir's long campaign to preserve the Yosemite Valley, only 20 miles southeast of Hetch Hetchy, by convincing the state to cede title to the valley to the federal government. Two years later, Muir's larger cause triumphed when the entire park was placed under Interior's jurisdiction. But by then the resource policies of President Theodore Roosevelt's administration were being shaped by Chief Forester Gifford Pinchot.

The controversy over San Francisco's plans for the Hetch Hetchy set the two wings of America's nascent conservation movement against one another. To Muir, founder of the Sierra Club and defender of the High Sierra, San Francisco's proposal was anathema. "Dam Hetch Hetchy?" he exclaimed. "As well dam for water tanks the people's cathedrals and churches; for no holier temple has ever been consecrated to the heart of man." As an advocate of planned, regulated use of the resources in the public domain, however, Pinchot was a utilitarian, not a preservationist like Muir. "I feel very strongly that San Francisco must have an adequate water supply," he told the Sierra Club. Hitchcock's decision on the city's application, he decided, "entirely failed to meet the needs of the situation." The prospects for the eventual triumph of Pinchot's belief and San Francisco's plan improved markedly when Hitchcock was replaced in 1907 by Pinchot's close friend and ally, James R. Garfield.

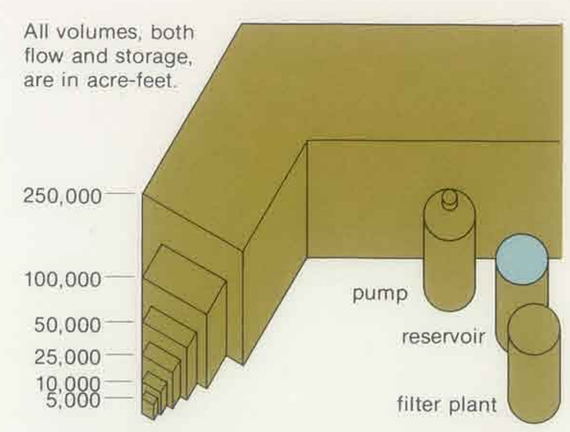
By this time, however, San Francisco's enthusiasm for the project had begun to cool. The earthquake of 1906 ruptured the Spring Valley pipeline, leaving the city with an inadequate water supply to fight the fires that swept the city. While this experience underscored the urgency of San Francisco's need for an expanded water supply, the Hetch Hetchy project seemed to be a tremendously difficult engineering task which would create a great drain on public finances already overextended to meet the costs of rebuilding the city. Moreover, San Francisco's application had come under attack not only by environmental preservationists but also by the Modesto and Turlock Irrigation Districts, which claimed prior rights to the waters of the Tuolumne. When William Tevis of the Bay Cities Water Company stepped forward in the aftermath of the earthquake with an offer to build an alternative system to the watersheds of the American and Cosumnes rivers near Lake Tahoe for only $10.5 million, the San Francisco supervisors approved the plan without hesitation. Tevis' plan, however, collapsed the next year amidst charges that one million dollars of the project's cost would be used for kickbacks to the supervisors, the mayor, and to the city's political boss, Abraham Ruef. So chastened, the city turned once again to the Hetch Hetchy.

Northern California Urban Delivery Systems

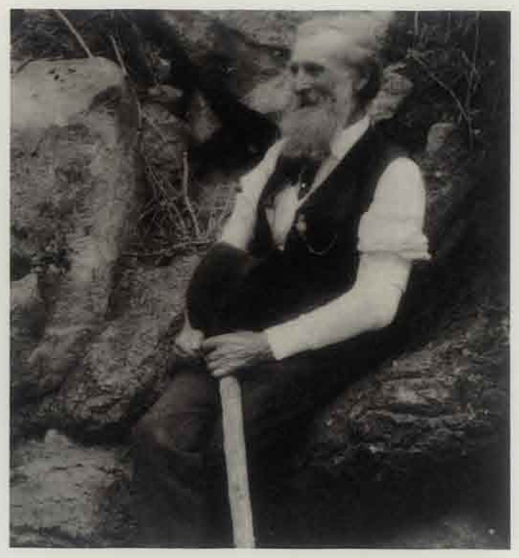
This graphic compares the flows, capacities and overall operation of the cross-country delivery systems of the San Francisco Water Department and the East Bay Municipal Utility District during fiscal year 1975. East Bay MUD draws 92 percent of its supplies from the Mokelumne River. Pardee Dam retains water for use by East Bay MUD while Camanche Reservoir conserves water for the protection of downstream riparian rights. The Tuolumne River provides 86 percent of the water San Francisco distributes to meet its own needs and those of over 50 communities, water agencies and private concerns in the Bay Area.



All volumes, both flow and storage, are in acre-feet.



Cross sections of the water conduits on the diagram are directly proportional to the flow through them in fiscal year 1975. Diagrammatic reservoirs, however, are not scaled by capacity, nor are other point facilities. Flow volumes in **boldface type** are reported values, medium type represents inferred values. Dashed paths represent no flow in fiscal year 1975.



John Muir's last and least successful battle was fought for the Hetch Hetchy Valley. Muir is shown here with views of the valley before and after it was flooded in 1923 to provide a water supply for San Francisco. In the valley photographs, Tueeulala and the lower Wapama falls can be seen cascading down the north wall of Tuolumne Canyon.

At Pinchot's urging and with President Roosevelt's endorsement, Garfield approved San Francisco's application in 1908. He required, however, that San Francisco's voters support the cost of initial construction and that the work not be delayed. Preservationists were shocked by the decision; the Roosevelt men, they grumbled, were obviously angling for political support from California. But Muir's associates had admittedly been "inexact dreamers" whose arguments about beauty and precedent could not even convince all members of the Sierra Club, not to speak of the diverse interests of the city. Commercial organizations warned that by 1950 San Francisco's per capita water consumption would go from 87 gallons to 130 gallons a day (a level not actually reached until the 1960s). They also promoted the project with claims that it would eliminate mosquito breeding grounds and prevent typhoid epidemics, feats which then enjoyed popular currency in connection with the Panama Canal project. With Garfield's approval secured, voters in 1908 approved a $600,000 bond issue and the city's attorneys set about acquiring rights of way along the proposed aqueduct from the river valley.

The advent of William Howard Taft's administration in Washington, however, set Pinchot at odds with the new Secretary of the Interior, Richard Ballinger. Ballinger visited Yosemite with members of the Sierra Club in 1909 and then suspended his predecessor's approval of the use of Hetch Hetchy. The Secretary ordered the city to demonstrate the insufficiency of all other alternative water supply sites. His successor, Walter Fisher, extended the deadline for decision to 1912, but then concluded as he left office that the Right of Way Act gave no clear authorization for granting such use of the national park.

Despite these uncertainties, San Francisco's officials pushed forward with land purchases and planning for transportation routes into the Hetch Hetchy. Their cause was substantially boosted when a 1912 report demonstrated that three reservoir dams in the Hetch Hetchy area could impound enough water to meet every estimated municipal need without impairing the irrigation requirements of the Modesto and Turlock districts. Realizing at last that no administrative permit could assure the permanent approval San Francisco required, the city focused its efforts upon obtaining statutory authority for the Hetch Hetchy project. Although Muir was resolute in his opposition and sought to block Congressional approval with pamphlets and circulars "in a country wide storm thick as snowflakes," Muir's publicity was no match for what President Woodrow Wilson described as "pressing public needs." And, while California Senator John D. Works complained that San Francisco's water project would wind up costing the public $100 million, his warnings were rejected because he came from Los Angeles. San Francisco's ultimate victory, however, can perhaps be ascribed to one single factor. For, both Congress and the President relied upon the recommendations presented by Wilson's new Secretary of the Interior, Franklin K. Lane, a former city attorney of San Francisco who had written many of the briefs in the city's long battle for the project.

The legislation authorizing the Hetch Hetchy project, known as the Raker Act for its author Congressman John E. Raker, attempted to satisfy all the contending interests in the controversy. To appease the preservationists, it compelled the city to construct scenic roads and trails in Yosemite National Park and donate them to the United States. To mollify the concerns of irrigationists in the Turlock and Modesto areas, it extended recognition of their rights, assured their deliveries, and prohibited San Francisco from diverting any more water from the San Joaquin Valley than could be used for its own domestic or municipal purposes. To protect the interests of the Spring Valley Water Company, it required San Francisco to use all local supplies before any water could be taken from the Tuolumne. And, to assure the fiscal stability of the project, it directed the city to begin work immediately and to include within the project a hydroelectric power system for municipal and commercial use, provided that no water or power from this public project could ever be sold or given to a private interest for resale.

This last provision proved to be a point of continuing controversy because the prospect of public power development by the City of San Francisco posed an immediate threat to the consortium of private utility companies newly formed in the Pacific Gas and Electric Company. Although construction began in 1914, progress on the tunnels that had to be drilled was slow and the funding soon proved inadequate. Storage of water at Lake Eleanor started in 1918 but it took five more years to erect O'Shaughnessy Dam at Hetch Hetchy. By this time some San Franciscans had begun referring to the city engineer, M. M. O'Shaughnessy, as "More Money" O'Shaughnessy.

In order to stretch its financing as far as possible and reduce the burden on San Francisco's taxpayers for the payment of interest and redemption charges on the bonds for the project, the city decided to concentrate first on the revenue-producing aspects of the project, specifically the development of power-generating facilities. Recalling the prominent role played by PG&E in the investigation of municipal corruption under Boss Ruef, some thought it a little too neat when the city announced it had run out of funds for the construction of transmission lines just as the project reached PG&E's transmission facilities at Newark in 1924. The San Francisco supervisors, however, promptly granted PG&E a contract to wheel the Hetch Hetchy power to Bay Area communities. Since PG&E paid San Francisco $2.4 million for power it then sold at retail for $9 million, longtime supporters of the Hetch Hetchy system strongly objected to the contract as a violation of the Raker Act's prohibition against sales to private entities and as an alienation of property the city had paid for. Others thought the arrangement economical and convenient: the company, they argued, was no more than an agent for the city. Ray Lyman Wilbur, another Californian in the Interior secretaryship, ignored objections to the contract, and San Francisco's Mayor James Rolph, soon to be governor, supported it.

The controversy, however, continued to simmer as the project moved forward with repeated injections of new funding. In 1928 city voters approved an additional $24 million in bonds by a wide margin. In 1930 they approved an expenditure of another $41 million to buy out the Spring Valley Water Company. Further funds to complete O'Shaughnessy Dam and construct hyrdoelectric power stations were passed in the early 1930s despite the Depression. But in a series of eight political campaigns between 1927 and 1941, the voters of San Francisco repeatedly refused either to buy out PG&E's distribution system or pay for the construction on their own.

In the political climate of the New Deal, with its abhorrence for business domination of public interests, PG&E's critics presented their objections to Franklin Roosevelt's Secretary of the Interior, Harold L. Ickes. A strong advocate of public power, the secretary ruled in 1935 that San Francisco's contract violated the terms of the Raker Act. After he ordered the city to establish its own power distribution system, San Francisco tried twice to develop a plan Ickes would accept. Even after Ickes approved a plan, the city's voters twice failed to support the $50 million bond issue it would have required. When the federal government won a suit enabling Interior to ban sale of Hetch Hetchy power to PG&E, Ickes found it necessary to suspend full enforcement of the limitation until the city established an alternative to the private monopoly. City voters, however, again refused to support a $66.5 million bond issue to pay for a municipal system. Two attempts to amend the Raker Act failed and in 1942 wartime exigencies finally convinced the federal government to confirm a new contract between the city and PG&E.

Water from Hetch Hetchy began flowing to San Francisco in 1934. As Senator Works had predicted, the project wound up costing $100 million. But as the city engineers had promised, the supply was sufficient to meet the city's needs while at the same time providing a surplus for sale to more than a dozen Bay Area communities. The revenues from these sales in turn provided funds for the continued expansion of the system. In 1939, the city began the development of additional storage and power-generating facilities in the Cherry Valley. The Modesto and Turlock Irrigation Districts joined San Francisco in this project, which provides flood control as well as increased supplies of water and power for all. As a further part of this cooperative effort, the voters of San Francisco in 1961 over whelmingly approved a $115 million water bond issue, of which $45 million went to pay the city's share of the costs of constructing the 580-foot Don Pedro Dam. The completion of this project, in turn, has substantially reduced PG&E's role in wheeling power for the City of San Francisco.

The modern San Francisco water system delivers nearly six times as much water as the original Hetch Hetchy project. Federal funds constitute only about two percent of the more than $500 million invested in the system. San Francisco sells over half of its water supplies to suburban communities in San Mateo, Santa Clara, and Alameda counties. In addition to the $14 million these water sales generate each year, the city earns gross revenues of $18.6 million from its sale of electrical power. The project has thus more than repaid its costs and it has assumed an importance as a source of funding for the city which is at least as great as the value of the water it provides.

THE LOS ANGELES WATER SYSTEM

While San Francisco's Hetch Hetchy project labored forward, Los Angeles, starting at the same time, built its own system to a watershed adjoining the Hetch Hetchy, a project half again as long and nearly six times as large as San Francisco's in a fifth the length of time it took San Francisco and for only a quarter of the cost. The completion of this system, which carries water from the Owens Valley 233 miles south to the San Fernando Valley, laid the basis for the modern South Coast metropolis and helped to assure Los Angeles' success in the race with San Francisco for primacy among California's urban centers.

Los Angeles' success in this enterprise can be attributed to at least three principal advantages it

WILLIAM MULHOLLAND

When asked once in court to describe his qualifications as an expert on water engineering, William Mulholland responded, "Well, I went to school in Ireland when I was a boy, learned the three R's, and the Ten Commandments—or most of them—made a pilgrimage to the Blarney Stone, received my father's blessing, and here I am." From this uncertain background, Mulholland rose to become at one point the highest paid public official in California and for nearly half a century the personal embodiment of Los Angeles' water policy.

Born in 1855, Mulholland landed in New York in 1874 as a journeyman sailor. After knocking about in the dry goods business and the lumber camps of Michigan for two years, he set to sea again on the way to California. After an unsuccessful stab at prospecting, Mulholland settled in Los Angeles in 1878, where he took a job as a ditch tender for the Los Angeles Water Company. An earlier experience as a laborer on a well-drilling rig had set the course of his career in water. "When we were down about six hundred feet we struck a tree," he recalled. "A little further we got fossil remains and these things fired my curiosity. I wanted to know how they got there, so I got hold of Joseph Le Conte's book on the geology of this country. Right there I decided to become an engineer."

Blessed with a natural flair for mathematics and a phenomenal memory, Mulholland rose rapidly through the ranks of the Los Angeles Water Company to become its superintendent in 1886. When the city bought out the company in 1902, Mulholland remained in charge, in part because the city had found that as a result of his profound distaste for paperwork, the only records the city had of the distribution system it had acquired were those Mulholland carried in his head.

His managerial skill and the stunning success of his aqueduct to the Owens Valley quickly gained him the affection of the city and confirmed the confidence the public had placed in his abilities. To the progressive reformers of the period, Mulholland stood "as an example of what the applied scientist can do for his state when he holds his brief for the people." Mulholland, however, always held himself apart from politics. When pressed to run for public office after the opening of the aqueduct had assured his fame, Mulholland responded, "I would rather give birth to a porcupine backwards than be Mayor of Los Angeles." Instead, he pursued the cause of public water development, serving as a consulting engineer to water projects for Sacramento, San Francisco, Oakland, Seattle, and the State of California while at the same time continuing his management of the Los Angeles water supply.

The high esteem in which he was held, however, began to decline after 1920 as relations between Los Angeles and Owens Valley worsened. His prominence as the principal exponent of Los Angeles' water policy cast him as the villain in the Owens Valley. Events in the Owens Valley thus worked to stiffen resistance to Muholland's drive to tap the Colorado through the formation of the Metropolitan Water District. His career came to an abrupt and tragic end with the collapse of the Saint Francis Dam on the night of March 13, 1928. Mulholland had personally inspected the dam and declared it safe on the morning before it fell. To his credit, he accepted complete personal responsibility for the hundreds of lives lost and millions of dollars of damage done by this unnatural disaster. His reputation irretrievably lost, he resigned only a month before President Calvin Coolidge signed the legislation creating the Boulder Canyon Project for the city he had served so long.

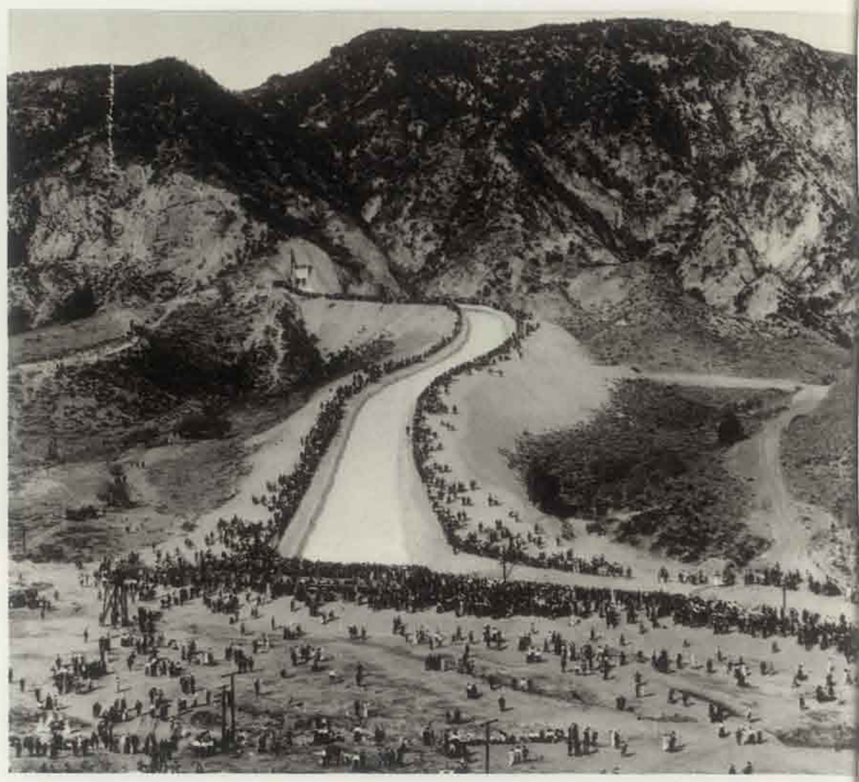
enjoyed over San Francisco in the development of a distant water supply. In the first place, whereas the Hetch Hetchy project stalled time and again while the city sought additional funds to cover its escalating costs, Los Angeles appropriated all of the money required for its project at the outset through two bond issues which stretched the city's permissible indebtedness to the limit. The first of these issues, for $1.5 million in 1905, covered the cost of surveys, planning, and initial land acquisitions; the second, for $23 million in 1907, went to pay for the actual construction of the aqueduct. The voters of Los Angeles were making a desperate gamble: failure of the project could have placed the entire city in receivership, and the head of the city's newly municipalized water system, William Mulholland, had no formal training as an engineer and had never constructed a waterworks system of the size proposed for the aqueduct.

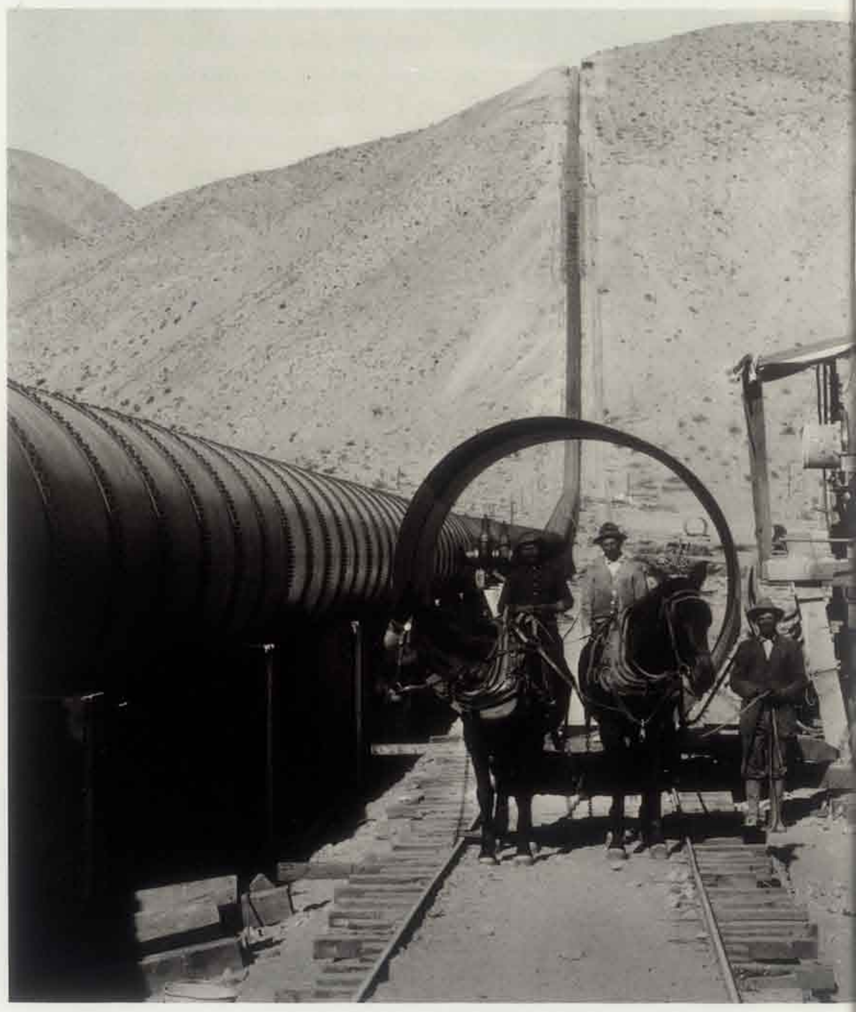
Mulholland had, however, directed the activities of the private company which owned the lease on Los Angeles' water supply before the turn of the century, and when the city bought out the company's distribution system in 1902, Mulholland made the conversion from the private to the public sector with a vengeance. In his first three years as head of the municipal system, he rebuilt the outmoded distribution network, cut the rates for domestic service in half, turned a profit for the city of $640,000, and, in the third year, announced his plan for the Owens Valley aqueduct. Once begun, Mulholland declared that the project should be "public owned from one end to the other." Municipal crews built all but 11 miles of the canal and a quarter-mile of the tunnels, using municipal cement and municipal power, a policy which Mulholland estimated would save the city 20 percent of the cost of private contractors. Mulholland also set quotas for the progress of his work crews and paid bonuses when the quotas were exceeded. As a result, the project raced forward, setting records for drilling all along the way and finishing ahead of schedule and under budget.

Los Angeles' second great advantage was that it did not have to contend with the Pacific Gas and Electric Company, which worked so effectively to block efforts by San Francisco and the federal government to assure that the Hetch Hetchy project would be entirely public. In place of the unified strength of the many corporations joined under PG&E's banner, Los Angeles only had to deal with three power companies which had divided the city's distribution markets among themselves. Although the power companies fought bitterly for the right to distribute electricity from the aqueduct within Los Angeles and succeeded temporarily in disrupting the financing of the project by undermining the market for the city's bonds, Los Angeles absorbed their systems one by one, making itself in the process the largest municipal electric utility in the nation. Electrical power, however, was not the original purpose of the project, only a profitable by-product.

Opposition to the bond election for the aqueduct, in fact, centered not upon the question of public versus private ownership but instead upon charges of municipal corruption during the planning of the project. In the midst of the 1905 bond election, the Hearst press revealed the existence of a syndicate of investors who stood to profit fabulously when the aqueduct delivered water to their vast but heretofore arid holdings in the San Fernando Valley. Headed by Henry Huntington, the region's foremost financier, the syndicate included not only a brace of Huntington's associates in the railroad, banking, and power industries but also the publishers of three of the city's most prominent newspapers, the *Times, Herald,* and *Express*. Although critics charged that the project was being promoted principally for the profit of these wealthy financiers, the existence of the syndicate was apparently irrelevant to most of the voters of Los Angeles. And the prospect that certain private interests would profit personally from the city's water project did little to discourage support for a proposal which the voters believed would bring prosperity for all.

Finally, and perhaps most important, unlike San Francisco which saw its project repeatedly delayed for further studies of the alternative water supplies it could tap instead of the Hetch Hetchy, Los Angeles had no choices available to it. Mulholland warned the voters that Los Angeles' local supply could not support a city larger than 200,000 people. Although Mulholland clearly understated the limits of the local supply during the heat of the election, his essential point was correct. For the Owens Valley aqueduct, like the Hetch Hetchy project, was built not to serve actual and immediate needs but instead to serve the prospective demands of a greatly increased future population. Although the city surveyed the prospects for drawing additional supplies from nearby watersheds on Piru Creek in Ventura County and the Kern, Santa Ana, Mojave, and San Luis Rey rivers, all were tied down by pre-existing claims and none could guarantee the kind of supply available in the Owens Valley, which Mulholland declared was capable of supporting a city of two million.





"There it is. Take it," Mulholland told his audience as the first water from the Owens Valley arrived in the scene pictured above. Also shown, construction along the line of the aqueduct.

The aqueduct opened November 5, 1913, and immediately began delivering four times as much water as the City of Los Angeles was then capable of consuming for domestic purposes. The city's ability to dispose of this surplus, however, was severely restricted. In response to charges concerning the land syndicate's role in planning for the project's development, President Theodore Roosevelt had attempted to assure that water from this public enterprise would not be used to benefit the syndicate's holdings in the San Fernando Valley. As a condition for his approval of the aqueduct's right of way in 1906, Roosevelt therefore stipulated that no water from the aqueduct should ever be offered to any private interest for resale as irrigation water outside the city limits.

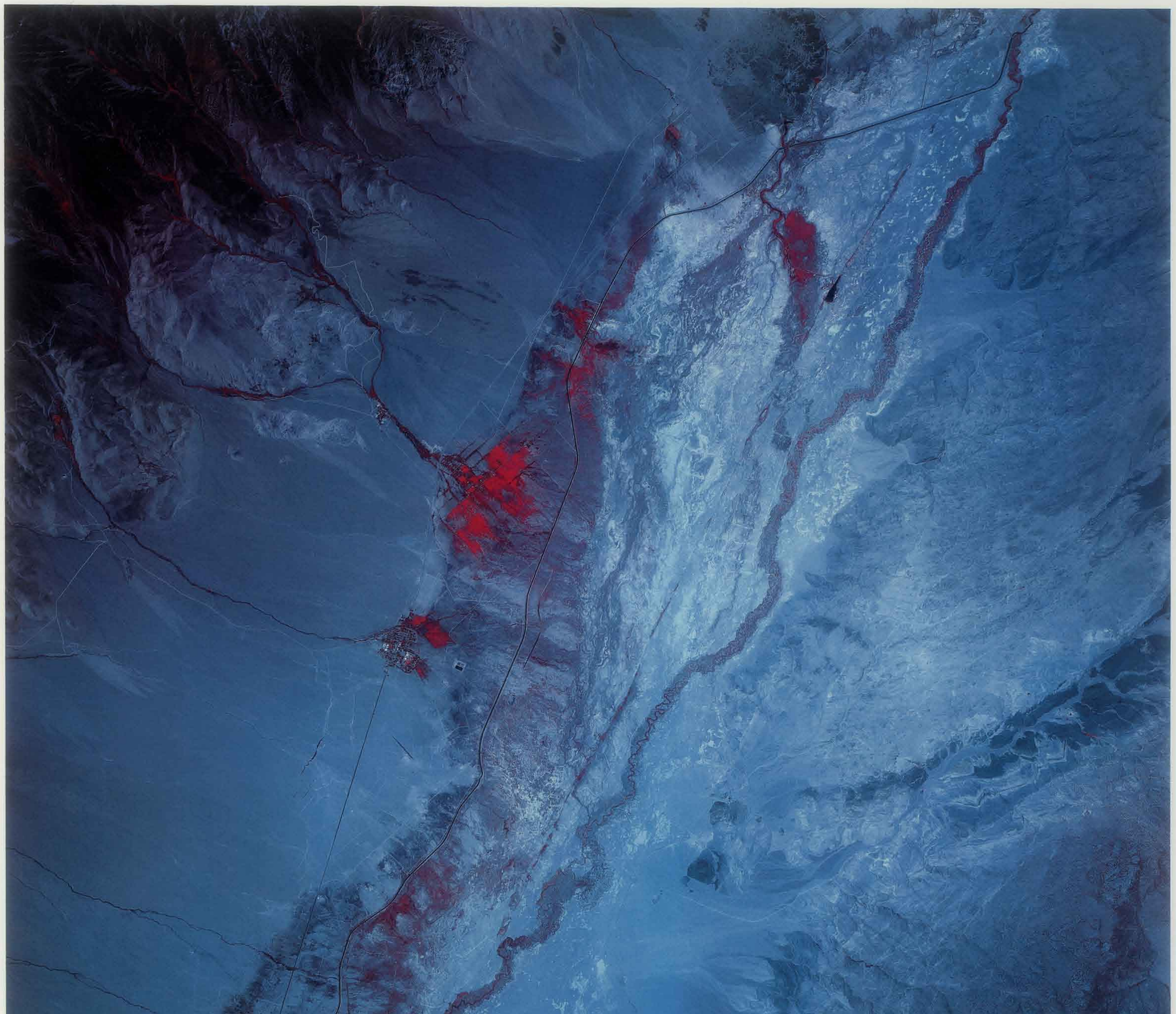
The city responded to these restrictions by rapidly extending its boundaries as a way of applying its surplus. Between 1914 and 1923, Los Angeles initiated a series of annexations which nearly quadrupled its land area and eventually embraced all of the syndicate's holdings. Once annexed by Los Angeles, the barren tracts of the San Fernando Valley blossomed into citrus groves, beans, and potato fields, and the aqueduct, as an urban water development project, functioned for its first years of operation principally for the benefit of agriculture. With the opening of the Panama Canal in 1914, however, Los Angeles began to establish itself as the principal port and commercial center of the West Coast. The end of World War One brought a flood of new immigrants to the city at the rate of 100,000 per year. Overall, between 1900 and 1920, the population of the Los Angeles metropolitan area quintupled, while that of the San Francisco Bay Area did not quite double, with the result that the two regions had drawn equal in size by 1920.

The aqueduct project did not operate entirely without controversy. In contrast to San Francisco, which found its new water supply in an unpopulated watershed within the public domain, Los Angeles had to purchase its water rights and the lands that went with them from the agricultural communities of the Owens Valley. When Mulholland first toured the Owens Valley in 1904, the area was already under investigation by the newly created federal Reclamation Service as the prospective site for a systematic irrigation project which would have doubled the acreage then in agricultural production within the valley. When Los Angeles declared its own interest in the region, the Reclamation Service withdrew, in part at the urging of its Chief of Southwest Operations, Joseph B. Lippincott, a loyal Angeleno who resigned to take a high position on Mulholland's staff after it was revealed that he had been under contract to Los Angeles while drawing his federal salary. When the residents of the Owens Valley protested the actions of the Reclamation Service and the City of Los Angeles, President Roosevelt reviewed their claims at the time that he considered whether to grant a right of way for the aqueduct. Roosevelt, however, resolved the question in Los Angeles' favor, arguing, "It is a hundred or a thousand fold more important to state that this [water] is more valuable to the people as a whole if used by the city than if used by the people of the Owens Valley."

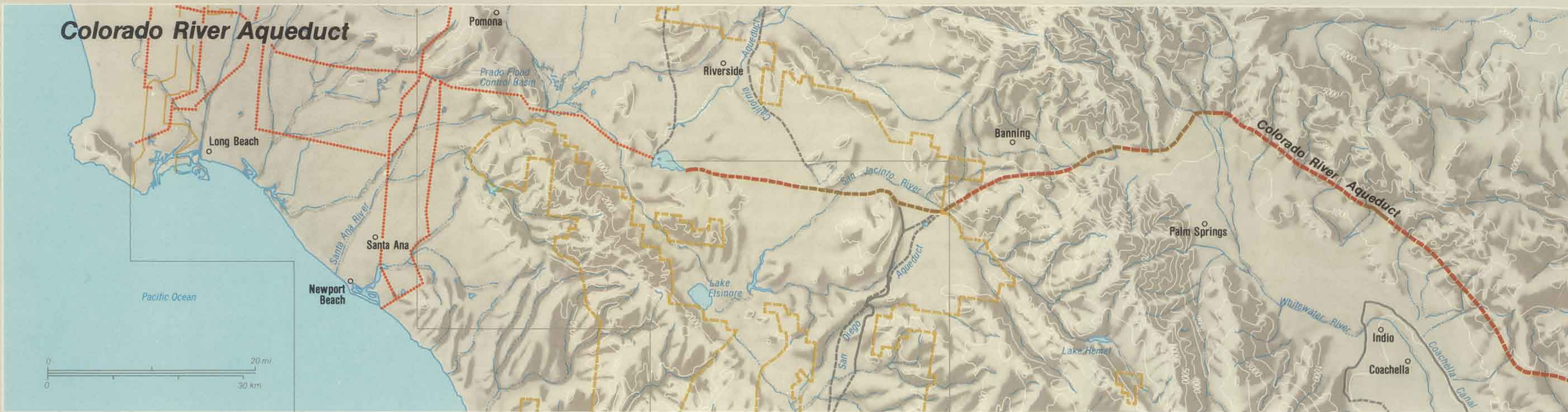
At first, Los Angeles' water exports did not interfere with agricultural productivity in the Owens Valley because the point of intake for the aqueduct lay downstream from the valley's irrigation systems. Moreover, the prosperity of the valley was enhanced by the business activity associated with the construction of the aqueduct and by the extension of a railroad line to service the aqueduct which opened Los Angeles markets, for the first time, to the valley's products. For a time, the valley and the city flourished together.

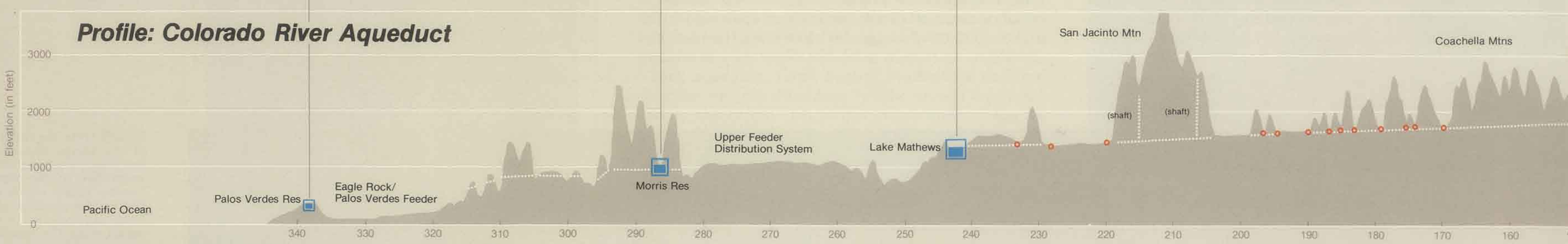
As Los Angeles' population growth, however, rapidly outran all of the predictions upon which the construction of the aqueduct had been founded, the city began to expand its water exports by extending its land acquisitions steadily northward into the heart of the valley's principal agricultural regions. Fearing that their homes and the future of their region as an agricultural area were threatened, the ranchers and businessmen of the Owens Valley banded together during the 1920s in an effort to extract from the city the highest prices they could for their lands. When the city resisted, the aqueduct was repeatedly blown up and at one point, in 1924, the aqueduct's principal diversion works at Alabama Gates were seized by an angry mob of valley ranchers. In the end, Los Angeles wound up purchasing virtually all of the private lands in the Owens Valley not already held by the federal government, thereby creating the anomalous situation by which one public entity, the City of Los Angeles, has become the principal landowner and taxpayer for another public entity, the County of Inyo. Since the 1930s, Los Angeles has exercised its control over more than 300,000 acres of the Inyo and Mono basins to transform the region from an agricultural area into a major recreational resource for the people of the South Coast.

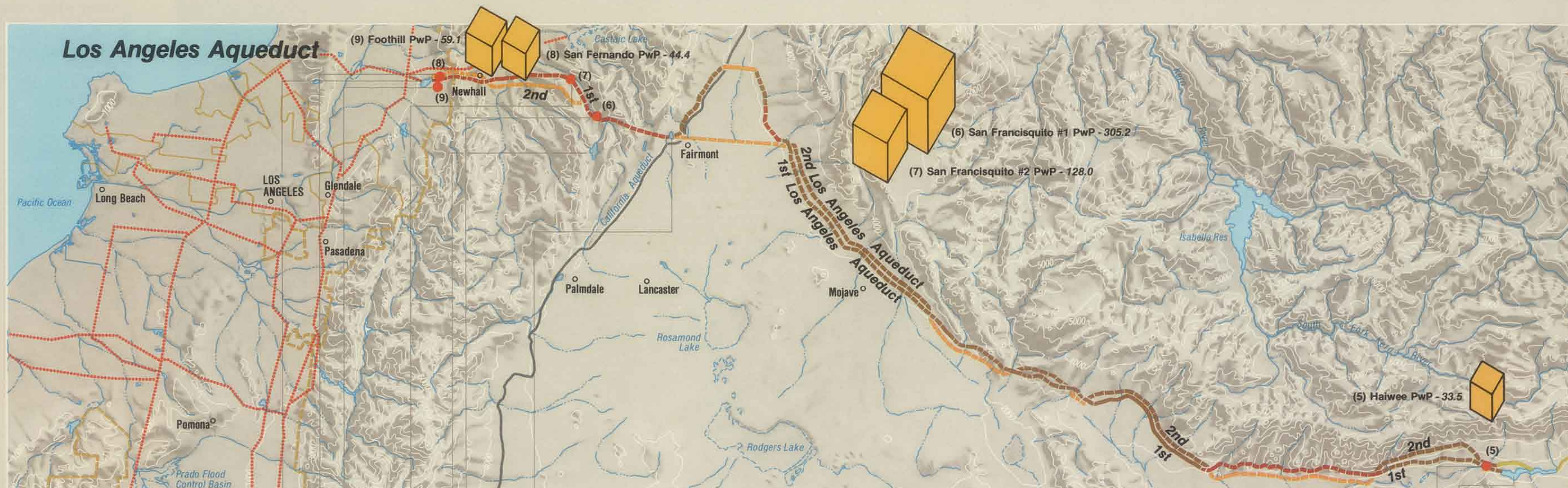
The acute pressure of its population growth, coupled with a severe drought which descended on Southern California in the mid-1920s, forced Los Angeles to begin looking for new sources of water within only ten years of the completion of the aqueduct. In 1924, Los Angeles filed applications with the federal government for 1.1 million acre-feet from the

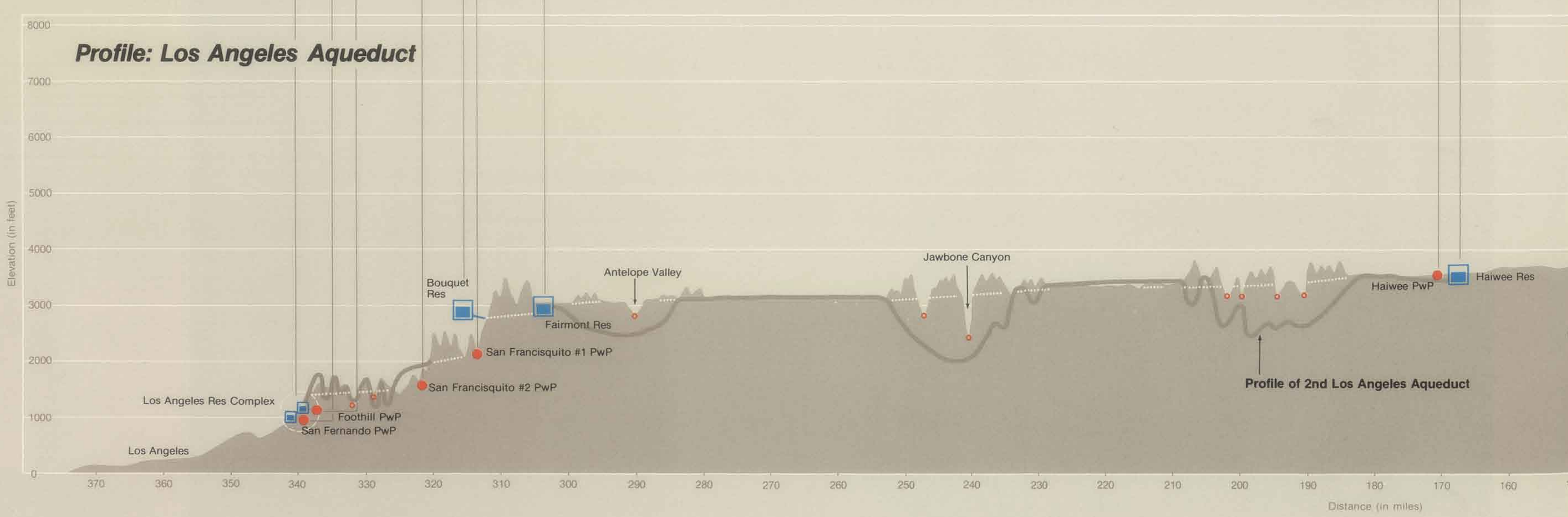


Runoff from the melting snows of the Sierra Nevada provides the principal source of water for vegetation in the areas of the Owens Valley which appear as red in the photograph at left. From its headgates in the upper right corner, the aqueduct traces a course which roughly parallels that of the Owens River to the east. Independence is near the middle of the photograph and a fault trace can be seen between the river and the aqueduct.

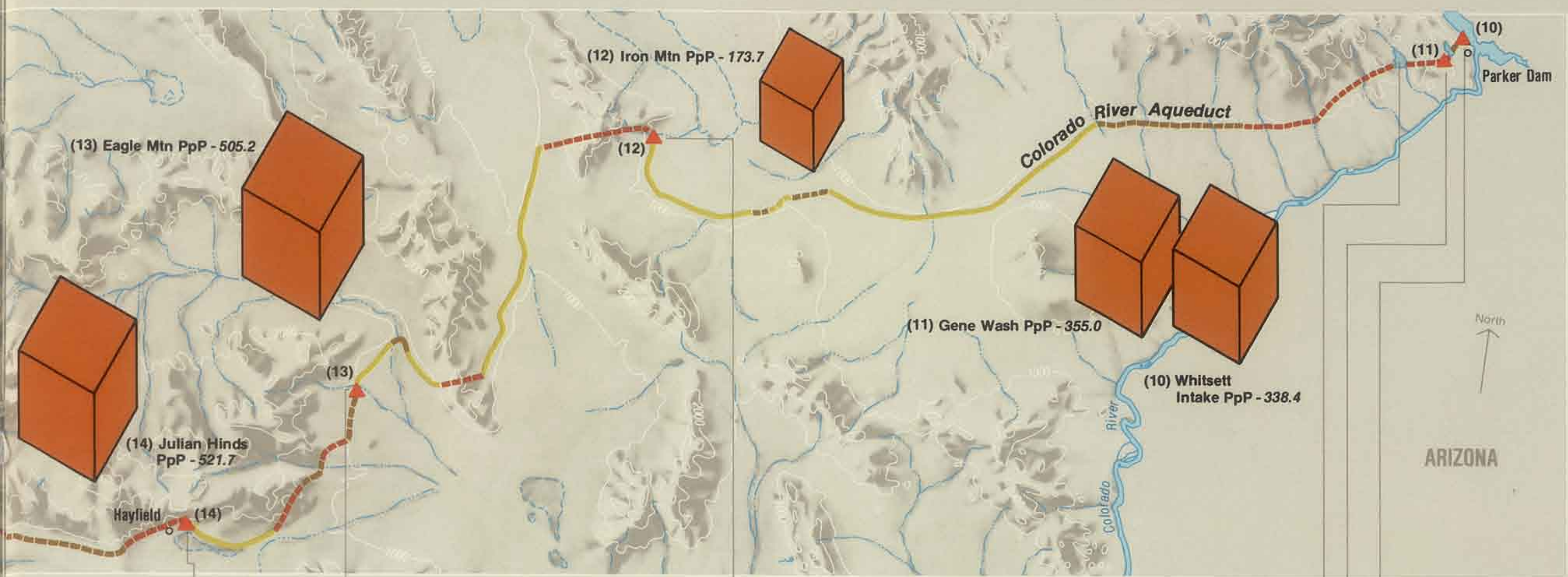

Colorado River Aqueduct
Pomona
Prado Flood Control Basin
Riverside
California Aqueduct
Long Beach
Banning
San Jacinto River
Colorado River Aqueduct
Santa Ana River
Santa Ana
Palm Springs
Newport Beach
Pacific Ocean
Lake Elsinore
Aqueduct
San Diego
Whitewater River
Indio
Coachella
Lake Hemet
Coachella Canal
0
20 mi
0
30 km

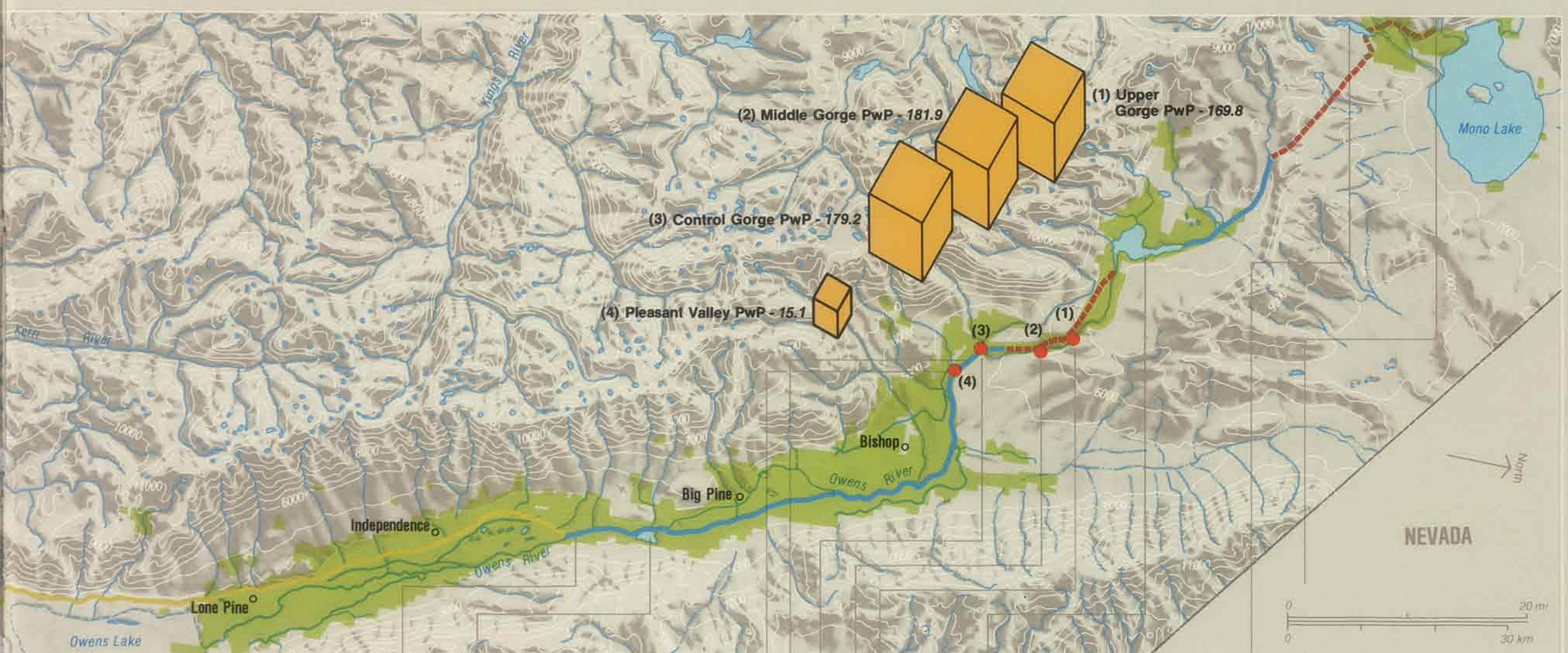

Profile: Colorado River Aqueduct
Elevation (in feet)
3000
2000
1000
0
San Jacinto Mtn
Coachella Mtns
(shaft)
(shaft)
Upper Feeder Distribution System
Lake Mathews
Morris Res
Eagle Rock/ Palos Verdes Feeder
Palos Verdes Res
Pacific Ocean
340
330
320
310
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160

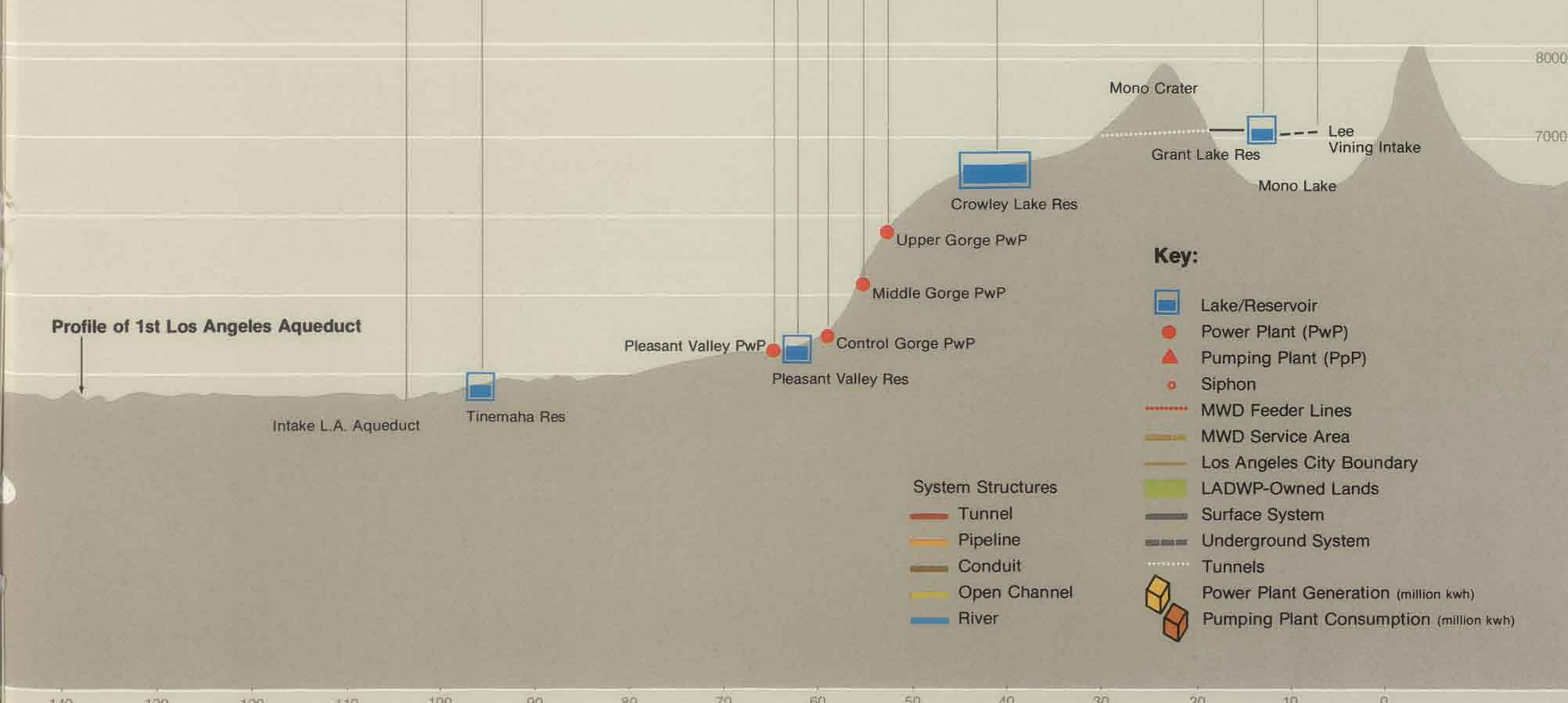

Los Angeles Aqueduct
(9) Foothill PwP - 59.1
(8) San Fernando PwP - 44.4
Castaic Lake
(8)
(9)
Newhall
2nd
(7)
1st
(6)
Fairmont
(6) San Francisquito #1 PwP - 305.2
(7) San Francisquito #2 PwP - 128.0
2nd Los Angeles Aqueduct
1st Los Angeles Aqueduct
Pacific Ocean
Long Beach
LOS ANGELES
Glendale
Pasadena
California Aqueduct
Palmdale
Lancaster
Mojave
Rosamond Lake
Isabella Res
(5) Haiwee PwP - 33.5
Pomona
Rodgers Lake
Prado Flood Control Basin
2nd
1st
2nd
1st
(5)


Profile: Los Angeles Aqueduct
Elevation (in feet)
8000
7000
6000
5000
4000
3000
2000
1000
0
Jawbone Canyon
Antelope Valley
Bouquet Res
Fairmont Res
San Francisquito #1 PwP
San Francisquito #2 PwP
Haiwee PwP
Haiwee Res
Profile of 2nd Los Angeles Aqueduct
Los Angeles Res Complex
Foothill PwP
San Fernando PwP
Los Angeles
370
360
350
340
330
320
310
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
Distance (in miles)

Southern California Urban Delivery Systems







Topography is a major factor in distinguishing the operations of the interbasin delivery systems serving Southern California's urban population. As a gravity-fed, passive delivery system, water flowing through the Los Angeles Aqueduct generates electricity, the sales of which help to keep city power rates low. The Colorado River Aqueduct, in contrast, consumes large quantities of electricity in pumping its water over mountain barriers.

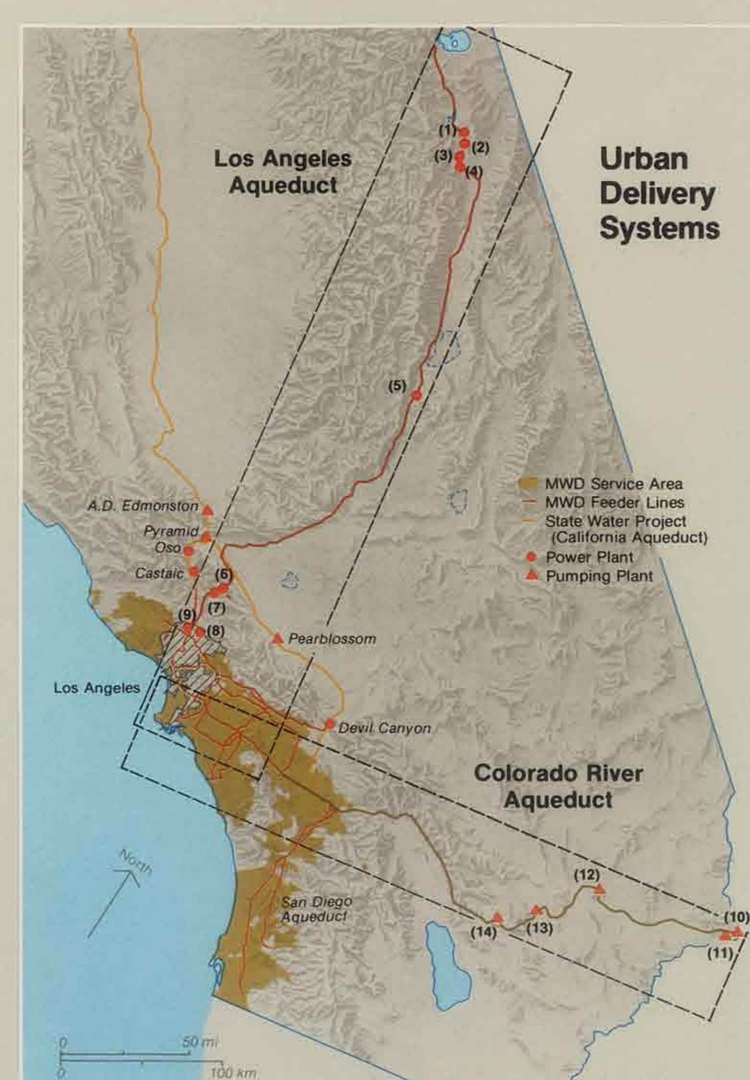
The Los Angeles Aqueduct provides approximately 80 percent of the water used by the City of Los Angeles; the balance of the city's needs are met by local supplies and purchases from the Metropolitan Water District (MWD). Each of 27 member agencies of the Metropolitan Water District have a preferential right to a share of the district's supplies proportionate to that agency's contribution to the district's overall taxes. Some agencies, such as Los Angeles, draw far less water from the district than this right would entitle them to receive; others, such as San Diego, draw far more. On an overall basis, however, the Metropolitan Water District's supplies from the Colorado River and the State Water Project provide approximately 40 percent of all the water used within its 5105 square-mile service area.

MWD Operations, 1974/1975

(All figures in thousands of acre-feet)

Member Agency	Local Production	Water Supply: MWD Entitlement	Water Supply: Total MWD Deliveries	Water Supply: Colorado River Aqueduct	Water Supply: State Water Project	Use of MWD Water: Municipal	Use of MWD Water: Agricultural	Use of MWD Water: Groundwater Replenishment
Anaheim	35.3 [1]	5.7	7.4	6.6	.8	7.2	.2	0.0
Beverly Hills	2.8	23.9	11.2	.5	10.7	11.2	0.0	0.0
Burbank	13.6	25.3	9.9	.1	9.8	9.9	0.0	0.0
Calleguas MWD	16.9	26.2	49.5	0.0	49.5	46.3	3.2	0.0
Central Basin MWD	152.3	216.0	141.4	66.6	74.8	57.1	0.0	84.3
Chino Basin MWD	164.5	33.6	8.8	8.8	0.0	5.9	.9	2.0
Coastal MWD	1.1	27.9	42.0	41.9	.1	41.9	.1	0.0
Compton	6.0	7.6	2.6	1.0	1.6	2.6	0.0	0.0
Eastern MWD	91.3 [2]	12.1	40.6	40.6	0.0	7.7	32.9	0.0
Foothill MWD	7.5	15.0	7.5	7.1	.4	7.5	0.0	0.0
Fullerton	13.6	10.2	14.7	14.3	.4	14.0	.7	0.0
Glendale	14.4	26.7	8.8	.5	8.3	8.8	0.0	0.0
Las Virgenes MWD	.5	3.6	13.6	0.0	13.6	13.6	0.0	0.0
Long Beach	29.7	69.2	39.9	14.3	25.6	39.9	0.0	0.0
Los Angeles	534.2 [3]	540.8	32.5	14.6	17.9	22.1	4.0	6.4
MWD/Orange County	167.0	129.5	215.5	161.6	53.9	93.1	23.4	99.0
Pasadena	15.5	30.0	17.7	16.7	1.0	17.7	0.0	0.0
Pomona Valley MWD	60.5	30.3	19.2	18.4	.8	18.7	.5	0.0
San Diego CWA	27.8	160.5	378.1	378.1	0.0	289.5	88.6	0.0
San Fernando	3.1	.7	0.0	0.0	0.0	0.0	0.0	0.0
San Marino	4.8	5.7	0.0	0.0	0.0	0.0	0.0	0.0
Santa Ana	23.9	12.4	9.6	9.4	.2	9.6	0.0	0.0
Santa Monica	7.2	22.7	9.9	.4	9.5	9.9	0.0	0.0
Torrance	3.3	20.5	18.8	6.6	12.2	18.8	0.0	0.0
U. San Gabriel V. MWD	175.2	68.6	34.7	13.9	20.8	.3	0.0	34.4
West Basin MWD	42.6	151.1	158.8	35.3	123.5	124.6	.6	33.6
W. MWD/Riverside Co	167.1	35.1	36.3	36.3	0.0	9.8	26.5	0.0
Totals:	1,781.8	1,710.9	1,329.0	893.6	435.4	887.7	181.6	259.7

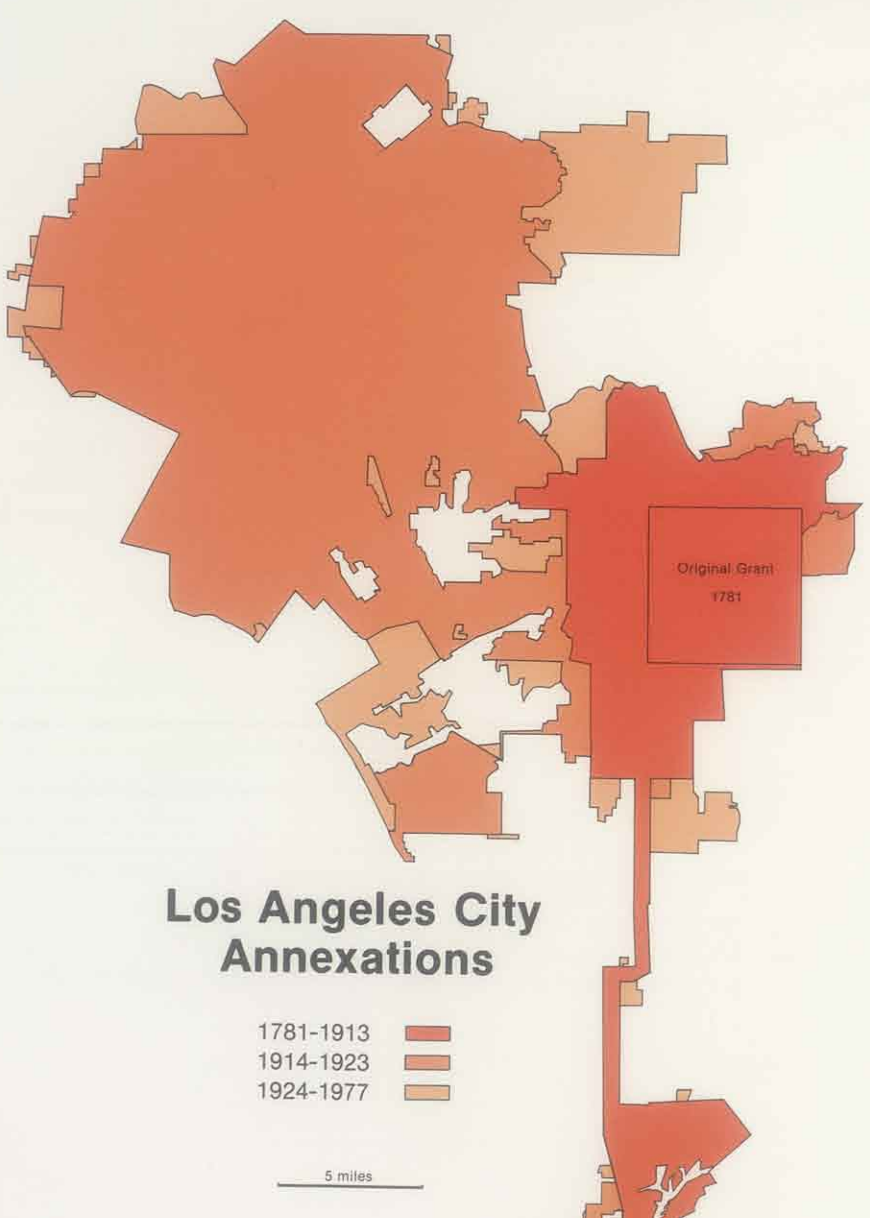
[1] Excludes deliveries by MWD of Orange County
[2] Includes 4.9 thousand acre-feet of seepage into San Jacinto Tunnel
[3] Includes Owens Valley imports



Colorado River, a supply four times greater than its aqueduct to the Owens Valley could deliver. The $220 million cost of such a project, however, lay beyond even Los Angeles' resources, and the city consequently led the drive to form a consortium of southland communities in the Metropolitan Water District which would underwrite the costs of a canal to the Colorado, a process described in detail in the next chapter.

With the approval of the Colorado project in 1928 and the completion of its acquisition of the Owens Valley soon after, Los Angeles in 1930 initiated a 105-mile extension of its aqueduct still further northward into the Mono Basin. Although completed in 1940, the Mono extension could not be operated at its full capacity because the water rights the city had secured within the Mono Basin would deliver more water south than the original aqueduct could carry. If the rights were not exercised, however, Los Angeles was in jeopardy of losing them. Faced with this risk and the prospect that deliveries from the Colorado would be reduced under the United States Supreme Court decision in the lawsuit between California and Arizona, the city, in 1964, began construction of a second, smaller aqueduct, paralleling the first, which is designed to carry not only increased exports from the Mono Basin but also additional supplies to be pumped from the Owens Valley's groundwater basin. The second aqueduct was completed and put into operation in June 1970. Although the city's pumping program is intended in part to provide for the first time an assured dry-year supply for 19,000 acres of leased, irrigated city lands in the Owens Valley, groundwater pumping has been restricted as a result of litigation by Inyo County, which wants to assure that the environmental effects of the proposed pumping program are fully evaluated.

The photograph at right displays the three stages of transition that descended almost simultaneously upon the San Fernando Valley as a result of its annexation by Los Angeles. Water from the Owens Valley transformed this formerly barren valley into rich croplands which were rapidly converted to urban development as Los Angeles' population grew. This view, taken in 1928, looks northward from a point over the intersection of Winnetka Avenue and Sherman Way.



The arrival of water from the Owens Valley laid the basis for the modern metropolis of Los Angeles. Through a series of massive annexations, the city of Los Angeles nearly quadrupled its land area in order to make full use of the surplus waters its aqueduct delivered. This map distinguishes the areas added to the city in the 10 years between the first arrival of aqueduct water and 1923, when the city's rate of growth finally caught up with its new water supply and the city called a halt to further large-scale annexations.

Los Angeles today derives 80 percent of its water supply from the aqueducts to the Owens Valley and Mono Basin. Local supplies make up another 17 percent of the approximately 600,000 acre-feet of water the city uses each year. Local supplies play so prominent a role because the advent of imported water in the San Fernando Valley coupled with the water spreading and streamflow regulation programs of the Los Angeles County Flood Control District have substantially enhanced the region's groundwater storage. The balance of the city's needs are drawn from the Metropolitan Water District's supplies from the State Water Project and the Colorado River.

The city's full entitlement to water from the Metropolitan Water District assures it access to a water supply far in excess of its current needs. Although currently entitled to approximately 30 percent of the 1.2 million acre-feet MWD provides today, Los Angeles rarely draws more than a small portion of its share. By 1977, for example, Los Angeles had received only 1.6 of the 21.5 million acre-feet to which it was entitled as a charter member of MWD. Los Angeles prefers to rely principally upon the Inyo-Mono aqueducts because the aqueduct water is of a higher quality than the Colorado River, because the aqueduct supply is cheaper than the water MWD must pay to pump into the region, and because reductions in the aqueduct flow would reduce as well the quantity of hydroelectric power generated along the city's gravity system.

The water Los Angeles does not use from MWD's supply goes to enhance growth and development in the other districts and cities served by MWD, while maintenance of Los Angeles' entitlement offers the city a margin of safety against decreases in MWD's supplies or droughts which may affect the city's other water sources. MWD membership, however, is an expensive form of insurance because Los Angeles has had to pay its share of the costs of MWD's development regardless of how much water it actually derives from the system. Between 1942 and 1972, when the city took only eight percent of the total MWD water to which it was entitled, Los Angeles taxpayers paid a cumulative total of $335 million in property taxes to maintain the city's right of access to MWD's supply. And the first time conditions occurred which might have compelled Los Angeles to draw a large part of its full entitlement during the drought of 1976-77, the city was unable to secure more than a modest increase in the water it purchased from MWD and Los Angeles consequently became the only one of MWD's members to undergo mandatory water rationing.

In comparison to the other major water delivery systems in California today, that of the City of Los Angeles does not loom particularly large; it distributes only a little more than 600,000 acre-feet of water to a population of three million. Long-range planning, the aggressive pursuit of new water sources, and a continuing commitment to construction in advance of demand have, however, given it an importance far greater than its relative size. The success of the city's original aqueduct provided an early and convincing demonstration of the potential benefits that could be gained through public water development. Its water projects today reach out hundreds of miles across the Southwest, while its electrical power is drawn still farther from projects scattered throughout six states. The fact that the city controls one of the largest blocks of votes within the Metropolitan Water District gives it the opportunity to exercise continued influence in the overall development of the South Coast. And its decisions consequently help to shape water policy not only for California but for the entire western United States.

OWENS VALLEY WATER WAR

The events later popularized as California's "Little Civil War" have had a substantial influence in shaping the development of water law and policy in the twentieth century. Driven by drought and the demands of its ever-increasing population, Los Angeles in 1920 began a series of acquisitions of riparian lands upstream of the aqueduct's intake. Owens Valley resistance to the city hardened in 1922 when negotiations failed for the construction of a reservoir at Long Valley which many local ranchers believed would have provided sufficient storage to sustain their crops while at the same time supplying the city's needs. When the city brought suit in 1924 to prevent upstream diversions which interfered with the streamflows to which the city felt it was entitled, the ranchers responded by blowing up the aqueduct.

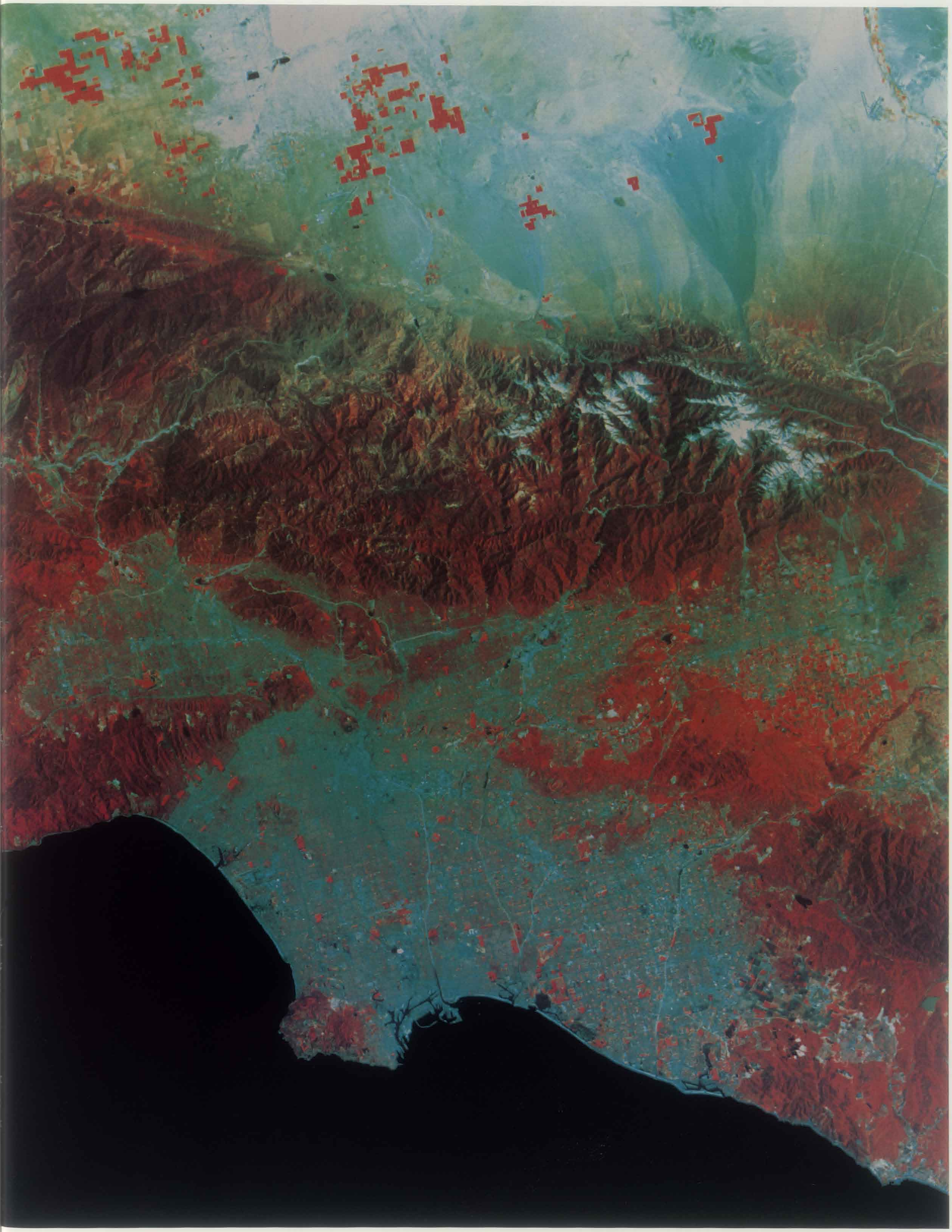
The seizure of the Alabama Gates that fall riveted popular attention to the struggle in the valley. Except for the Los Angeles newspapers, accounts of the conflict were generally supportive of the valley's position and an investigative report by the State Engineer, W. F. McClure, in 1925 was severely critical of Los Angeles' actions. Thus encouraged, the valley interests pressed their demands, not only for purchase of their lands but also for "reparations" to reimburse valley merchants for the trade Los Angeles' actions had denied them. While the city stood ready to purchase land and water rights, it steadfastly refused to pay reparations, despite the passage of legislation in Sacramento specifically authorizing such payments.

Although no blood had yet been shed, the threat of violent conflict increased in the summer of 1927 when the bombing of the aqueduct was renewed and the city dispatched trainloads of guards armed with Tommy guns to protect its embattled water project. In the midst of this tension, a state audit conducted at Los Angeles' suggestion revealed substantial misdealings by the valley's local bankers, who were themselves leaders in the resistance to the city. The collapse of the banks destroyed the valley's economy and broke the back of the resistance. In a conciliatory gesture, Los Angeles purchased the townsites and outstanding agricultural holdings at prices well above their depressed fair market values.

The example of the Owens Valley helped to underscore the need for the more orderly system of statewide water development proposed in the Constitutional Amendment of 1928. In order to assure that no other remote region would face the fate of the Owens Valley, the Legislature in 1931 passed the "County of Origin" law which prohibits the draining of one area's water supply for the sake of another. These same provisions were amended into the legislation authorizing the Central Valley Project, which went a long way toward removing the concerns of water-rich northern counties to that proposed development. The controversy also had a profound effect upon Los Angeles, which has seen its plans for new water projects repeatedly countered by opponents recalling "the rape of the Owens Valley." In this way, Los Angeles' actions in the Owens Valley provided an invaluable tool to the opponents of public water development, as exemplified by these editorial remarks from the *Sacramento Union* which appeared at the time of the controversy: "Here is a case where political ownership of public utilities had full sway for demonstration. The city concerned reverted to ruthlessness, savage disregard for moral and economic equations, to chicanery and faith breaking.... The municipality became a destroyer, deliberately, unconscionably, boastfully."

Through the development of roads, fish hatcheries, recreational reservoirs, and wildlife preserves, Los Angeles has worked to shift the economy of the Owens Valley from agriculture to recreation. As a result, many valley residents today regard the city's stewardship as beneficial because, by preventing urban development, Los Angeles has helped to preserve the valley's scenic splendors intact.

Resistance to the city, however, has been renewed with the litigation over the city's proposed pumping program which many valley residents fear will work irreversible damage to the valley's environment by effecting a permanent reduction in the groundwater table. With questions of groundwater management now emerging among the critical issues for California's future, the example of the Owens Valley may thus once again play a central role at another critical juncture in the development of California water law.

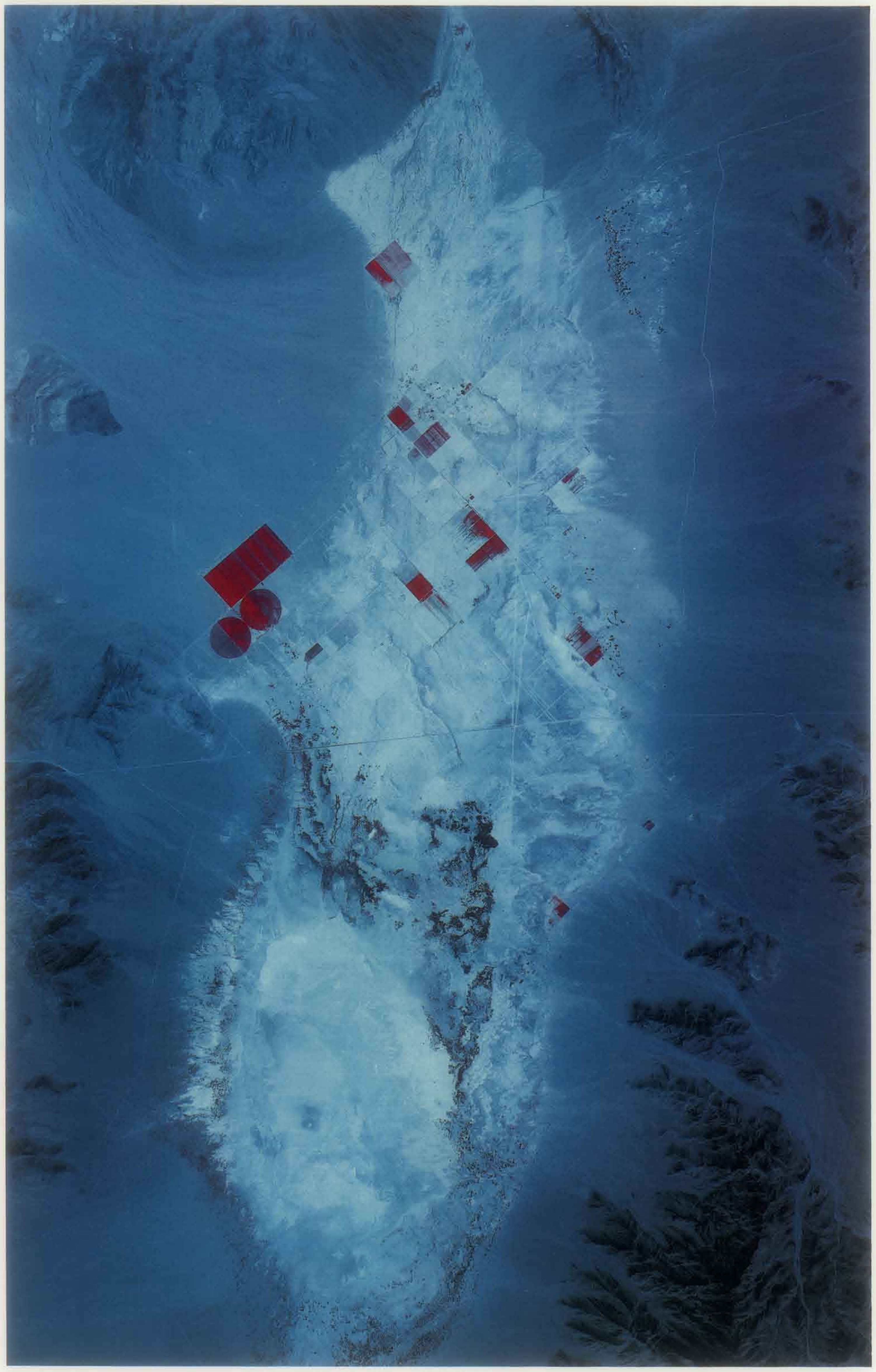


In 1901, William Smythe, a prominent advocate of systematic irrigation in California, predicted that the Los Angeles area would grow no further because it lacked a natural water supply sufficient to sustain a large population. Smythe failed to foresee the massive delivery systems whose construction made possible the modern metropolis of the South Coast. In this satellite image red colors indicate the presence of vegetation. Thus, a reddish tinge distinguishes the suburbs from the blue areas where urban development has been concentrated. The few remaining agricultural lands on the coastal plain appear as bright red patches on the right.

CHAPTER 5

The Colorado River

In the absence of a delivery system like the Colorado River Aqueduct, agricultural lands in desert areas are sometimes irrigated by pumping from groundwater basins that cannot be replenished. The bright red areas mark the irrigated lands in this photograph of such a "water mining" operation above Mesquite Dry Lake near the border of California and Nevada. These practices were common in large areas of Arizona before the development of the Central Arizona Project to bring water from the Colorado River.



Unlike many other states, California's water system is in large part self-contained. With few exceptions, Californians have focused their efforts at water development upon surface and groundwater resources which lie almost entirely within the state's borders. The all-important exception to this general rule is the Colorado River, which today supplies water to half the state's population while at the same time supporting an agricultural industry which produces crops and livestock valued at many hundreds of millions of dollars a year.

One of the great rivers of North America, the Colorado rises in the Rocky Mountains and flows southwesterly through the states of Wyoming, Colorado, Utah, New Mexico, Arizona, California, and Nevada. Along its 1,400-mile course to the Gulf of California, the Colorado River Basin drains an area of 242,000 square miles or about one-twelfth the area of the contiguous United States, and an additional 2,000 square miles in the Republic of Mexico.

The unregulated flow of the river varies widely during the year, from year to year, and over long periods of years. The long-term average virgin flow of the river is approximately 15 million acre-feet per year. Although early and possibly incomplete records suggest that there were higher flows during the early part of this century, the flows at Lee's Ferry, Arizona, dividing point between the upper and lower Colorado basins, have averaged approximately 14 million acre-feet per year from 1922 to the present.

In order to minimize the effects of extreme fluctuations in the Colorado's flow, the federal government has constructed a network of immense storage reservoirs. Anchored by Lake Mead in the Lower Basin and Lake Powell in the Upper Basin, the nine major storage reservoirs in the Colorado River Basin have a total usable storage capacity of 61.6 million acre-feet. After deduction for required flood control capacity, these reservoirs make available approximately 56.4 million acre-feet of usable storage on January 1 of each year.

These reservoirs have also worked to ameliorate the problem of siltation. In its natural state, the Colorado was one of the heaviest carriers of silt in the world, bearing a concentration of sediments about five times that of the Rio Grande, ten times that of the Nile, and 17 times that of the Mississippi. As the river slowed near its delta, it dropped much of these sediments, thereby creating the alluvial flood plains of the Yuma and Imperial valleys. Since the construction of Glen Canyon and Hoover dams, the other dams throughout the Colorado River Basin, and works to stabilize the channel and river banks, the river's silt load at Imperial Dam has dropped to only a fraction of the total load and concentrations encountered under natural conditions.

Through these regulatory works and the construction of diversion canals to urban and agricultural regions lying hundreds of miles outside the river basin, the Colorado currently serves a population of nearly 12 million people in the coastal plain of Southern California, and the Denver, Salt Lake City, Phoenix, and Las Vegas areas. The supplies of the Colorado, however, are inadequate to meet all of the demands planned to be placed upon it in the future to serve one of the most arid and fastest-growing regions in the United States.

As a result of the various demands placed upon the river's flow by the seven states and Mexico, the

Colorado has become one of the most litigated, regulated, and argued about rivers in the world. This keen competition for the river's water supply can be expected to intensify as water use increases throughout the Colorado River Basin. Because California's current withdrawals from the Colorado are approximately equal to the combined use of the other six basin states, the future of this "river of controversy" has become a key element in shaping the prospects for California's continued growth and development.

DEVELOPMENT FOR CALIFORNIA AGRICULTURE

Californians first turned to the Colorado for the means of opening the rich desert lands of the Imperial, Coachella, and Palo Verde valleys to agriculture. A onetime Indian agent, Dr. Oliver M. Wozencraft, first conceived of irrigating the Imperial Valley with a gravity-fed canal from the Colorado when he passed through the area on his way to the gold fields in 1849. His scheme foundered, however, upon his determination to own not only the water system but the land it served as well; although the State Legislature endorsed his request for a federal grant of 1,600 square miles of the public domain in 1859, Congress refused.

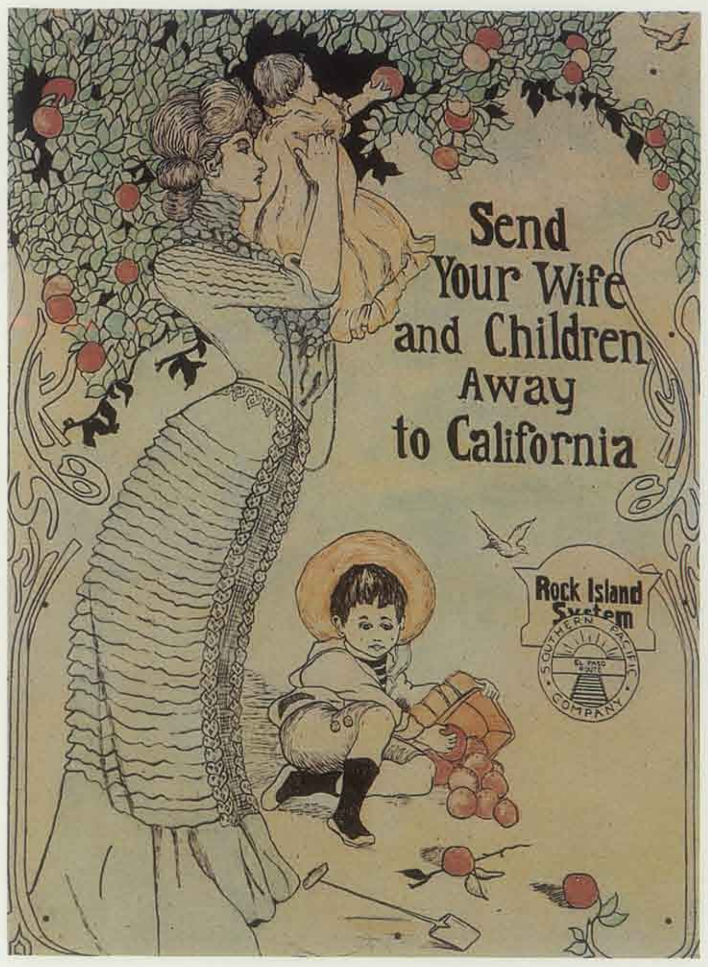
In 1877 Thomas Blythe secured from the state a grant of 40,000 acres in the Palo Verde Valley near the town which bears his name. Blythe filed one of the earliest diversion rights on the Colorado River for a canal he built using Indian labor from a point one mile above the valley's present diversion dam. Farming on these lands languished, however, after Blythe's death in 1883, and despite continued exhortations to develop the Colorado by nineteenth century advocates of systematic irrigation such as John Wesley Powell, second director of the United States Geological Survey, no serious effort was made to realize Wozencraft's original dream until California's agricultural potential had been firmly established in the 1890s.

In 1896 Charles R. Rockwood took Wozencraft's idea and the financing which his association with the prominent water engineer George R. Chaffey helped him to secure, and formed the California Development Company. Commencing in 1900, Rockwood tapped the Colorado just north of the international border and began feeding water into the Alamo, an overflow channel of the Colorado River which ran through Mexico and bypassed the large, shifting sand hills that separated the river from the Imperial Valley on the American side of the border. The first water reached the valley in 1901, and within eight months, 400 miles of canals and laterals had been built and more than 100,000 acres were ready for cultivation within the Imperial Valley.

Those who followed Rockwood into the desert soon began to doubt the venture. Because the Alamo flowed through Mexico for 50 miles before turning north again to the United States, Rockwood had promised to provide half the water diverted into the Alamo to Mexico in exchange for permission to cross Mexican lands. The land in Mexico, however, sloped toward the United States and the Imperial Valley farmers consequently found themselves threatened by flooding unless they constructed and maintained levees in Mexico to protect their lands on the American side of the border.

The heavy silt load of the Colorado River soon complicated their problems. The intake of the Alamo Canal was blocked by silt during the winter of 1903-04, but when bypasses were built around the headgate, these too quickly silted up. To avoid this problem, the company opened a cut between the canal and the Colorado River within Mexico but failed to protect the cut with an adequate headgate. Unfortunately, 1905 proved to be an unusual year and five major floods eventually hit the canal intakes that winter and spring with the result that by August 1905 the entire river was pouring into the intake, a half-mile wide at its juncture with the Colorado. In a matter of weeks, most of the Salton Sink filled to form the Salton Sea. The flood ruined the California Development Company and in 1905 the firm surrendered its management and much of its stock to the Southern Pacific Railroad. The railroad, however, did not turn the river's flow back to the main channel until February 1907.

By 1909 the land boom Rockwood initiated had drawn more than 15,000 people into the Imperial Valley where more than 160,000 acres had been turned to agricultural production. The water system upon which these settlers depended, however, had by this time passed into a joint receivership with Mexico and neither the Southern Pacific nor any other private company seemed interested in operating it. The farmers, therefore, banded together to create the Imperial Irrigation District in 1911 which, five years later, assumed the assets of the California Development Company for a payment of $3 million. Rather than bear the continuing costs of a flood control program which benefited an increasingly unstable government in revolutionary Mexico, the residents of the Imperial Valley immediately set about securing support for a new canal from the Colorado which would lie entirely within the United States. In this effort to construct an "all-American" water project, the Imperial Valley soon found it had an unexpected and not entirely welcome ally in the City of Los Angeles.



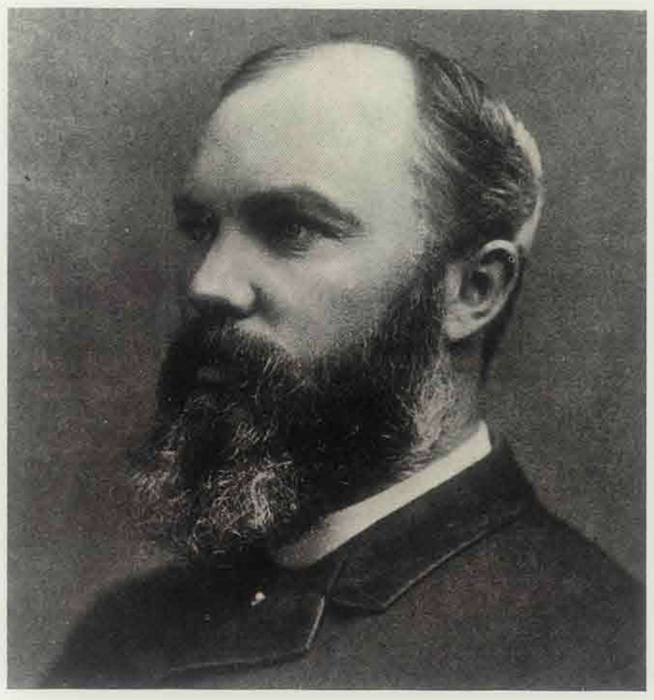
Chaffey's skill as a promoter was reflected in his decision to change the name of the Colorado Desert to the Imperial Valley. Railroad companies applied similar stratagems to lure new settlers to California with posters like the one above.

THE BOULDER CANYON PROJECT

It should have come as no surprise that urban interest in the Colorado River would be spearheaded by Los Angeles. As early as 1912, Los Angeles had sent an investigator to the river who reported on the stream's capacity to support "a large and prosperous population." "We have in the Colorado an American Nile awaiting regulation," declared Joseph B. Lippincott, one of the pioneers in western reclamation, "and it should be treated in as intelligent and vigorous a manner as the British Government has treated its great Egyptian prototype."

In 1912 city leaders felt no compelling need to turn to so distant—nearly 240 miles—and, consequently, expensive a source. Just nine years earlier the United States Supreme Court had confirmed the city's title to the Los Angeles River, thus assuring control of the major local water supply; and the city's 233-mile-long aqueduct to the Owens Valley was by then within a year of completion. But by 1920, with its population approaching 600,000, the city's water planners turned their eyes again to the Colorado.

The city's concern at first was for electricity rather than water. As late as 1890, electricity for household use had been unheard of in Los Angeles. But thereafter, electrical use increased rapidly and by 1920 a severe shortage was predicted. At the current rate of population growth, stated a special report prepared for the city council, the power supply would be inadequate to meet the demand within three to five years. Construction of local plants could postpone the shortage, but city fathers agreed with William Mulholland, chief of the Bureau of Water Works and Supply, and E. F. Scattergood, head of the Bureau of Power and Light, that only the Colorado River could provide enough electric power "for all future needs" of Los Angeles. Though hindsight would eventually reveal the overoptimism of that prediction, no one doubted the impending shortage and the Colorado as a means of meeting the city's hydroelectric requirements for years to come. The city council therefore welcomed the news that the United States Reclamation Service had joined with settlers along the lower Colorado, especially those in the Imperial Valley, in advocating the construction of a high dam in Boulder Canyon that could be built so as to



GEORGE CHAFFEY

At the time he joined Charles Rockwood in the desert, George Chaffey was probably the most successful example of the engineer as entrepreneur in his generation. Chaffey built the first hydroelectric plant in California and the first electrically lighted house west of the Rockies. He achieved his greatest success, however, through the invention of mutual water companies, a system of organization for the private development of water resources which helped to open large sections of Southern California to settlement during the late nineteenth century.

Born in Canada in 1848, Chaffey was for the most part a self-taught genius. His formal education ended at the age of 13, when his parents withdrew him from school due to ill health. After his family moved to California in 1880, Chaffey studied the success of the Riverside Colony and then initiated his own water colony, Etiwanda, the next year. Ontario, "the model colony" described in greater detail in the preceding chapter on nineteenth century water development, followed in 1882. The success of these ventures prompted an invitation in 1885 for Chaffey to bring his organizing principles and engineering skill to Australia. Although his Mildura Colony prospered in the first years of its existence, a financial crisis in 1893 led to a revolt of Chaffey's Australian shareholders and government investigations ended in charges of gross inefficiency in Chaffey's design.

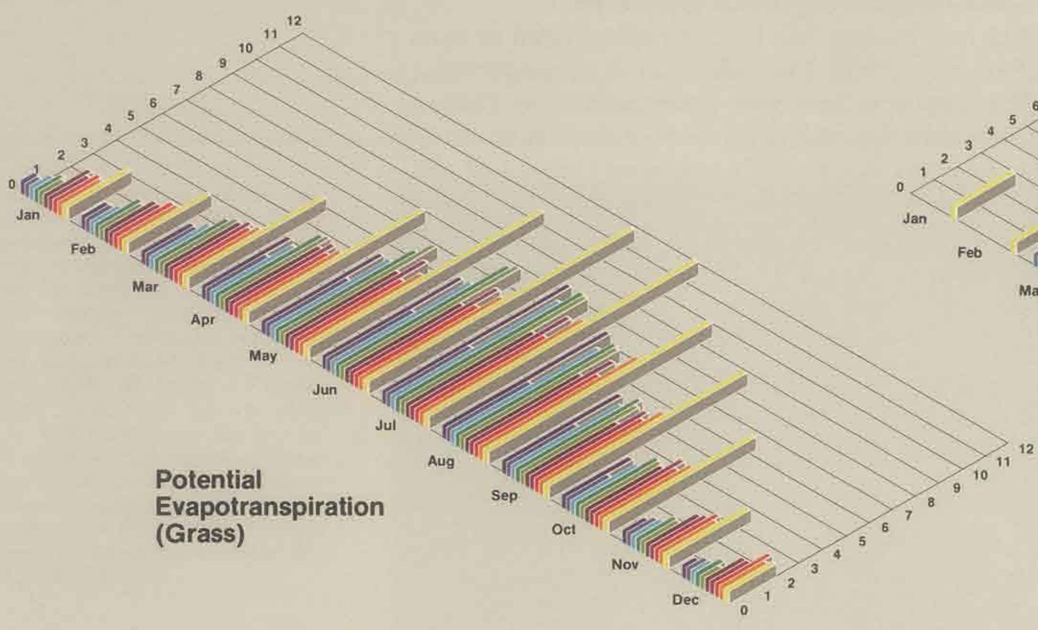
Chaffey's reputation in the United States, however, was untarnished and upon his return he set about the project with which his name would be most enduringly linked in California history, the development of the Imperial Valley. It was Chaffey's idea as a masterful promoter, in fact, to name the area Imperial instead of its more forbidding identification as the Colorado Desert. Chaffey brought to the project not only his profits from Ontario but more importantly the good name Rockwood needed to attract financial backing. Although his son warned him against association with Rockwood, Chaffey was determined to "do one more big thing before I die." Soon after signing on as president, manager, and chief engineer of the California Development Company, Chaffey realized he had been swindled. The company owed more than $400,000 in unpaid taxes to New Jersey, where Rockwood had chartered it. These debts, combined with Rockwood's complicated arrangements with Mexico for a right of way on the Alamo, forced Chaffey to sell out his interest in 1901 in order to save the company from receivership.

Chaffey was thus not involved in the engineering mistake that would form the Salton Sea and destroy the company. His last years were spent in developing the East Whittier-La Habra Valley and in an unsuccessful effort to create a new colony at Manzanar in the Owens Valley. This last venture set him at odds with the Los Angeles Department of Water and Power, whose aqueduct to the Owens Valley was already bringing the end to the era of water development through private capital in which Chaffey had flourished. He died in 1932.

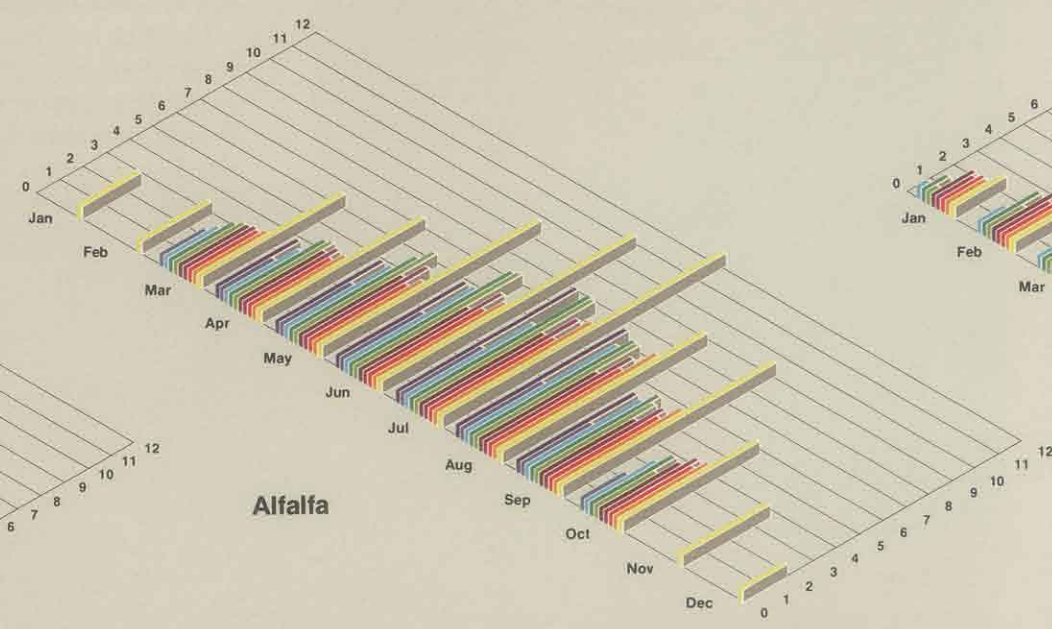
Growing Season Evapotranspiration

- **North Coast** - Coastal Valleys and Plains
- **North Coast** - Interior Valleys
- **Northeastern Mountain Valleys**
- **Sacramento Valley**
- **San Joaquin Valley**
- **Central Coast** - Coastal Valleys and Plains
- **Central Coast** - Interior Valleys
- **South Coast** - Coastal Valleys and Plains
- **South Coast** - Interior Valleys
- **Southern California Desert**

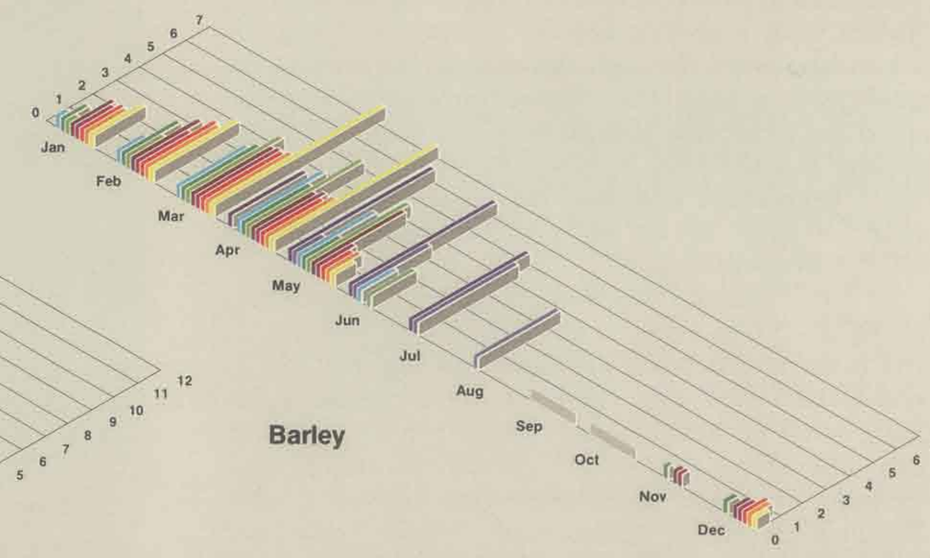
Each isometric graph displays crop evapotranspiration, measured in inches per month, during the growing season within each of ten distinct regions.



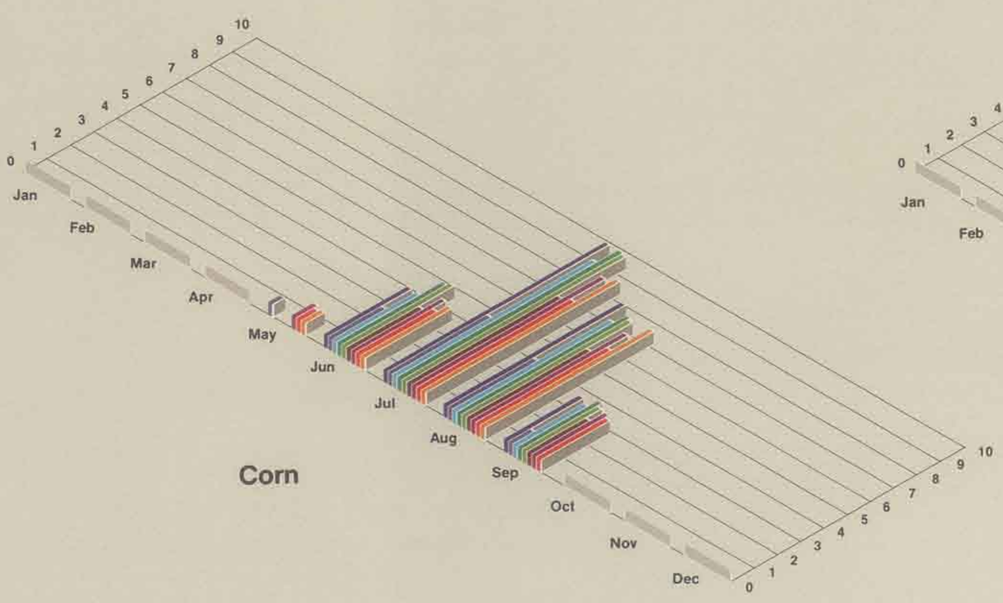
Potential Evapotranspiration (Grass)



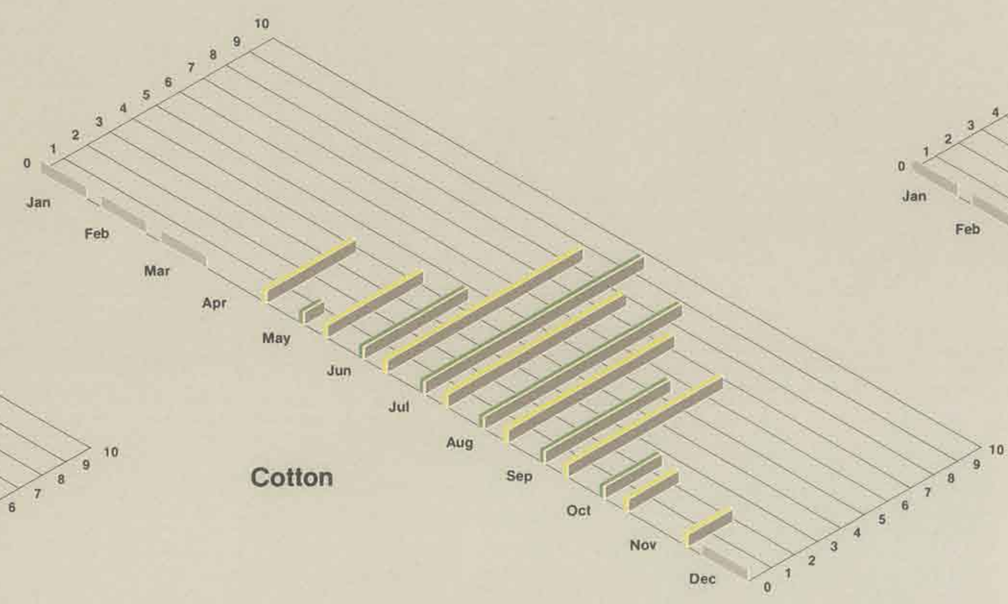
Alfalfa



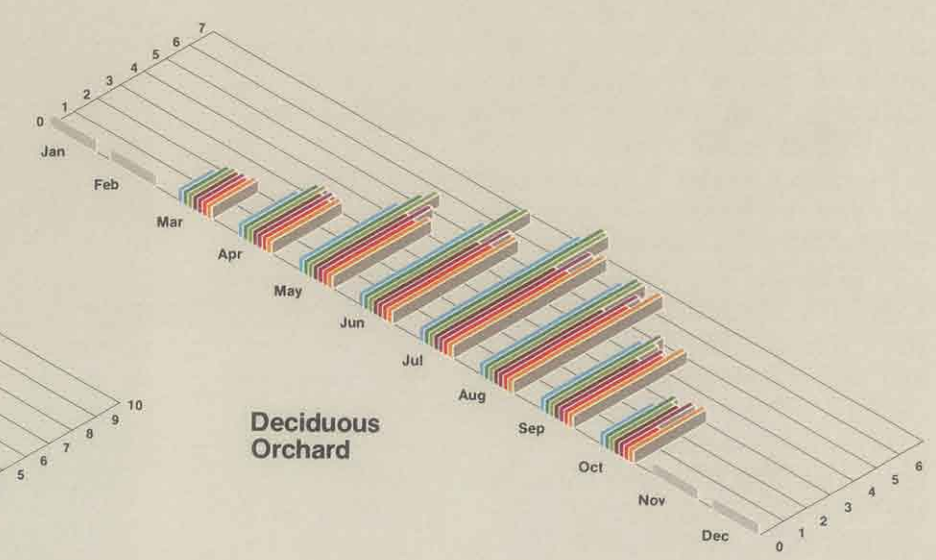
Barley



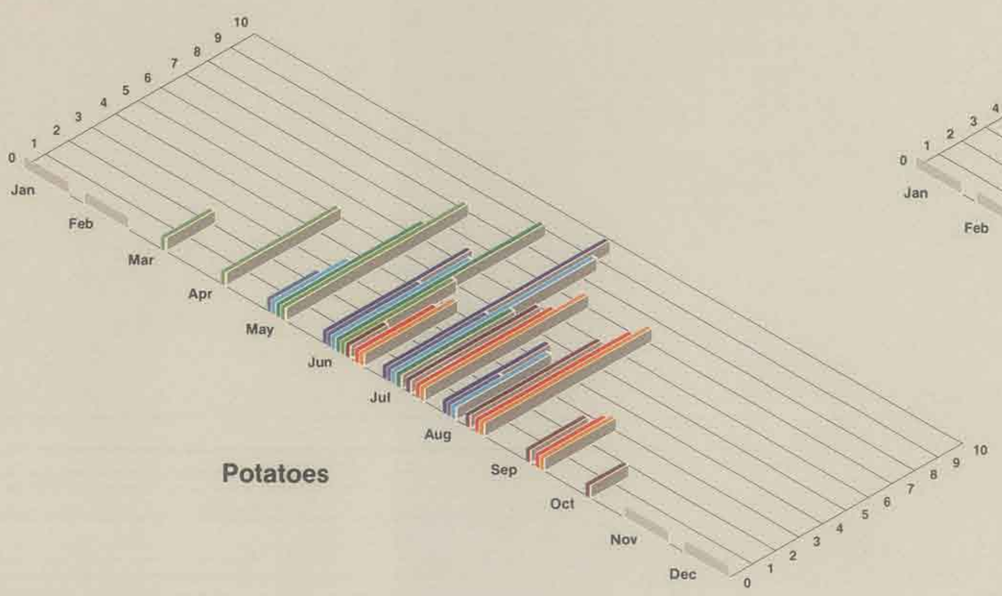
Corn



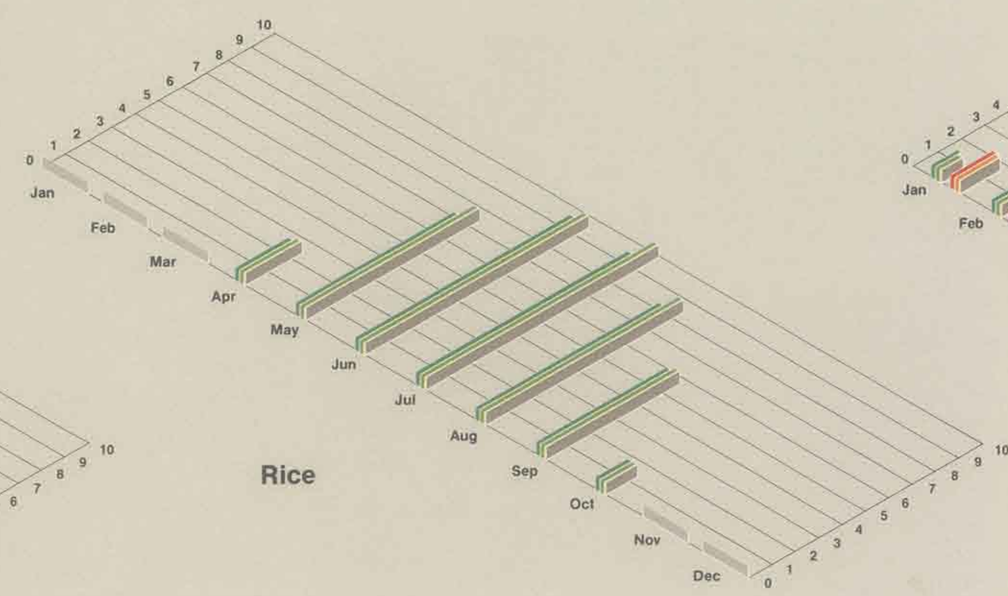
Cotton



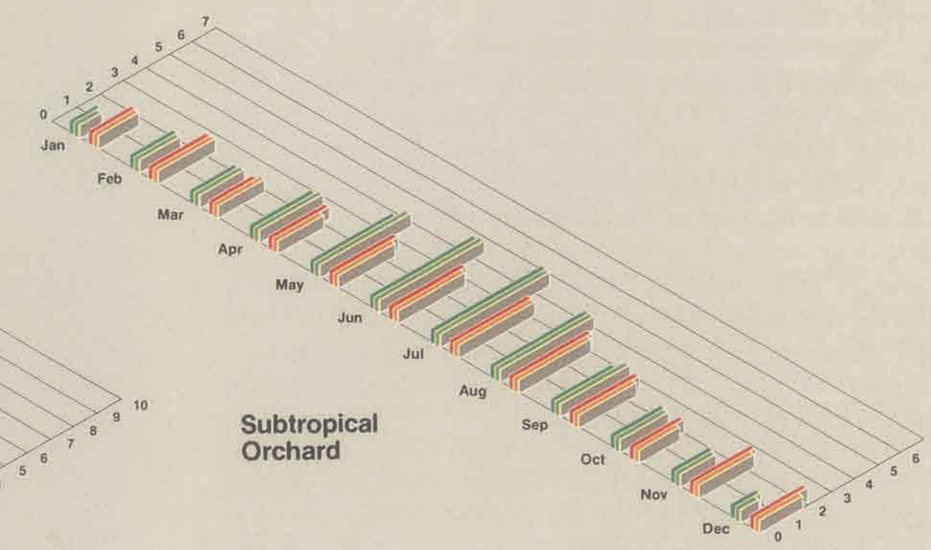
Deciduous Orchard



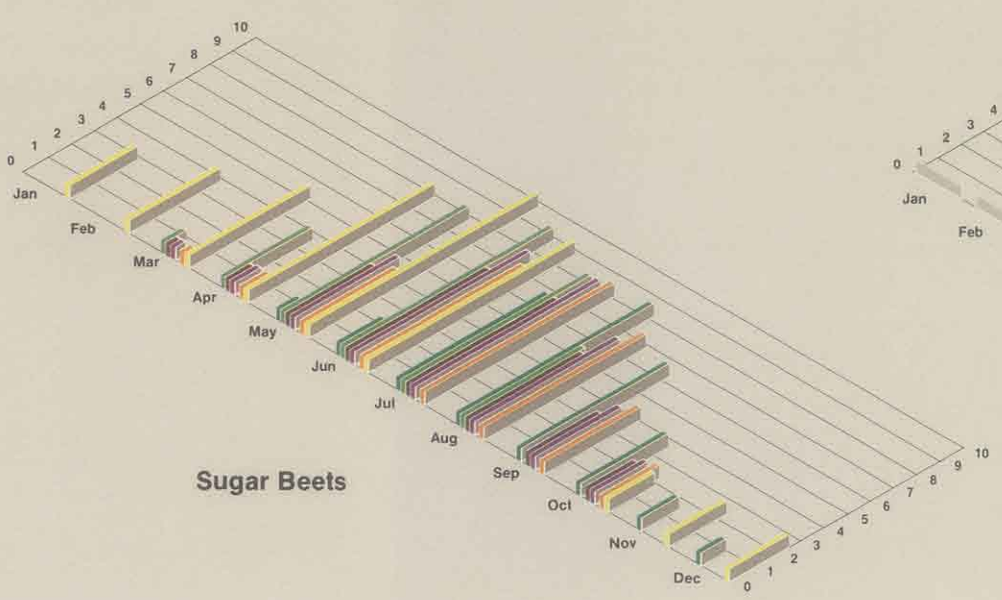
Potatoes



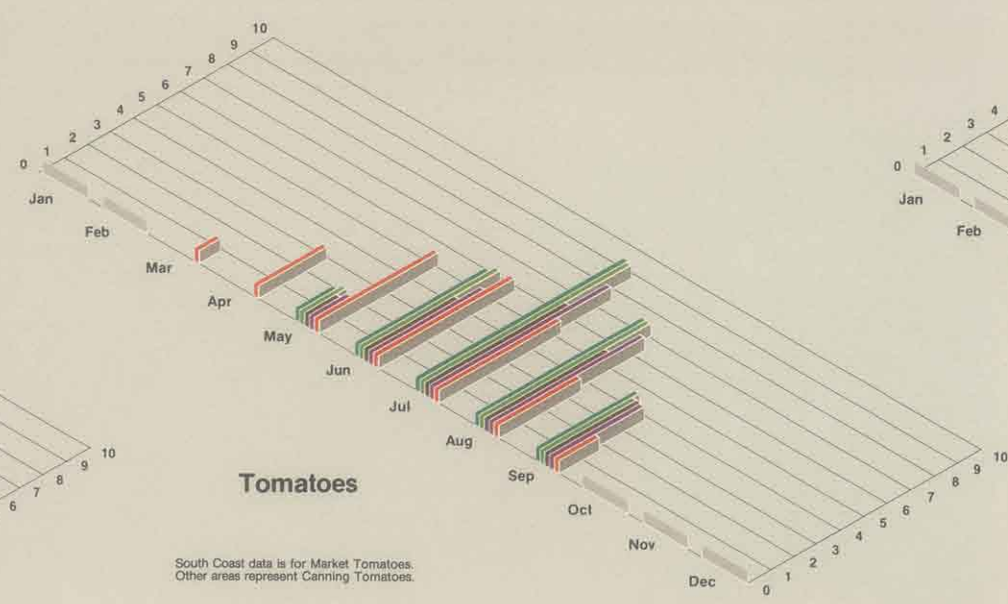
Rice



Subtropical Orchard

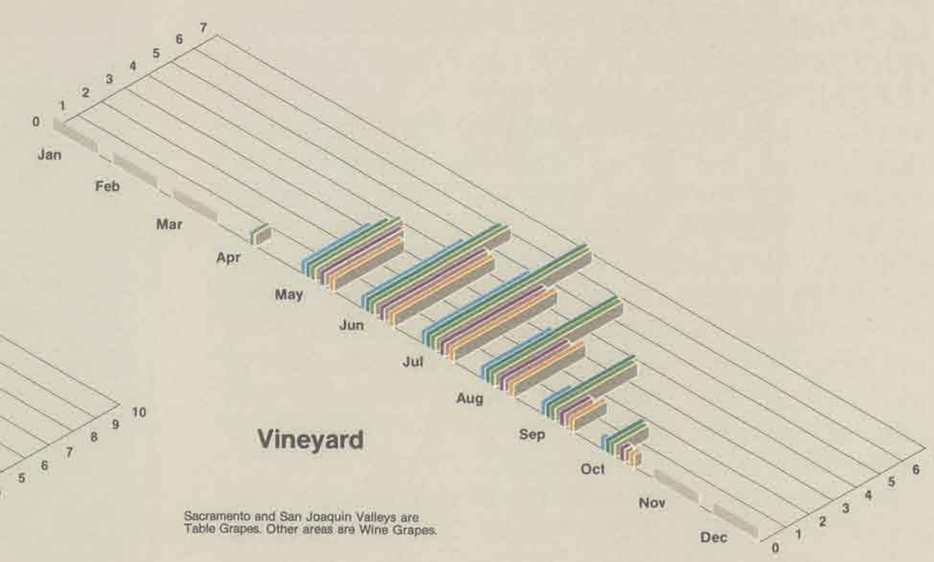


Sugar Beets



Tomatoes

South Coast data is for Market Tomatoes. Other areas represent Canning Tomatoes.



Vineyard

Sacramento and San Joaquin Valleys are Table Grapes. Other areas are Wine Grapes.

accommodate a large power plant. On August 30, 1920, the city council officially endorsed construction of the dam and boldly announced its intention to obtain electric power "direct from the Colorado River."

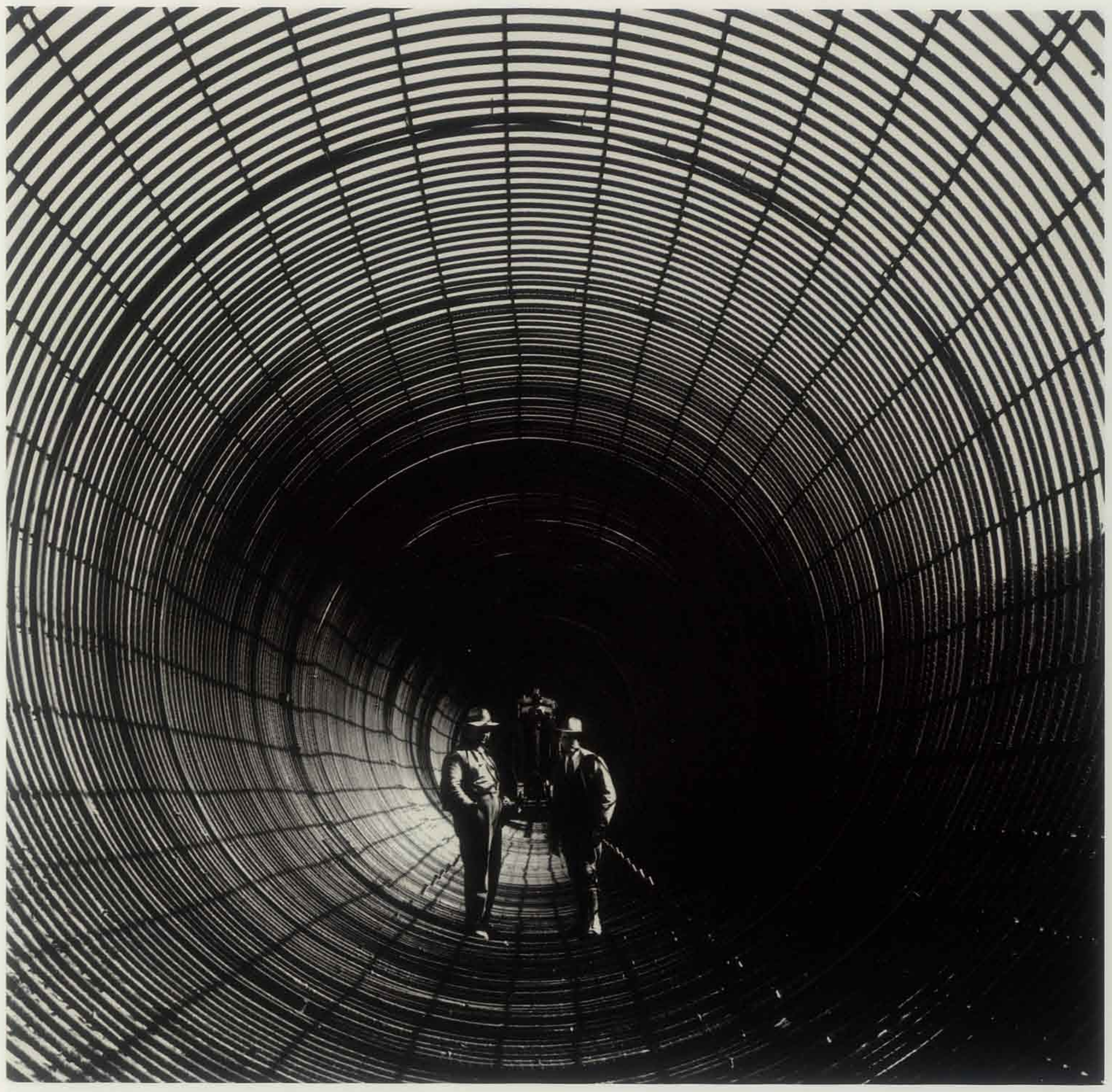
News of Los Angeles' action at first alarmed the farmers and smaller cities on the south coastal plain. They too needed additional electric power and they viewed with concern the rapidly deteriorating state of Los Angeles' relations with the Owens Valley. "I am skeptical of Los Angeles," announced a San Bernardino official whose views were shared widely. "She has always been inimical to the interests of the back country when she should be the reverse." A representative from Riverside went still further, declaring, "I would rather pay $1.27 per kilowat[t] hour and get it than have Los Angeles take it all and we get nothing."

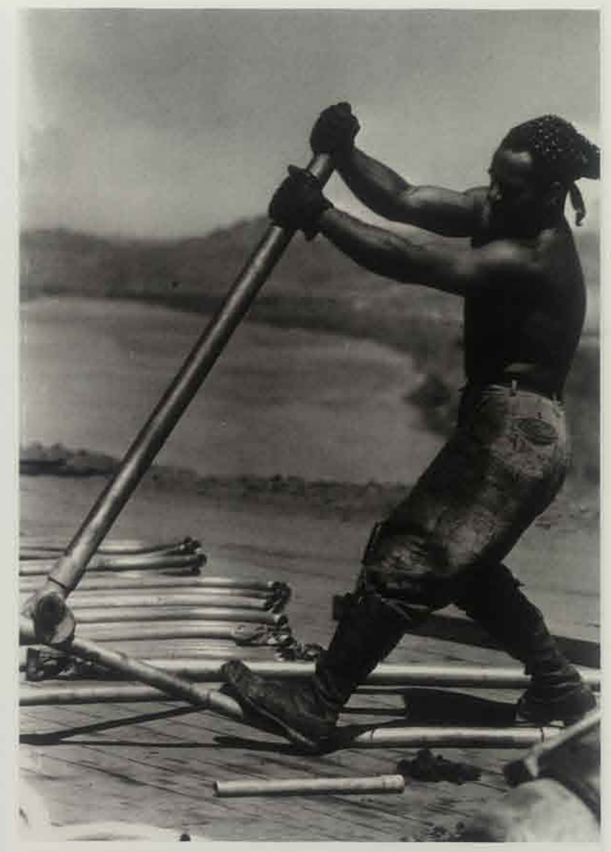
The city's efforts to improve its image among neighboring communities took on added importance in 1923 when a dry cycle caused the city to announce that it now wanted water as well as electricity from the Colorado River. The interest in water brought with it the realization that expensive aqueducts and pumping stations would be required to tap the distant river. Considerations of cost and a belief that there was enough water for everyone prompted city leaders in 1924 to negotiate with representatives of nearby communities for the creation of an agency to oversee water distribution, arrange for construction, and assess costs. The State Legislature approved the idea and in 1927 the Metropolitan Water District of Southern California was created "to provide a supplemental water supply to the coastal plain of Southern California."

Los Angeles and its allies in the Metropolitan Water District recognized that a desire for Colorado River water and the creation of an agency to distribute the water assured them of no water whatsoever. First, the river would have to be regulated since an aqueduct was a practical impossibility so long as the Colorado remained a raging torrent during part of the year and little more than a creek at other times. The wide fluctuation in streamflow from year to year also meant that regulation would be necessary to assure a dependable supply of water throughout the year. This merely served to reinforce their enthusiasm for the proposed dam at Boulder Canyon, even though a dam of that size would be so expensive that only the federal government could finance it. The United States Reclamation Service vigorously supported the project, but Congress balked. The representatives of the other Colorado River Basin states feared that California would use the project to get the lion's share of the river. They refused therefore to support the undertaking until an agreement could be reached among the states as to their respective water rights.

As the fastest-growing state in the basin and the state which contributed the least amount of runoff to the river, California had early aroused concern among the other basin states—Wyoming, Colorado, Utah, New Mexico, Nevada, and Arizona. The doctrine of prior appropriation, which prevailed throughout the basin, vested a right to water in the first person who used it—"first in time, first in right." When the United States Supreme Court in June 1922 in *Wyoming v. Colorado* announced that this principle was applicable to states as well as to individuals, the concern of the other basin states turned to alarm. Already uneasy because of the rapid increase of water use in California's Imperial Valley and the news of Los Angeles' interest in the river, their resistance to the Boulder Canyon project stiffened sharply following the court action. They could do nothing to undo the development in the Imperial Valley, but their control of key congressional reclamation committees gave them a powerful weapon with which to combat California's attempts to obtain federal regulation of the river.

In 1928 California finally achieved the Boulder Canyon Project Act, but to get it California's representatives had to agree to two major restrictions which still govern the state. The first was embodied in the Colorado River Compact of 1922 and the second in the California Limitation Act of 1929. The Colorado River Compact appeased most basin opponents to the Boulder Canyon legislation by dividing the river's waters between Wyoming, Colorado, Utah, and New Mexico in the upper basin and the lower basin states of Arizona, California, and Nevada. The agreement apportioned the beneficial consumptive use of 7.5 million acre-feet per year to each basin and, in addition, permitted the lower basin to increase its apportionment by a million acre-feet.





Construction along the Colorado River Aqueduct

The provision for this latter million acre-feet was added at the insistence of Arizona, which wanted compensation for the runoff of major tributaries of the Colorado which drained the state. Since the compact divided the water between basins and not among individual states, however, Arizona could not be assigned this water by name. Instead, the million acre-feet were apportioned to the lower basin, though the negotiators fully expected this water to be assigned specifically to Arizona in a future lower-basin agreement. Regrettably, this lack of specificity in the compact would later fuel bitter controversies between Arizona and California.

In 1922, however, the agreement was considered a major achievement, the first time in American history that a group of states had apportioned the water of an interstate stream and the first time that more than two or three states had negotiated a treaty to settle any sort of problem among themselves. The compact apportioned a total of 16 million acre-feet, leaving, according to estimates at the time, a surplus of about two million acre-feet for later apportionment. The existence of this alleged surplus and the setting aside of water for slower-developing states in the basin helped remove a major barrier to California's river development plans.

Unfortunately, California and Arizona began quarreling almost immediately over their shares of the apportionment to the lower basin. The compact had repealed the doctrine of prior appropriation so far as it applied between the basins, but the principle still applied to the states within each basin. Of the three states within the lower basin, only Nevada was relatively unconcerned. Her topography was such that she sought only a small volume of water, and Arizona and California readily agreed to her requests. The two states were unable to harmonize their own demands, however, and their differences intensified as each discovered potential uses for Colorado River water and hydroelectricity not anticipated earlier. Arizona's concern was so great that her Legislature repudiated her representative at the compact negotiations and refused to approve the agreement.

When the quarrel had dragged on for nearly six years, thereby frustrating federal attempts to control the river's often devastating flood waters, Congress intervened with a solution of its own. It would approve the Boulder Canyon legislation, but the measure would become effective only if Arizona joined the other basin states in ratifying the compact. Failing that, the measure could still take effect, but California would first have to limit itself to a specific volume of water. Congress set the amount of this limitation at 4.4 million acre-feet per year plus no more than half of any surplus water unapportioned by the compact. Because Arizona believed California should be restricted even further, she persisted in her refusal to approve the compact. On March 4, 1929, the California Legislature therefore agreed to the limitation imposed by Congress. The Boulder Canyon Project Act, approved by President Calvin Coolidge on December 21, 1928, was declared effective by President Herbert Hoover on June 25, 1929.

Californians enthusiastically greeted news of the Boulder Canyon legislation. Especially delighted were those in Los Angeles and the other coastal communities, but also elated were the farmers and investors in agricultural lands along the lower Colorado. The new law called for an All-American Canal to free the Imperial Valley from dependence on the canal that went through Mexico. More important from the point of view of the communities on the coastal plain, the law authorized construction of the long-sought high dam and power plant. The enormity of the undertaking and the onset of the Great Depression in 1929 complicated construction plans, but by 1935 Hoover Dam had been completed (in Black Canyon, rather than Boulder Canyon as originally envisaged) and a year later hydroelectric power from the river was being used on the South Coast. California's willingness to contract for all of Hoover Dam's power at a time when there were no other customers in the basin made construction of the dam and power plant possible. Arizona and Nevada eventually contracted for power but, until they did so, the Metropolitan Water District of Southern California, the Los Angeles Department of Water and Power, the Southern California Edison Company, and several small contractors obligated themselves to purchase the electricity and underwrite construction costs.

Regulation of the river by Hoover Dam (then the world's highest) and the availability of large amounts of electricity now made possible the construction of

High natural moisture demands in naturally arid regions like the Imperial Valley are an important factor in determining the amount of water required for desert agriculture and the types of crops that can consequently be grown most efficiently. The plate on the facing page compares evapotranspiration by selected crops in the various regions of the state.

Although initially reluctant to join MWD, San Diego today is one of the principal beneficiaries of water from the Colorado River. In the photograph above, Point Loma is in the foreground while the Salton Sea and Imperial Valley can be seen gleaming in the distance. Even more striking is the fact that the International Boundary between Mexico and the United States is actually visible here as a straight line on the right defined by the different land uses which an abundant water supply makes possible.

diversion works and pumping plants to bring water to Southern California. By 1940 the Metropolitan Water District had completed the 242-mile-long Colorado River Aqueduct and on June 17, 1941, the first water was delivered to the coastal plain. The next year, the All-American Canal commenced service to the Imperial Irrigation District's 1,600-mile distribution system. In 1947 San Diego completed its connection to the Colorado River Aqueduct. And two years later, Colorado water began arriving in the Coachella Valley.

The advent of Colorado River water had a profound impact upon Southern California, commercially, industrially, and agriculturally. Los Angeles nearly doubled its population between 1940 and 1970, growing from 1.5 million inhabitants to about three million. Other communities registered even greater growth rates, and new cities sprang up where earlier there had been only vacant fields. The four coastal plain counties of Ventura, Los Angeles, Orange, and San Diego tripled their combined populations during the three decades after 1940, increasing from 3.3 million to more than ten million. Those portions of Riverside and San Bernardino counties receiving Colorado River water from the Metropolitan Water District experienced similar growth patterns during these years. Especially dramatic was the population explosion in the City of Riverside which nearly quadrupled in size.

THE COLORADO TODAY

Contracts between Southern California agencies and the Secretary of the Interior for Colorado River water currently total 5,362,000 acre-feet per year. The United States Supreme Court decree in *Arizona v. California* apportioned 4.4 million acre-feet to California of the first 7.5 million acre-feet per year available for consumptive use plus 50 percent of any surplus above 7.5 million. Actual use, however, is somewhat less than the full contracted amount, currently about 4.7 million acre-feet per year. Annual withdrawals by the Metropolitan Water District, for example, peaked at approximately 1.2 million acre-feet between 1967 and 1972. Since that time (with the exception of the drought year of 1977), the district gradually reduced its consumption and has been using about 800,000 acre-feet in each year since 1975. The arrival in 1973 of the first deliveries from the State Water Project in part made this reduction possible and thereby helped to relieve MWD of the high cost of electrical energy needed to pump greater quantities of water through the aqueduct. MWD's allotment of low-cost power from Hoover and Parker dams is sufficient to pump 800,000 acre-feet a year. It is expected that some time during the middle 1980s, when the Central Arizona Project commences deliveries, California will cut back its use still further to the basic 4.4 million acre-feet per year entitlement.

Overall, the Colorado River supplies a little more than half of all the water used in Southern California. Nearly 80 percent of California's entitlement is used by the four agricultural districts of the Imperial, Coachella, and Palo Verde valleys and the Bureau of Reclamation's Yuma Project. The Yuma Project, which serves the Fort Yuma Indian Reservation and the adjoining Bard Water District, is one of the earliest federal reclamation projects and the first to be developed on the Colorado. Today, however, it is the smallest of the four; in 1977, for example, only 12,156 acres were under irrigation here as compared with the more than 500,000 acres cultivated that same year in the mammoth Imperial Irrigation District. Nearly three-fourths of the 675,000 acres receiving irrigation water from the Colorado in California during 1977 lay within the Imperial district, where crops and livestock production that year were valued at more than half a billion dollars.

This great agricultural productivity is a function of the district's success in achieving a delicate balance with the salts that suffuse the land and water upon which settlement depends. The Imperial Valley's rich earth is made up almost entirely of waterborne sediments which extend not six or ten inches deep but, in most areas, a mile or more below the surface. Because of the prevalence of fine-grained clay and silt deposits in the sediments, water does not drain readily through most of the soils of the Imperial and Coachella districts. Consequently, farmers in these areas have had to install a vast complex of thousands of miles of tile drains to carry away the salts which

THE METROPOLITAN WATER DISTRICT

The Metropolitan Water District today is a wholesaler of water to cities and water districts serving 11 million people over a 5,105-square mile area. The sheer size of its operations assures it a major role in the determination of water policy for California. For the first years of its existence, however, MWD sometimes seemed an idea whose time would never come.

When the first water from the Colorado arrived in 1941, MWD only had 13 members: Anaheim, Beverly Hills, Burbank, Compton, Fullerton, Glendale, Long Beach, Los Angeles, Pasadena, San Marino, Santa Ana, Santa Monica, and Torrance. Other communities were slow to join because, in addition to the rates they pay for the water itself, the member agencies of MWD must pay through property taxes their respective shares of the overall cost of the project itself. To assure that no late-joining community escapes its portion of this burden, back taxes are assessed as well as a four percent delinquency charge for the amount that a new member would have paid had it joined the MWD in 1928. Rather than pay these high and ever-escalating costs of entry, many areas of the southland preferred simply to rely upon their local groundwater sources. Rainfall in the South Coast was high during the first years of MWD's operation and in 1941 the district delivered only 15,000 of the 430,000 acre-feet of water its system was capable of handling. For the first five years, MWD operated at less than two percent of its capacity. And despite substantial annexations to the MWD service area between 1948 and 1952, MWD's huge pumps as late as 1954 could deliver all the water that was required by operating only half the time.

San Diego's long resistance to membership was perhaps the most surprising because San Diego had been one of the earliest and most enthusiastic advocates of Colorado River development. In 1917, San Diego led the formation of the League of the Southwest to promote the Boulder Canyon Project as the means to making San Diego a major port and industrial center. Although Los Angeles' decision in 1923 to seek Colorado water for itself dashed San Diego's dreams of leadership, the city's reluctance to join thereafter in support of the Boulder Canyon Project was based on more than spite. For, San Diego had filed its own application for 112,000 acre-feet of Colorado River water and this right would have to be turned over to MWD if the city ever joined. Throughout the 1920s and 30s, San Diego's water planners dreamed anew of someday constructing their own system to connect with the All-American Canal. With the advent of World War Two and the vital role San Diego's shipyards came to play in that conflict, it seemed that federal funds for such a massively expensive undertaking might be made available in the interests of national defense. But the war ended before San Diego's plans came to fruition and, faced with a continuing drought that cut deeply into the city's water supply from 1944 onward, San Diego in 1946 gave up its precious right to the Colorado flows in exchange for a connection to the MWD system. This arrangement ultimately proved to work to San Diego's advantage in that the San Diego County Water Authority today takes approximately four times as much water as its own filing with the Department of Interior would have allowed.

MWD's early difficulties in finding a market for its ample supplies were further complicated by the fact that few of its members took as much water as their assessed valuation entitled them to receive. San Marino, although a charter member, did not receive a drop of Colorado River water until 1960 and has only taken a total of 32 acre-feet since then, and Los Angeles has taken only seven percent of the water it might have received since 1941. Despite these problems, however, MWD pressed ahead in 1952 with a $200 million expansion program to bring its underused pipeline up to its full 1.2 million acre-feet a year capacity. By the 1960s, demand at last began to catch up with MWD's supply, and with the addition of the water it has contracted to receive from the State Water Project, the system's total deliveries are expected to reach 3.2 million acre-feet after 1990.

Each of MWD's 27 member agencies appoints at least one representative to MWD's board of directors and one additional director for each three percent of MWD's total assessed valuation that is taxable for district purposes. Each representative in turn is accorded one vote for every $10 million of his or her agency's assessed valuation. Directors for each member agency are required, however, to cast their votes as a block, and no member may have more votes than all the other members combined. This last provision assured that Los Angeles would never exercise more than half the votes of the district. Although the City of Los Angeles' share of the votes has declined since 1953 from 50 percent to only about 25 percent, the city still commands almost twice as many votes as any other single member. By vesting control of its operations in its constituent members, however, MWD acts as a forum for the development of water policy for most of the South Coast.

would otherwise accumulate near the surface as a result of extended agricultural production. Seasonal variations in the salinity of the Colorado's flows make these drainage systems all the more essential; for the Colorado tends to carry its highest concentration of salts during the autumn and winter when the most salt-sensitive crops are being planted and seed germination is taking place.

The accident which destroyed Rockwood's California Development Company has been made the heart of the Imperial and Coachella valleys' drainage system and the basis, therefore, of their continued prosperity. As an unnatural body of water, the Salton Sea has been maintained as a drainage sump which receives 90 percent of its surface inflow in most years from the saline wastewater of the Imperial and Coachella districts. For the Palo Verde Irrigation District, on the other hand, the only one of the four districts not served by the All-American Canal, the problem of securing adequate drainage was not solved until the river itself was moved into a new channel in 1970. This channel, called the Cibola Cut, bypassed the meanders of the old channel and lowered the water levels in the Palo Verde Outfall Drain and feeder drains by several feet.

Careful management, backed up by substantial capital investments, has thus dammed the floods, reduced the sediment loads, and set about controlling the salts which would otherwise have made agriculture in the Colorado Desert impossible. Increasing demands upon the limited water resources of the region could, however, someday upset the delicate balance that has been achieved. The Imperial Irrigation District, for example, has done more than prevent the accumulation of salts; since 1955, the district has been a net exporter of salts, draining out approximately 15 percent more salt than the Colorado carries into the district each year. Because the drainage flows into the Salton Sea are about one-tenth the concentration of salinity levels within the sea, these drainage waters slow the rate of increase in the Salton Sea's overall level of salinity. Studies have shown, however, that salinity in the Salton Sea will increase, despite the diluting effect of drainage waters, with the result that recreational and fish and wildlife resources of the Salton Sea could someday be in danger unless measures are taken to reverse the rise in salinity.

Salinity levels in the flows of the Colorado are expected to increase substantially as the upper basin states expand their consumptive uses of the river for agricultural and industrial development. Recognizing this problem, Congress passed the Colorado River Basin Salinity Control Act of 1974, which established a salinity control program designed to maintain salinity levels in the lower basin at or below the levels set in 1972. In addition, the basin states have adopted numerical salinity standards and a plan of implementation to achieve this goal. These are major steps, but considerable work remains to be done before the salinity problem can be considered fully resolved.

The responsibility for dealing with these problems and protecting the state's interest in the river is vested in the Colorado River Board of California. Created by the Legislature in 1937, the board originally consisted of representatives from the six public agencies with rights to Colorado River water and power: Palo Verde Irrigation District, Imperial Irrigation District, Coachella Valley County Water District, the Metropolitan Water District of Southern California, the San Diego County Water Authority, and the Los Angeles Department of Water and Power. In 1976 the State Legislature added five additional members to the board—three individuals representing the public and the directors of the Department of Water Resources and the Department of Fish and Game. In the years ahead, this body will continue to play a central role in the major issues surrounding California's continued reliance on the Colorado.

THE FUTURE OF THE COLORADO

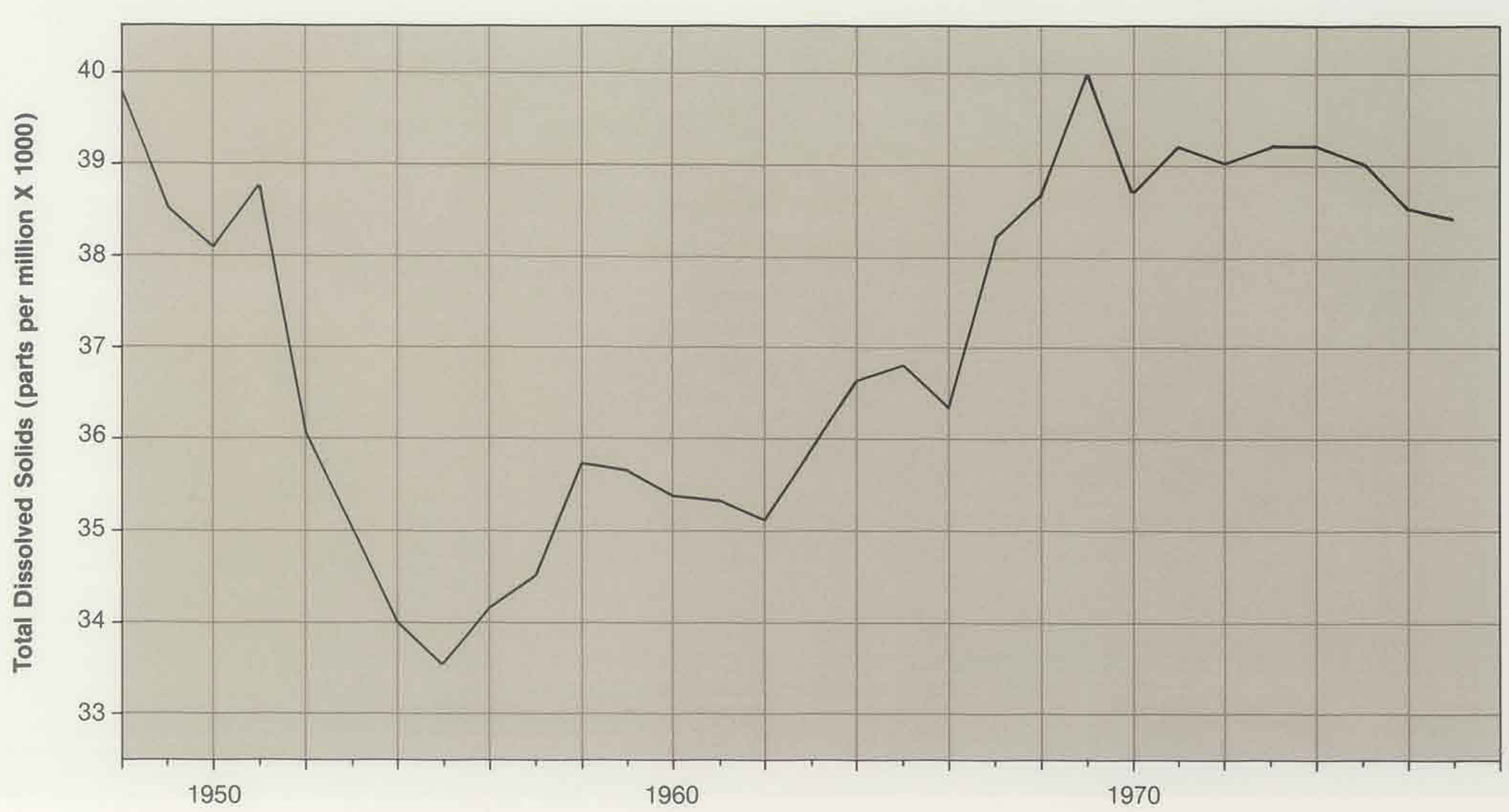
Southern California has been successful in using the resources of the Colorado River to support a rapid rate of growth, but it faces continuing problems in the future. One of the most serious of these has been the gradual realization that the Colorado River has much less water than earlier believed. Although the negotiators of the compact believed there were 16.4 million acre-feet at Lee's Ferry, the river's actual annual flow at Lee's Ferry since 1922 has averaged about 14 million acre-feet. Although there is presently a surplus of water in the river when compared to current uses, there will not be sufficient water to cover all of the apportionments made by the compact.

This lowering of reliable expectations most directly affects the upper basin, which obligated itself in the compact to provide the lower basin with "75,000,000 acre-feet for any period of ten consecutive years." This provision obligated the upper basin to deliver to the lower basin an average of 7.5 million acre-feet annually. Although deliveries may vary from year to year, the effect of this apportionment meant that the upper basin's depletion measured at Lee's Ferry would not be more than the residual amount of water available after meeting the required deliveries to the lower basin. The upper basin states of Colorado, Wyoming, New Mexico, and Utah currently deplete the flow of the river at Lee's Ferry by 3.8 million acre-feet per year. By 1990 upper basin uses are projected to total about 4.2 million acre-feet per year. Beyond 1990 the demands are highly conjectural, being dependent upon available water supply, agricultural development, and the uncertain prospects for development of the area's huge reserves of oil shale and coal. Although numerous projections have been made of the basin's future water demands, California water planners believe that the upper basin will not reach a level of use of 5.8 million acre-feet per year until early in the twenty-first century. The overestimate of the 1920s has thus compelled the basin states to reassess their plans. Although there have not been any actual shortages of water so far, the fact that there is less water today in the Colorado River system than the negotiators of the compact estimated has caused more pressure on planners than there would have been under more favorable water flow conditions.

In addition to the sharply reduced estimate of streamflow, there have been other developments which have further restricted or threatened to restrict water use in the Colorado River states. One of these was the Mexican-American Water Treaty of 1944. This treaty, which Californians vigorously opposed, awarded Mexico 1.5 million acre-feet, an amount which approximated the Republic's maximum uses prior to the agreement. The treaty requirement represents a first lien on the river and it must be satisfied ahead of any uses in the United States. According to the Colorado River Compact, Mexico is to be supplied from surplus waters unless there is insufficient surplus, in which event each basin must provide half the Mexican obligation. The two basins, however, currently disagree over the extent of their respective obligations to Mexico; the heart of their disagreement involves the manner in which the lower-basin tributaries are to be counted in determining the existence of a surplus. Both basins agree, nonetheless, about the seriousness of the Mexican burden.

The gravity of the matter was reinforced in 1961 when heavily saline "return flow"—water already used at least once—from Arizona's Wellton-Mohawk Project crossed into Mexico. While the United States insisted that the 1944 treaty imposed no obligation "with respect to the quality of the water," Mexico disagreed and demanded water as good as that which was being used when the treaty was signed. In August 1973, after lengthy negotiations between the two countries, the United States agreed to build a desalination plant at Yuma and to construct other facilities designed to provide a "permanent and definitive solution" to the salinity problem. The agreement represented a major step forward, but the future must reveal whether it will bring about the desired results.

The severest blow to Southern California's plans



Salinity is an important factor in determining the future value of this artificial inland sea as a resource for recreation and wildlife. This chart traces the salinity levels of the Salton Sea between 1948 and 1977. The values shown are the average of samples taken from Bertram Station, Desert Beach, Sandy Beach, and Salton Sea Beach.

THE ARIZONA NAVY

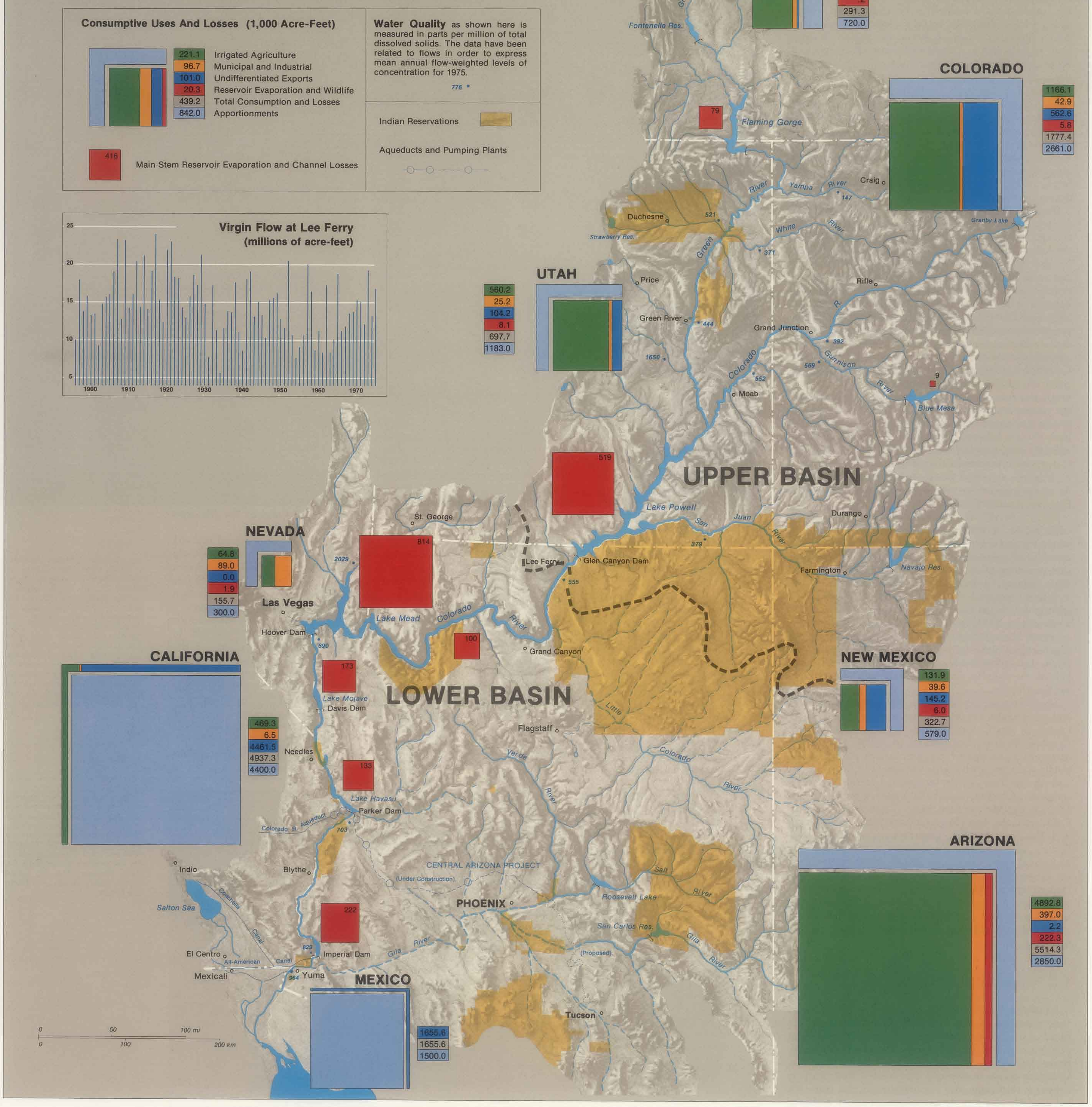
Arizona's long resistance to development of the Colorado River for California reached a bizarre turn in 1934, when the Governor of Arizona dispatched a waterborne army to "repel the threatened invasion of the sovereignty and territory of the State of Arizona." In February of that year, drilling began for the construction of Parker Dam, which would provide the principal water source for the aqueduct to California's South Coast. Although financed by the Metropolitan Water District, the dam was built by the Bureau of Reclamation because California had no authority to construct a project on the Arizona side of the river which would be used exclusively for the benefit of Californians.

On March 3, Governor B. B. Moeur of Arizona dispatched his personal secretary and Major F. J. Pomeroy in command of the 158th Infantry Regiment, Arizona National Guard, with orders to "protect the rights of the State and report at once any encroachment on the Arizona side of the river." Finding that the drilling site was virtually inaccessible by land, Pomeroy borrowed the *Julia B*, a ferryboat owned by Joe and Nellie Bush which normally plied the trade between Parker, Arizona, and Earp, California. Working their way upstream to the point at which drilling was being conducted from barges anchored to the riverbanks, the military force found its way blocked by the barge cables. The workmen, however, obligingly sent a rowboat to the *Julia B* to convey the soldiers to a suitable bivouac site upstream. Leaving a six-man scout team at the encampment, Pomeroy returned home to enthusiastic applause from loyal Arizonians who were by now calling upon Congress to dispatch the battleship *Arizona* up the Colorado to reinforce the *Julia B*.

After a nine-month vigil on the river, the scout team telegraphed an urgent message in November that construction of the dam had at last reached the Arizona side of the river. Governor Moeur immediately declared martial law in the area and ordered up the army once again, promising United States Secretary of the Interior Harold Ickes that he was prepared to "go down fighting." Eighteen army trucks carrying a hundred troops, machine guns, and a mobile hospital, set out for the dam site on November 12. Because the river was low at that time of year, the *Julia B* could not be used. The next day, Ickes ordered all work stopped, and both sides adjourned to the courts. Pointing out that the dam had not been specifically authorized by Congress, Arizona succeeded on April 29, 1935, in obtaining a court order that the dam should not be built. Four months later, however, Congress corrected its oversight, granting specific authority for the construction of Parker Dam and thereby ending the threat of military action between the states.

Colorado River Basin 1975

This map displays the amounts of water used for various purposes in each of the seven states of the Colorado River Basin and Mexico during calendar year 1975. The water is obtained from the mainstream of the Colorado River, its tributaries, and the groundwater basins. The map also details evaporative losses from the principal reservoirs on the lower mainstream, the location of major Indian reservations, the quality of flows at key stations along the river, and the Imperial, Coachella, and Mexicali valleys outside the basin. Also shown are the assumed apportionments to the four Upper Basin states, the apportionments of mainstream water for the three Lower Basin states, and the 1944 treaty obligation to Mexico. In most instances, direct comparison of apportionment to consumptive use is not possible, as explained in the accompanying discussion 'Apportionment and Use of the Colorado River Water Supply.'



APPORTIONMENT AND USE OF THE COLORADO RIVER WATER SUPPLY

The Upper Basin states and the Lower Basin states do not agree on the interpretation of the Colorado River Compact. The most significant issue of disagreement involves the Upper Basin's obligation with respect to the Mexican Water Treaty. Although the Compact apportions an average of 7.5 million acre-feet per year to the Upper Basin, it seems clear that downstream requirements and the actual water supply will limit use in the Upper Basin to less than this amount. The estimate most commonly used is that the Upper Basin will not be able to use more than 5,800,000 acre-feet per year. The Upper Colorado River Basin Compact apportioned 50,000 acre-feet per year to Arizona and the remainder according to the following percentages: Colorado 51.75, New Mexico 11.25, Utah 23.00, and Wyoming 14.00.

In the Lower Basin, the United States Supreme Court's decree in *Arizona v. California* apportioned the first 7.5 million acre-feet per year available in the lower Colorado River mainstream for consumptive use by the three Lower Basin states as follows: Arizona 2.8 million, California 4.4 million, and Nevada 300,000. If more than 7.5 million acre-feet are available, then California is apportioned 50 percent of the surplus, Arizona 46 percent, and Nevada 4 percent. During shortage conditions, the Secretary of the Interior is directed first to satisfy present perfected rights and then to apportion the amount remaining to the states. The 1968 Colorado River Basin Project Act gave California's basic apportionment of 4.4 million acre-feet per year priority over the Central Arizona Project. Streamflows from the tributaries in the Lower Basin have not been apportioned by compact nor adjudicated among the states.

For the Upper Basin states, the total water use shown on the map for Colorado and Wyoming may be compared with the indicated apportionments. The total water use shown for Utah and New Mexico includes use in both the Upper and Lower Basins, whereas the indicated apportionments are for the Upper Basin only since the Lower Basin tributaries have not been apportioned.

For the Lower Basin, the apportionment shown for Nevada is of Colorado River mainstream and tributaries. For Arizona, the apportionment shown is the sum of the state's Upper Basin apportionment plus the state's Lower Basin apportionment from the mainstream only. The water Arizona uses is drawn from three major sources: the mainstream of the Colorado River, its tributaries, and ground water basins. For California, both the apportionment shown and the total use are from the mainstream only. California's 1975 water use is in excess of the indicated basic apportionment of 4.4 million acre-feet because the 1970 Operating Criteria provides that California can use as much water as it can put to beneficial use under its contracts with the United States until the Central Arizona Project becomes operational in 1985. California has water delivery contracts with the Secretary of the Interior totaling 5,362,000 acre-feet annually.

That the Drought of 1976-77 affected other parts of the state more severely than Southern California is suggested by this photograph of the snow which fell on the Angeles Crest in January 1977—a rare event in any year but especially so in the midst of the worst drought of this century. Expanded deliveries from the Colorado enabled MWD to turn back water from the State Water Project in order to assist other regions in need.

for the Colorado occurred in 1963 in the United States Supreme Court decision of *Arizona v. California*. Arizona went to court when she proved unable to reach an agreement with California over their shares of the water apportioned to the lower basin by the Colorado River Compact. Though California in 1929 had agreed to limit itself to 4.4 million acre-feet of the 7.5 million acre-feet apportioned by the compact, this assurance had not settled fundamental differences between the two states over how Arizona's tributaries were to be counted. Aware of the declining water supply, California insisted that the tributaries be counted in a way which would lessen Arizona's share of mainstream water and thereby assure sufficient supply for California's contracts for surplus water. The court's decision disappointed California and gave Arizona a major victory. Of the first 7.5 million acre-feet available in the mainstream for the lower basin, the court, basing its opinion on its interpretation of the Boulder Canyon Act of 1928, awarded Nevada 300,000 acre-feet, California 4.4 million acre-feet, and Arizona 2.8 million acre-feet plus all the water in her tributaries. The court further apportioned 50 percent of any surplus water to California, 46 percent to Arizona, and 4 percent to Nevada.

Arizona, which currently uses about 1,250,000 acre-feet per year from the mainstream, is forecast to increase its use to 2.8 million acre-feet per year upon completion of the Central Arizona Project. Nevada's use of approximately 100,000 acre-feet per year is projected to increase to its full 300,000 acre-feet per year apportionment by the year 2000. Mexico is guaranteed 1.5 million acre-feet per year under the terms of the 1944 Mexican-American Water Treaty. The effect of the Supreme Court decision thus left California with the prospect of its uses being reduced to the basic 4.4 million acre-feet per year when the proposed Central Arizona Project becomes operative and the further prospect of additional reductions. The congressional legislation authorizing the Central Arizona Project in 1968, however, protected California's use of its 4.4 million acre-foot apportionment by assigning it a higher priority than the demands of the Central Arizona Project. Thus, diversions to the Central Arizona Project, estimated to average 1.2 million acre-feet a year, would have to be completely eliminated before California's apportionment of 4.4 million acre-feet per year could be reduced.

Water use and depletions by the United States and Mexico currently total approximately 11.4 million acre-feet per year. Reservoir losses to evaporation from Lake Mead are approximately balanced by the inflow between Glen Canyon Dam and Hoover Dam. River losses and reservoir evaporation below Hoover Dam total approximately 600,000 acre-feet per year. Thus, the current overall use of the entire mainstream, which must be essentially met by the virgin flow at Lee's Ferry, is approximately 12 million acre-feet per year. This can be compared with what is considered to be the dependable flow of the river at Lee's Ferry of about 14 million acre-feet per year. Surplus water has been going into Lake Mead and the large reservoirs constructed in the upper basin in the last decade. There has been almost no flow to the Gulf of California since 1961. If average runoff conditions prevail for the next several years, reservoirs will reach the flood control space in about five years and the probability is high that approximately 56 million acre-feet of water in storage can be obtained prior to commencement of operation of the Central Arizona Project.

Total basin uses are projected to approach the dependable annual flow of 14 million acre-feet by about 1990, after the Central Arizona Project goes into full operation. Thereafter, as annual uses in the upper basin increase to the maximum annual level of 5.8 million acre-feet that the lower basin's planners project, water could be withdrawn from reservoir storage at a rate equal to the increases in upper basin uses. Based upon current projections of future storage increases and runoff, California's water planners are therefore confident that the basic water requirements can be met for many years beyond the turn of the century. Shortages would occur earlier, however, if the rate of growth in the upper basin proceeds more rapidly than assumed, or if long periods of below-average flow should occur.

In addition to the risks inherent in any long-range forecast, however, there is another consideration which threatens to reduce California's supply of Colorado River water. This threat comes from the basin's forgotten people—the American Indians. Scattered throughout the Colorado River states are numerous reservations, including the nation's largest, the Navajo. The Indians living on these reservations possess characteristics that are the envy of no one: lowest income in the nation, highest unemployment, highest suicide rate, least formal education, highest death rate from alcoholism. Indian leaders are arguing that the economic and other conditions of their reservations cannot be improved unless they obtain a sufficient supply of water, and they have turned, or are planning to turn, to the courts for help.

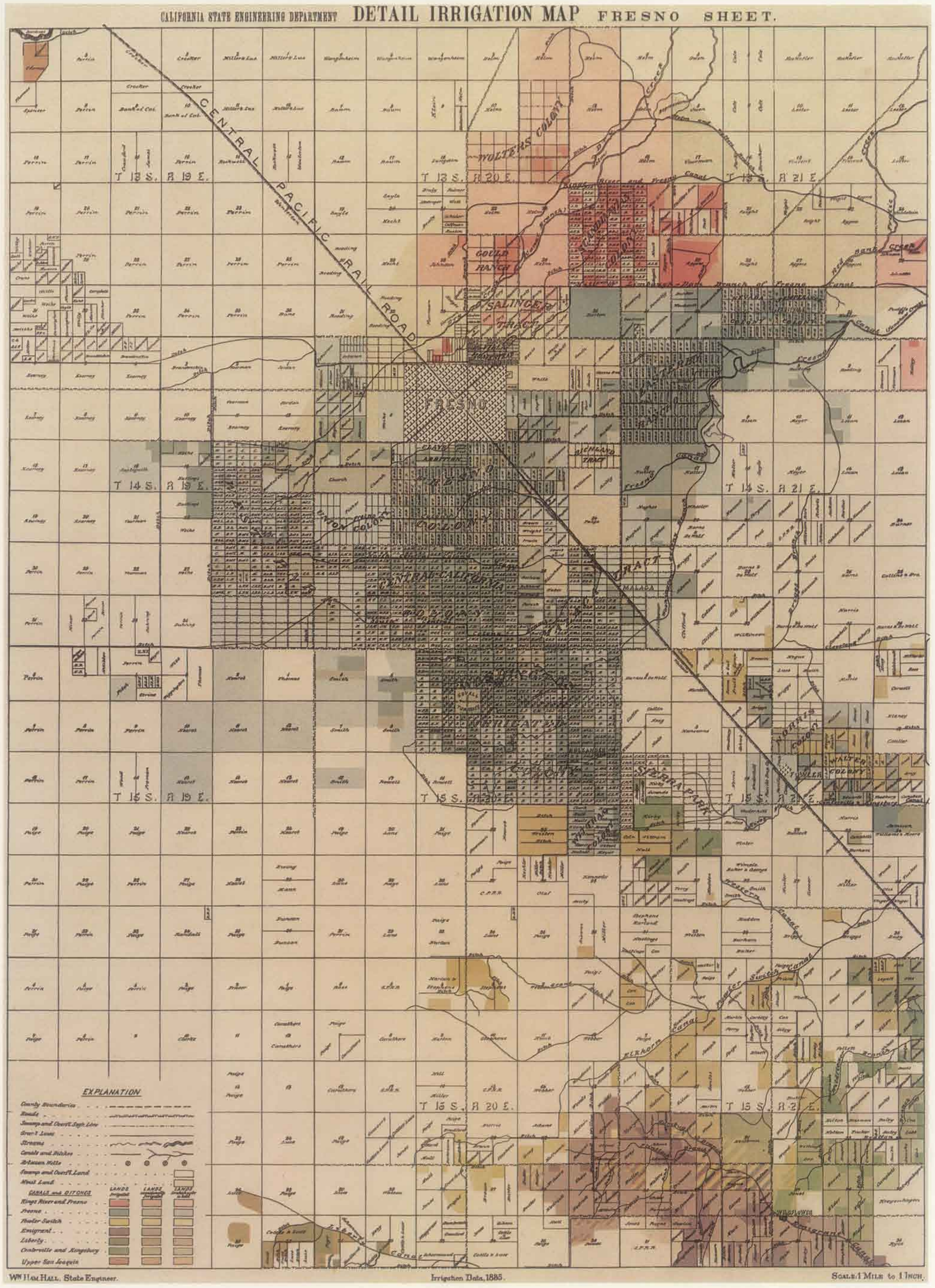
What the outcome of their suits will be is difficult to predict, but they have powerful precedents on their side. One is the so-called Winters Doctrine, first enunciated in 1908 in the U. S. Supreme Court decision of *Winters v. United States*. This doctrine holds that Indians possess a special right which dates from the time a reservation is created and continues unimpaired whether the Indians are using the water or not. In *Arizona v. California*, the court reaffirmed the doctrine and held that the quantity of the right was determined by the extent of the "practicably irrigable" acreage on the reservation. On this occasion the court limited itself to the reservations along the mainstream of the lower Colorado where five tribes are entitled to about 900,000 acre-feet of diversions, mostly in Arizona, with actual consumptive use estimated to be 600,000 acre-feet. But the decision has prompted other tribes in the basin to plan suits of their own. The Navajo, for example, have talked about suing for as much as ten million acre-feet or about 70 percent of the flow of the Colorado River. The outcome of Indian claims and their impact on Southern California's water uses will not be known for years.

Colorado River water has permitted Southern California to become one of the great industrial and agricultural centers of the world. The use of the river's waters has also led to bitter legal, political, and engineering battles and there is the prospect of more such controversies. Behind those disputes has been the realization that the Colorado contains enough water for only a limited number of cities and farms. Significant questions remain with respect to the rate of growth that will occur in the upper basin, the effectiveness of salinity control programs, the interpretation of the compact, and the extent of Indian claims. But the seven basin states have recognized that they use one common resource and that it is more advantageous to work cooperatively in resolving problems than to take adversary positions with respect to one another.

Southern California vigorously supported the State Water Project, which has been bringing about a million acre-feet of water from the northern portion of the state since 1973. Eventually, plans call for more than two million acre-feet to be diverted southward and the availability of this water will more than offset expected losses of Colorado River water and thus help to meet the needs that will be created with expected increases in Southern California's population. But water shortages will occur unless alternative sources are discovered or patterns of consumption altered. The water being brought southward, as events in 1977 indicated, can be shut down when drought hits the north. Southern California did not resist the shutdown in 1977 because sufficient water was still available from the Colorado. These conditions will change, however, as states elsewhere in the basin begin using their full shares of water.

CHAPTER 6

The Great Valley Systems



This map by Ham Hall displays the extent of irrigation in the Fresno area in 1885. The Central Colony, prototype for the plethora of water colonies clustered here, lies to the southwest of the Central Pacific Railroad line near the middle of the map.

The Central Valley and State Water Projects were born in the agricultural transformation of California's Central Valley during the first two decades of the twentieth century. Early settlers of the Central Valley had foreseen the potential of the area for irrigated agriculture if additional surface water could only be delivered to it, and the first State Engineer, William "Ham" Hall, proposed the development of a great system of irrigation canals in the 1880s. But it was the dry farming of wheat which instead dominated valley agriculture in the latter half of the nineteenth century. The ruthless exploitation of the soil by this one-crop economy, however, gradually lowered the yield of grain, and increasing competition from the Mississippi Valley and Russia brought the collapse of California's wheat empires by the end of the century. Enthusiasts of systematic irrigation such as William Smythe, author of *The Conquest of Arid America,* saw in the passing of the wheat barons a blessing for the future of California. "The fall in wheat prices has broken the land monopoly which kept labor servile and gave the most fruitful of countries to four-footed beasts rather than to men," wrote Smythe in 1900. "With the supremacy of wheat will go the shanty and the 'hobo' laborer . . . . In their places will come the home and the man who works for himself. Civilization will bloom where barbarism has blighted the land."

The turn of the century marked the end of a prolonged economic depression that had affected agriculture throughout California and the West. For the next two decades, California farmers enjoyed heightened prices for their products which were accentuated especially during the era of World War One. With prosperity came a flood of new immigrants. Between 1900 and 1920, approximately 45,000 new farmsteads were formed in California. Uniquely for the Golden State, most of the new farms were created from the subdivision of former grain and cattle ranches; only about a half million acres of new farmland came under cultivation in this period. The subdivision phenomenon produced smaller, family-sized farms than the typical mid-American quarter-section farm of 160 acres. Of the 45,000 new farms formed in this period, census data reveal that 37,600 of them were smaller than 50 acres in size. The San Joaquin Valley in particular surpassed the other regions of the state in the growth of its rural population. Fully a third of the state's overall growth in farm population occurred here, tripling the population of the area in only two decades.

The expansion of intensive, diversified, irrigated agriculture in the San Joaquin Valley followed the model established by the various colonies commercial companies had set up in the Fresno area during the 1870s. Developers such as William Chapman and Moses J. Church created the prototype Central Colony and its successors in clusters around the sites of Fresno, Selma, Dinuba, Kingsburg, and Reedley. Water companies such as the Fresno Canal and Irrigation Company laid out roads and town centers, planted shade trees, established nurseries for the culture of raisin grapevines, and divided the agricultural land into 20-acre plots. The developers sought homogenous social populations for each colony so that compatible, hard-working ethnic groups would make a successful adjustment. The settlers' water rights were made a part of their land purchase agreements.

The colonization program that began with a nationwide publicity campaign in the first decade of the twentieth century and ended in the 1920s, however, differed materially from earlier colonization efforts in other parts of the state. The promotional programs launched by the Sacramento Valley Development Association, the California Promotion Committee, the California Development Association, the colonization departments of the Southern Pacific and Santa Fe railroads, and the advertisements of innumerable land colonization companies emphasized the economic prospects of specialized farming on small acreage. The first years of the land boom after 1906 demonstrated the speculative profits that might be derived by realtors from the subdivision of large ranches where wheat land could be bought for $25 an acre and sold as prime vineyard and orchard property for prices ranging from $100 to $300 an acre. In consequence, the developers proved to be concerned principally with selling colony real estate. The customers, many of whom lacked actual farming experience, were left to their own devices once the contracts of sale and mortgage deeds had been executed.

The survival of many of these poorly planned colonies depended upon the grim determination of the original settlers, their ability to learn from adversity, and in many areas, the exploitation of groundwater resources through the introduction of centrifugal pumps powered by gasoline engines or electricity. Such was the history of the Wasco colony initiated in Kern County in 1907. The Patterson colony, established in 1909, was the first to draw its water by pumping from the lower San Joaquin River in Stanislaus County. Groundwater sources had been available in the San Joaquin Valley prior to 1900 from flowing artesian wells. But after the turn of the century, pumping became more and more a necessity. There were 597 pumped wells operating in the San Joaquin Valley in 1906; by 1910, the census reported 5,000; 11,000 in 1920; and 23,500 in 1930. A million and a half acres received the major portion of their irrigation supply from groundwater by 1940. This valuable supplement to the supply of surface streams encouraged the land boom in small farm sites. Present at all times, however, was the threat of lowering groundwater tables as the number of wells increased. The need for supplemental sources in order to halt the depletion of groundwater reserves led in time to demands for a comprehensive program of water importation.

The plight of the small farmers encouraged the coordination of water development. Some areas were dependent upon commercial or cooperative water companies for irrigation supplies that were drawn from both surface water sources and underground aquifers. During the 1920s, for example, some 400,000 acres of Miller and Lux Company lands were sold on the west side of the San Joaquin Valley. All water rights were reserved by the Miller and Lux Company, and the venerable San Joaquin and Kings River Canal Company with its 350 miles of canal sold water to subdivided tracts for less than two dollars an acre a year. Undoubtedly the most successful colonies in the Central Valley, however, were those whose members organized public irrigation districts. The advantages of this type of organization for water delivery were patent. The district raised money and built its facilities through the sale of bonds, all landowners were subject to common taxation, and democratic organization assured local responsibility and a means to solve mutual problems as the farmers became their own water suppliers.

Legislative changes in the Wright Act in 1909 and 1911 encouraged the subdivision of large, unimproved tracts in each district and provided greater security for district bonds, thus assuring their marketability. As a result, there was a real spurt in the number of irrigation districts formed after 1915. In 1922 three million acres in California were served by irrigation districts. By 1930 there were almost 100 districts financed by bonds valued at $100 million. The most successful districts in the San Joaquin Valley were the Modesto and Turlock Irrigation Districts with water rights to the Tuolumne River, the Merced District drawing from the Merced River, and the Fresno Irrigation District created in 1920 from the Fresno Canal and Irrigation Company. The financial success of the Modesto, Turlock, and Merced districts was assured by their development of storage reservoirs equipped with generators for the production and sale of hydroelectric power to local utilities. Altogether, irrigation districts provided 92 percent of the water used for irrigation in the San Joaquin Valley before the Central Valley Project came on line with its supplemental supplies.

By the time the boom in agricultural land sales finally began to taper off in the middle of the 1920s, the San Joaquin Valley was the acknowledged leader among the agricultural sections of the state. While the output of the valley as a whole was varied, individual farms and localities specialized in crops and products which had a national or statewide market and which were specially adapted to local climatic and soil conditions. Thus, cotton came to be associated with Kern County, oranges and lemons with the Porterville region, deciduous fruit and nut trees together with vines from the Fresno, Merced, and Turlock areas, alfalfa and dairy products from Modesto and the West Side. Cotton and melons also began to make their appearance on the west side of the San Joaquin River. And the Delta featured truck vegetables such as potatoes, onions, celery, and asparagus.

The realities of farming in the Central Valley before the development of the Central Valley Project often differed considerably from the idyll depicted in this nineteenth century painting of agriculture in the California paradise.

The nation's agricultural depression of the 1920s was delayed in reaching California until 1930 by continued capital investment and immigration to the state. The prevailing optimism associated with California agriculture in the 1920s was reflected in the stable value of California lands as prices remained fairly constant between 1921 and 1930. Nevertheless, trouble spots did begin to appear on the horizon in the 1920s as small farm owners found irrigation increasingly expensive. The speculatively inflated land prices were but the starting point for a small farmer's costs; to these expenses were added ground leveling, ditching, and charges for water rights. Generally it was thought that a farmer must have $5,000 in hand in order to make an effective start. As a result foreclosures and the failure rate among small farm owners were much higher than anticipated.

The mounting costs of farm operations thus seemed to favor large-scale agricultural operations. Certain areas in the San Joaquin Valley had never been subdivided but were farmed instead by corporate entities. The Kern County Land Company and its associates, for example, owned 300,000 acres drawing water from the Kern River. Corporations possessed over half the expansive Tulare Lake Basin and on the upper west side, banks, oil, railroad and food-processing companies controlled over 700,000 acres in the area that today makes up the Westlands Water District.

Tenantry was spreading. The Delta district, composed of some 350,000 acres of reclaimed land, was largely farmed by tenants of foreign extraction. Their truck crops were contracted to commission merchants who then deducted rental fees from the proceeds in favor of the large owners responsible for reclamation district operations. Alarmed by the growth of tenantry and the plight of the small farmer, the state itself inaugurated a land development colony program at Durham and Delhi in 1917. The public at large, however, considered the experiment a costly mistake with little effect on land tenure patterns and the state liquidated the program in 1930.

These mounting problems were compounded after 1917 by a series of subnormal rainfall years which encouraged overpumping and thereby depleted the water-bearing gravels in the upper San Joaquin Valley. Deeper wells consequently had to be drilled and new pumps installed. This additional $5,000 expense for a 60-acre tract proved fatal for many small operations in the disastrous drought years from 1928 to 1935 when 400,000 acres in the South San Joaquin Valley were seriously overdrawn and 20,000 acres had to be abandoned. The fate of California's most productive agricultural region thus came to be seen as dependent upon a successful state plan which would provide the engineering design for a vast water importation scheme to serve the Central Valley.

THE CENTRAL VALLEY PROJECT

Although attempts had been made for decades before 1920 to bring the state government directly into the business of water development, it was the private publication of a statewide water plan by Colonel Robert B. Marshall in that year which finally induced the state to undertake an ambitious program of water resource planning. Publicized broadly throughout the state by the California Irrigation Association in an *ad hoc* campaign subsidized by the agricultural interests of the Central Valley, Marshall's bold proposal caught the imagination of the public. Working from the concept of a coordinated, basin-wide water plan for the Central Valley, Marshall proposed the construction of a storage reservoir on the Sacramento River above Redding which would feed two parallel aqueducts running down both sides of the Sacramento and San Joaquin valleys to Dos Palos on the west and the San Joaquin River to the east. The plan also called for saltwater barriers at the Carquinez Straits and a tunnel to divert the waters of the Kern River south, through the Owens Valley to Los Angeles. Additional water for the Central Valley would also be drawn from the Stanislaus River.

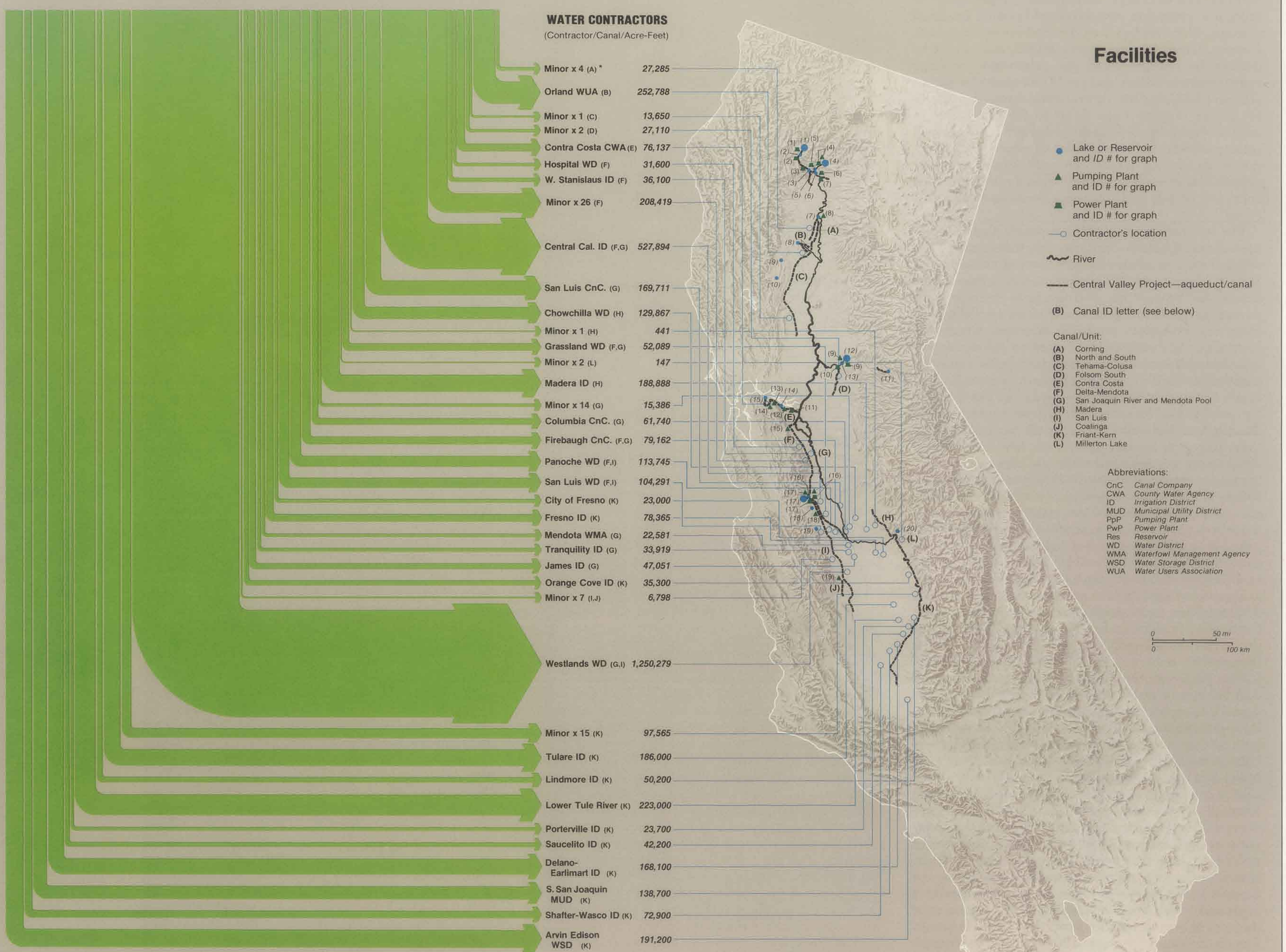
The scheme was far too grandiose to win ready acceptance among public officials and the engineering fraternity. There were more factors at work to create support for some kind of state program, however, than the emerging problems of Central Valley agriculture. A statewide conference on water use in 1916, for example, had identified navigation, irrigation, electric power generation, flood control, drainage, and land reclamation as problems needing special attention. The conference solved nothing, but it did advocate state aid for the creation of a general plan to attack these problems. Inspired by the popular enthusiasm Marshall's plan generated, and the example of the spectacular success of Los Angeles' aqueduct to the Owens Valley, the Legislature in 1921 initiated a series of comprehensive studies of California's water resources by the State Division of Engineering which eventually stretched out over the next ten years and cost over a million dollars.

The obstacles to the development of a state water project, whether Marshall's or anyone else's, were immense. For one thing, California's entire system of riparian rights had first to be modified. Those segments of public opinion most anxious for a comprehensive state water program were warned that large

Central Valley Project Water Year 1975

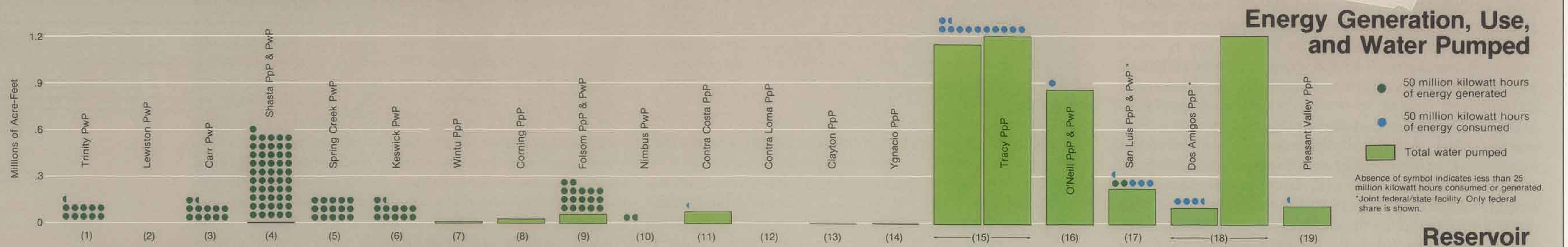
Deliveries

The width of the flow lines is proportional to the quantity of water, in acre-feet, delivered to that water contractor from October 1974 through September 1975.



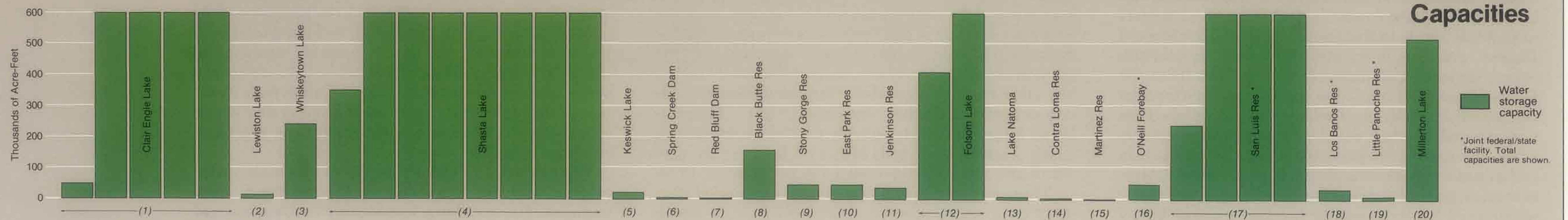
* Minor: Represents the total number of water contractors (x n) that received 20,000 acre-feet or less from that canal during the water year. The numerical figure represents the total amount delivered collectively to all these contractors.

Energy Generation, Use, and Water Pumped



Absence of symbol indicates less than 25 million kilowatt hours consumed or generated.
*Joint federal/state facility. Only federal share is shown.

Reservoir Capacities



*Joint federal/state facility. Total capacities are shown.

land holders with unrestricted riparian water rights could block the large-scale transfer of water essential to any plan. These fears, in turn, helped build support for passage of the constitutional amendment in 1928 that limited the owners of riparian rights to a reasonable use of water, the same sort of requirement heretofore imposed on appropriative water rights.

Financing proved an even more vexatious obstacle. Supporters of the Marshall Plan in the Legislature set to work implementing it through a proposed California Water and Power Act which would have provided for state distribution of all power generated by state-financed projects. The revenues from the sale of power would thus be used to offset the cost of water development. Such a proposal posed a direct threat to the private power companies, whose markets would be undercut by public power. Having failed to secure passage of the bill in the more conservative Assembly, backers of the bill promoted it as an initiative. In three successive campaigns in 1922, 1924, and 1926, the Pacific Gas and Electric Company, whose membership included virtually all of the light and power companies in Northern and Central California, paid out hundreds of thousands of dollars in support of successful efforts to defeat the proposal.

With the onset of the Depression, however, development of a water project for the Central Valley seemed a desperately needed curative for the state's troubled economy. In 1931 the State Engineer, Edward Hyatt, finally produced the results of the investigations the Legislature had begun ten years before. In his Bulletin 25, Hyatt addressed only the most critical water problems. Most of his proposed dams, canals, pumping stations, and the necessary hydroelectric generating plants to help pay for the innovative interbasin water conveyance system, however, were ultimately included in the modern Central Valley Project. The Legislature in 1933 approved the project with a provision calling for public construction of both generating plants and transmission lines. And that same year, $170 million in bonds were authorized by the voters to pay the initial costs of the project's development. PG&E fought back with a referendum campaign which attacked the project as a whole, claiming that additional irrigation would add to the state's agricultural surpluses while imposing an unfair burden on Southern California's taxpayers for a project that would benefit the northern and central portions of the state. Even though Los Angeles County voted two-to-one for repeal, the act authorizing the Central Valley Project was sustained by a narrow statewide majority December 19, 1933.

In the depths of the Depression, however, no market could be found for the state's bonds, and so they were not put up for sale. The lawmakers had foreseen the inability of the state government to finance the project and had therefore included within the act authorizing its construction a provision for negotiations to be carried forward for federal construction and operation. The first acceptance of some federal responsibility for implementing the Central Valley Project appeared in a federal-state commission report sponsored by President Herbert Hoover and Governor Clement Young in 1930. Here the recommendations were that the federal government build the dams and supporting facilities while the state would repay construction costs with interest and operate the project. The federal government would reimburse the state for flood control and navigation benefits. By 1934, however, it became apparent to state authorities that the entire burden of construction cost would have to be supported by Congressional appropriation. Thereafter, State Engineer Edward Hyatt was in the forefront of a continuing round of conversations with federal officials. Tentative proposals for loans from the Public Works Administration in Washington proved unacceptable to a financially troubled state administration. The way was finally cleared for the Bureau of Reclamation to take over construction of the project in 1935 when President Franklin D. Roosevelt authorized emergency relief funds and the Bureau turned in an approving feasibility report.

The Bureau set up its headquarters in Sacramento in 1935 and began construction of the first unit, the Contra Costa Canal, in 1937. It was blandly assumed in the Golden State that the project which had come from the state engineer's reconnaissance and drawing boards would be built at the same rate of speed the Bureau completed Hoover Dam. Development of the Central Valley Project, however, proved to be a far more complex undertaking, and the resulting delays in its construction had significant consequences for the administration of the initial facilities. There were several reasons why the project did not come on line with its first power sale from Shasta Dam until 1944 and its first delivery of Shasta Dam water to irrigators in the San Joaquin Valley until 1951. There was the time-consuming problem of right-of-way and water rights acquisition through eminent domain and purchase. Construction delays came through revamping some of the state's design to enlarge Shasta Dam and substitute the Delta-Mendota Canal for a proposed San Joaquin River pumping system. The organization of the Bureau was strained to provide engineering capability for the many public works projects it undertook in the West during the New Deal. Policy-making mechanisms for administering the new type of multi-purpose projects had to be developed from scratch. There were demands for continued local or regional control over the operations of Hoover Dam, the Columbia Basin Project, and the Central Valley Project. Most important, the outbreak of World War Two depleted the ranks of the Bureau's personnel and brought material shortages which interrupted development of many of the key structures in the Central Valley Project.

Although many of the wheat empires were initially divided up into small family farms, Mexican laborers still made up a significant part of the farm labor force in the Central Valley, as suggested by the scene at top of a summer work camp in 1897.

The celebrations of August 1951 marked the end of 14 years of construction and the fulfillment of a dream as water flowed through the Delta-Mendota and Friant-Kern canals, capping a triumphant engineering achievement in the Central Valley interbasin transfer system. The key structure was the majestic 600-foot concrete Shasta Dam which impounded 4.5 million acre-feet of Sacramento River water for release through its five generators to an afterbay created by Keswick Dam. Here, more electric power was generated and water moved downstream to meet the irrigation needs of the Sacramento and San Joaquin valleys. At the same time, the flows aided navigation, flood control, and protection of the Delta from saline intrusion. Protection of the Delta, however, was not one of the purposes of the project specified by Congress. A high-voltage power line ran to the Tracy pumping station where Shasta public power operated the pumps to lift Sacramento water to the Delta-Mendota Canal. The concrete-lined Contra Costa Canal, running 48 miles along Suisun Bay from the West Delta near Oakley to the Martinez Reservoir, began to deliver water to municipal and industrial customers in 1940 but was not completed until after the war. It represented an engineering answer to the demands of industrial and agricultural interests which had been troubled during the 1920s with saltwater seepage into groundwater tables and Suisun Bay saline pollution. The Delta Cross Channel was dredged out by Reclamation engineers between Walnut Grove on the Sacramento River and a natural slough that channeled Sacramento River water to the Tracy and Contra Costa pumping stations. The huge Friant Dam north of Fresno is a straight, concrete, gravity dam 315 feet high, which impounds a half million acre-feet from the San Joaquin River watershed. Its reservoir, Millerton Lake, provides flood control and conservation storage as well as a capability for diversion into the Madera Canal running to the Chowchilla River, and the 152-mile-long, concrete-lined Friant-Kern Canal ending at the Kern River near Bakersfield. The total cost of these initial facilities has been estimated in excess of $400 million.

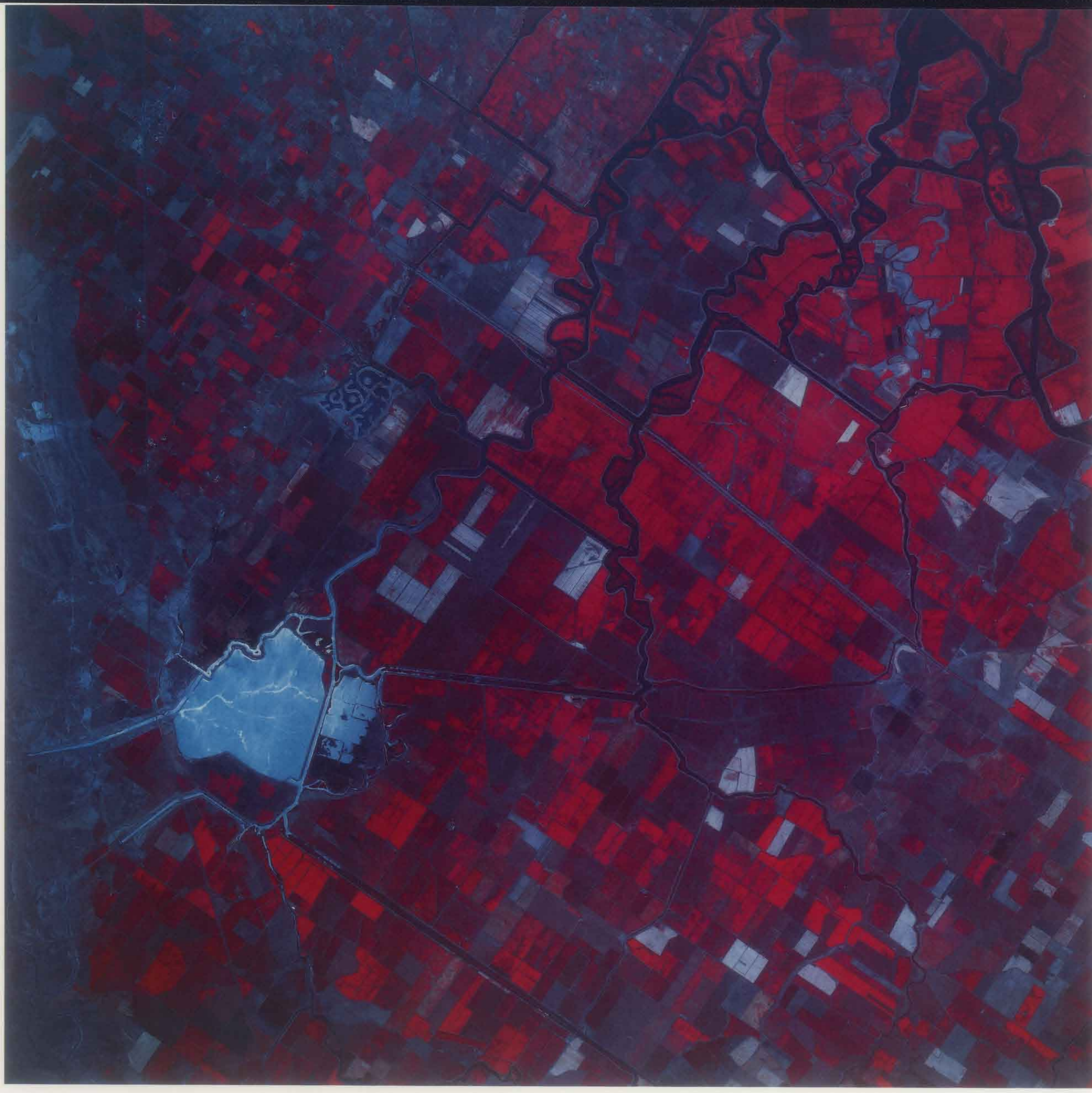
THE STRUGGLE FOR CONTROL

The extended delays in the completion of the project frustrated the efforts of New Deal social reformers to realize their goals for the distribution of public power and enforcement of the family farm provisions of reclamation law through the Central Valley Project. The years between 1944 and 1954 were, in consequence, crucial to the political struggle between California and Washington to determine how the Central Valley Project would be administered. Important decisions were made in this period concerning control of the facilities by the state or the Bureau of Reclamation, whether competing water delivery systems would be permitted to intrude upon the comprehensive, basin-wide, integrated water management system planned by the Bureau of Reclamation, and who would benefit from the distribution of cheap public power and the disposal of interest-free water for irrigation purposes.

The state Chamber of Commerce sounded the alarm in 1945 giving expression to the view that the Central Valley Project was more than a complex multipurpose water delivery system; it was a force representing a remote Washington bureaucracy which might through its irrigation and power facilities determine the shape of California's society and economy. The Chamber was reacting to the findings of the Central Valley Project Studies, a cooperative Bureau of Agricultural Economics program initiated in 1941 to anticipate social and economic impacts of the completed Central Valley Project. One study, for instance, noted the concentrations of corporate land ownership in the Central Valley and recommended changed cropping and marketing practices so that the family farm provision of reclamation law could be enforced.

A reorganization of the Bureau of Reclamation in 1944 put a strong advocate of public power and the excess lands law requirement in charge of the Bureau's activities in California. The large farm interests in the upper San Joaquin Valley were apprehensive over the strivings of the Bureau to expand its public power facilities with new transmission lines as well as a steam plant. They saw the energetic campaign for public preference customers as a betrayal of the state's Central Valley Project Act which had proposed public power development merely as an adjunct of the system to help pay for the delivery of irrigation water. Public power and the 160-acre limitation provision of reclamation law thus came to be the evils that must be exorcised. A campaign that merged the forces of the state Chamber of Commerce, the Pacific Gas and Electric Company, the Farm Bureau Federation, and the Irrigation Districts Association sought achievement of their ends through state purchase of the Central Valley Project, the introduction of the Corps of Engineers as a competitor to the Bureau in the Central Valley, and the Congressional exemption of the project's water services area from enforcement of the 160-acre limitation requirement.

In the prolonged battle against power distribution neither side could claim a complete victory. So long as PG&E refused to allow its own facilities to be used for the transmission of project power, the Bureau sought to build its own distribution system. And although PG&E through its allies in Congress successfully blocked all appropriations for the development of government-owned transmission lines while construction on the project went forward, a compromise had to be reached when the project finally came on line in 1951. Under the so-called wheeling agreement of that year, power



The reclaimed areas in the photograph above have been turned into richly productive croplands through the development of the modern water system. Clifton Court and the facilities of the State Water Project and Central Valley Project are at the lower left and the San Joaquin River is at the upper right corner.

generated at Shasta was transmitted by the Central Valley Project to its pumping station at Tracy over its own lines. In exchange, PG&E became the retail distributor for the project's public preference customers. The Bureau was denied its own steam generating plant to provide back-up power — PG&E agreed to provide that service. PG&E buys power from the project at nearly the same low rates the Bureau charges to its preference customers, but the power PG&E buys is only that which is surplus, after the project's needs and those of the Bureau's preference customers have been met. The rates at which PG&E sells project power are much higher than the public power advocates demanded in their zeal to provide cheap electricity for the public. But the large farm interests approved the rates because they help to pay a substantial portion of their irrigation water costs. The wheeling agreement has had the effect of binding the Bureau and PG&E together in a mutually beneficial arrangement. PG&E gets cheap power the project cannot use, and this helps delay the utility's need to build new power plants of its own. The Bureau, in turn, is able to extend the distribution of project power at low rates to a wider range of customers.

In 1944 representatives of California's major agricultural interests in Congress secured the passage of a flood control act which authorized the Corps of Engineers to initiate a chain of dams in the Central Valley whose principal function of flood control also provided water conservation capability. Although few of the Corps' projects could be integrated into the Central Valley Project, these proposed dams interfered with the original intent of the Central Valley Project to coordinate the flow of water and power throughout the basin under unified Bureau of Reclamation direction. Rivalry between the Bureau of Reclamation and the Corps of Engineers prompted both agencies to advance planning documents on proposed future dams for the Central Valley in the late 1940s and early 1950s. Of the initial series of Corps projects, only Folsom Dam was integrated into the Central Valley Project and subsequent efforts at coordination between the two federal agencies have not prevailed.

Because the Bureau markets all irrigation water from Corps projects in the West, the intervention of the Corps in Central Valley water development did nothing to relieve corporate farms within the Bureau's service area from the strictures of the 160-acre limitation. The large-scale agribusiness concerns, in league with many irrigation districts, have therefore fought the imposition of family farm controls on Central Valley Project service area lands from 1944 until the present day. In memorable Congressional struggles in 1944 and again in the period 1947-49, efforts to secure exemption for the Central Valley Project from the 160-acre limitation met defeat. Efforts to challenge these limitations in the courts were finally blocked as well in the United States Supreme Court *Ivanhoe Irrigation District v. McCracken* decision in 1958. Administrative devices, like the use of ten-year recordable contracts, combined with fluctuating degrees of enthusiasm for enforcement by federal authorities, relaxed the most immediate constraints of the law, but the threat of its implementation remained.

The movement for state purchase of the Central Valley Project came to nought when the system became fully operational in 1951. Many districts were quick to sign up for the interest-free federal water which eased the problems of groundwater depletion in the eastern San Joaquin Valley. Support for state ownership of the project facilities fell away, in the last analysis, because of the sheer cost of purchase. Inquiries had been made in 1945 when the Secretary of the Interior suggested a purchase price of $357 million. In 1952 the Legislature appropriated $10 million for feasibility studies of the proposal. But in 1954 the drive for state purchase foundered on the Bureau of Reclamation's reappraisal which doubled the value of the project. Governor Goodwin Knight's decision in October 1954 to drop the proposal altogether thus shifted attention to plans which the State Engineer, A. D. Edmonston, had put forward for the state to construct its own project on the Feather River.

THE STATE WATER PROJECT

Despite the opening of the Central Valley Project in 1951, the rush of migration to California in the years after World War Two combined with corporate agriculture's dissatisfaction with the 160-acre limitation to create a renewed interest in state development of additional water supplies to serve California's swelling population. In 1945 the Legislature created the State

THE 160-ACRE LIMITATION

Few legislative acts have had as enduring an effect in creating the economic basis for the modern prosperity of the western United States as the adoption under the administration of President Theodore Roosevelt of the Reclamation Act of 1902. In addition to creating the modern Bureau of Reclamation, this act and its succeeding amendments established a framework for the administration of lands benefiting from the Bureau's programs which has been the focus of intense controversy through this century.

Rather than breaking up large landholdings already in existence in 1902, the reclamation act sought in part to create new farmlands in the 17 contiguous states west of the 100th meridian which would then be reserved for settlement as small family farms. As Roosevelt told the Congress in calling for the reclamation act, "These irrigation works should be built by the National Government, the lands reclaimed by them should be reserved by the Government for actual settlers, and the cost of construction should, so far as possible, be repaid by the lands reclaimed....Our people as a whole will profit, for successful homemaking is but another name for the up-building of the nation."

In order to assure that reclamation projects will not be operated for the benefit of large landowners within their service areas, the act requires that water from these public projects cannot be delivered to landholdings larger than 160 acres. Individual owners or the members of a family may, however, combine their 160-acre plots into larger agricultural operations. And no single owner of more than 160 acres can be compelled to break up his holdings so long as he does not take water from the project for more than 160 acres. But those who do are required to sign contracts agreeing to sell any lands in excess of this 160-acre limitation within a specified period of their first receipt of project water. Lastly, in order to prevent these owners from profiting unduly from the sale of their lands at the increased values they would obtain as the result of the availability of project water, an amendment to the original act in 1926 provided that these "excess" lands must be sold at a price approved by federal officials that reflects the value of the land without the delivery of project water.

Since its adoption, virtually every aspect of the act has been the object of extended litigation and the precise effect of the 160-acre limitation and the obligations it creates for landowners is a question that remains before the courts today. As the agency responsible for enforcement of the 160-acre limitation, the Bureau of Reclamation has been criticized at various times and in different quarters for being either too lax or too vigorous in its efforts to implement the restriction. No state, however,has benefited more than California from federal reclamation programs, and in no state, consequently, has the contoversy over the 160-acre limitation raged with greater intensity. Of the 16,891,000 acres subject to the excess lands provision in all Bureau of Reclamation projects throughout the United States in 1977, fully 4,867,00 lay within California.

In recent years, questions involving the enforcement of the 160-acre limitation within California have centered upon two of the state's largest agricultural districts: the Imperial Irrigation District and the Westlands Water District. The Imperial Irrigation District secured a letter from the outgoing Secretary of the Interior, Ray Lyman Wilbur, in the closing days of the Herbert Hoover Administration supporting the district's contention that it should be exempt from the 160-acre limitation because its lands and irrigation systems had already been partly developed before the completion of the All-American Canal. Although the district has relied upon that letter in the years since, the federal government has sought since the 1960s to compel the district to accept a new water service contract which would apply the 160-acre limitation to lands of the Imperial Irrigation District. This question is still pending in the courts.

At least 217,700 of the approximately 600,000 acres in the Westlands Water District must be sold as excess lands between 1978 and 1987 under the contracts district landowners signed when they first accepted water service from the San Luis Unit. In addition, the district needs to enter into new water service and construction contracts with the Department of the Interior in order to continue receiving federal funds for the further development of the district's water distribution and drainage system. Numerous questions concerning the operations of the district and its compliance with federal law, however, were raised by a local, state, and federal task force in 1978. The administration of future land sales in the Westlands district and the precise terms of the contracts the district requires are consequently unresolved questions at this time.

Water Resources Control Board and directed it to make a comprehensive investigation of the water resources of California and to develop plans for a project to meet California's water needs in the near future. These studies were carried out for the board by the Division of Water Resources of the Department of Public Works. The first phase of the comprehensive study, and inventory of water resources throughout the state, was published in 1951.

The publication of the inventory coincided with the appearance of two proposals for the development of new water projects, one by the Bureau of Reclamation, and the other by the state engineer. The Bureau approached the problem of California's water supply from a broad perspective that took into account the needs of neighboring western states. Its study proposed the diversion of more than six million acre-feet from the Klamath River, whose flows California shares with Oregon, to serve the Central Valley and South Coast of California. Of this total, only 286,000 acre-feet would go to municipal uses, although the Bureau proposed taking another 1.2 million acre-feet from the Colorado River basin for unspecified purposes. Even more dramatic from the point of view of California's water planners, the Bureau proposed allocating the waters of Los Angeles' Owens Valley aqueduct to the Mojave Desert and diverting a part of the flow of the American River to Nevada.

Although Edmonston's report contained many of the features of the Bureau plan, it excluded, of course, the controversial proposals for massive shifts in the sources of Southern California's water supply and diversions to other states. Instead, Edmonston proposed a much smaller project to divert water from the Feather River to a multi-purpose dam, reservoir and power facility near Oroville which would control floods, augment the natural dry-weather flows to the Sacramento-San Joaquin Delta, and provide a source of supply for a state-constructed delivery system to transport water from the Delta to portions of the San Francisco Bay Area, the farmlands in the San Joaquin Valley, and to the people and industry of Southern California.

The Legislature authorized funds for continued planning for Edmonston's proposal and in early 1955, Edmonston made a more detailed report which reviewed the engineering and financial feasibility of the project and recommended modifying the original plan to include the San Luis Reservoir in the western San Joaquin Valley and additional service to the Bay Area. This report was then submitted to the Bechtel Corporation, an independent consulting firm, which approved the basic engineering concepts and financial arrangements by year's end. That winter a devastating flood hit Northern and Central California, causing loss of life and extensive property damage. This disaster pointed dramatically to the need for flood control on the Feather River and, with the start of its next session, the Legislature appropriated over $25 million to begin preliminary work on the Feather River Project.

The state government, however, had never constructed a water supply project of any size and was poorly organized to undertake a project of the dimensions Edmonston proposed. There were 52 independent California agencies with responsibility for some aspect of water development and more than 90 state officers working on water problems without coordination or central direction. Eight separate agencies dealt with questions of water rights, 14 handled pollution control, three flood control, and planning was conducted by four different offices. To bring order to this tangled bureaucracy, Governor Knight called a special legislative session in 1956 which created the Department of Water Resources as an amalgam of these formerly independent entities.

With the groundwork thus laid for his project, and his office as State Engineer abolished as a result of the formation of the new department, Edmonston retired. While inventories of the state's water resources continued and studies of alternative routes for the project were pressed forward, the task of building popular support for Edmonston's proposal fell to the *ad hoc* Feather River Project Association. Enthusiasm for the project, however, remained concentrated in the agricultural interests of the San Joaquin Valley. Edmonston had succeeded in enlisting urban allies in the Santa Clara Valley by including the Alameda-Santa Clara-San Benito Aqueduct in his 1951 proposal to supply the rapidly expanding communities of the South Bay. But most water interests in the north were unhappy with plans to export "their" water. If surplus water were to be sent south, they wanted the right to the water when they needed it. They also wanted funds to develop their own local projects.

To a greater extent probably than any other part of the state, the development of agriculture in the Central Valley has been the product of technological innovation. Before the introduction of centrifugal pumps powered by gasoline or electricity made the use of groundwater possible on a large scale, valley farmers experimented with wind and horse power to pump the water they required.

Even worse, the urban communities of the South Coast who were the proposed beneficiaries of the project greeted the plan through their representatives on the Metropolitan Water District with suspicion and outright hostility. Although their supply from the Colorado was threatened by the suit Arizona filed in 1952, many directors of MWD were reluctant to weaken their case before the Supreme Court by committing themselves to a large alternative source of water from the proposed state project. And, although Southern Californians recognized that they would eventually need an additional source of water, they were afraid that if they contracted for water from the Feather River, the Legislature at some future time might overturn their contracts, taking back "their" water for Northern California.

MWD, representing most of the population in that area, therefore demanded a state constitutional amendment guaranteeing its water deliveries from the project. When two-thirds of the state legislators proved unable to word an amendment acceptable to the different water interests they represented, MWD was in the forefront of the opposition to bills authorizing the project in 1958 and 1959. Under the leadership of Governor Edmund G. Brown, Sr., however, a new approach was tried. Instead of a constitutional amendment, guarantees for the proposed delivery contracts were written into a bond measure to be passed by the Legislature and submitted to the voters of the state. Although still opposed by MWD, this State Water Resources Development Bond Act, known as the Burns-Porter Act, passed the Legislature in 1959, subject to ratification by the voters at the 1960 General Election. In addition to authorizing $1.75 billion in general obligation bonds to help finance construction of specific state water facilities, the act provided for future dams on northern rivers and a drain to remove agricultural wastewater from the Central Valley.

The act attempted to strike an accommodation between competing regional interests. For the northern part of the state, it specifically guaranteed protection of water rights in the areas of origin of the water, and provided that $130 million from the sale of the bonds would be designated for loans and grants to public agencies for construction of local water projects as provided in a companion bill called the Davis-Grunsky Act. For water interests in the south, it required that the state not impair contracts for sale and delivery of water during the lifetime of the bonds. The campaign for authorization of the bonds in 1960 nevertheless became one of the most fiercely contested elections in the history of the state.

Proponents cited the need for water for California's rapidly growing cities and to supplement the badly overdrawn groundwater basins in agricultural areas. But many Northern Californians simply did not want Southern California taking "their" water. While some people felt that the state must help provide water for the growth of the Los Angeles area, especially if water from the Colorado River were not available, others did not want to provide water which they felt would encourage growth in an area which could not accommodate it. Some believed that the state's high rate of growth would not continue unabated, that the projections of future water needs were consequently unrealistic, and that the water, therefore, would not be sold. While the large-scale, industrialized farmers in the San Joaquin Valley were anxious for a new source of water not subject to acreage restrictions by the federal government, the State Grange opposed the project and many people felt that the 160-acre limitation was desirable in order to preserve small family farms. Organized labor, which today provides one of the most resolute reservoirs of support for public works projects of every kind, split on the issue of the bonds. While the teamsters, steelworkers, and operating engineers supported the project, the California Labor Federation opposed it, arguing that the project would principally benefit agribusiness, which the Federation regarded as the enemy of the farmworkers it hoped to organize. Environmentalists pointed to possible adverse effects on the Delta and San Francisco Bay, and the future dangers of development on the North Coast rivers. Furthermore, they felt that not enough attention had been paid to

VALLEY DELIVERERS

In contrast to Mulholland and Chaffey, the self-taught geniuses who shaped water development in an earlier era, the men who conceived the Central Valley Project and State Water Project were products of the governmental bureaucracies and twentieth century engineering professions which have come to dominate the modern course of water development. Robert Bradford Marshall joined the United States Geological Survey after his graduation from Columbian (now George Washington) University in 1888, and rose over the next 20 years to become its chief geographer. Arthur D. Edmonston, a native Californian, took his civil engineering degree from Stanford University in 1910 and spent virtually his entire professional career inside the Department of Water Resources.

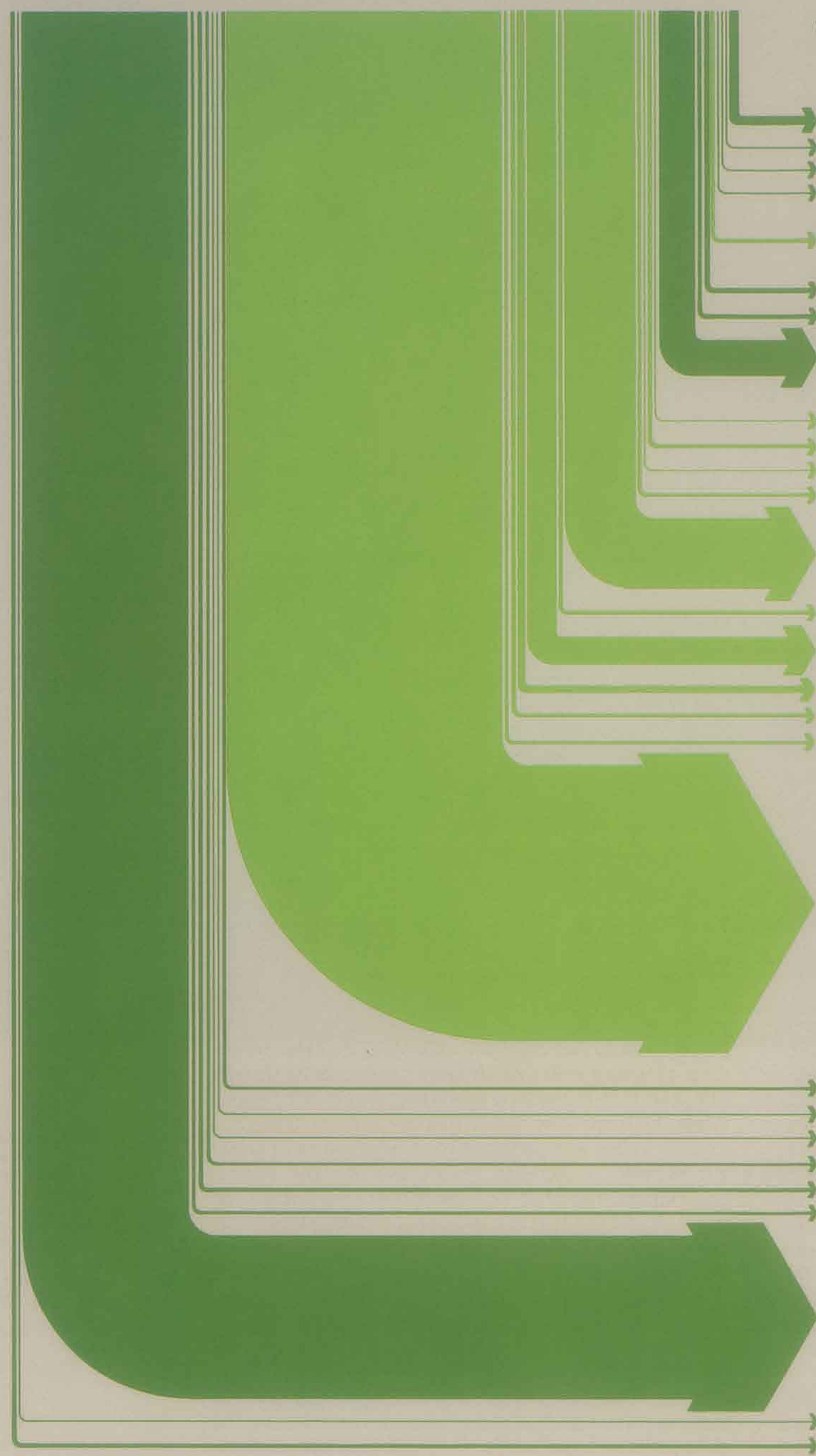
Both men served with the army engineers during World War One; Marshall as a Lieutenant Colonel, Edmonston as a Second Lieutenant. But, whereas Edmonston joined the state after the war, Marshall left government service in 1919 to promote his plan for the Central Valley. The long hours Marshall devoted to arguing for his project ultimately cost him his voice, although a bellows-like device developed by the Bell Telephone Company in 1929 enabled him to regain at least partial speech.

Following the loss of his campaign and the decision to turn development of the Central Valley Project over to the federal government, Marshall ended his career as an employee of the California Division of Highways. Marshall lived to see the transformation of his dream into concrete reality before his death in 1949, and it was Edmonston, as the state's Principal Hydraulic Engineer, who was responsible for drawing up many of the specific plans and designs for the Central Valley Project. Edmonston, however, died within a year of his retirement and so never saw his plan for the State Water Project take shape.

State Water Project Water Year 1975

Deliveries

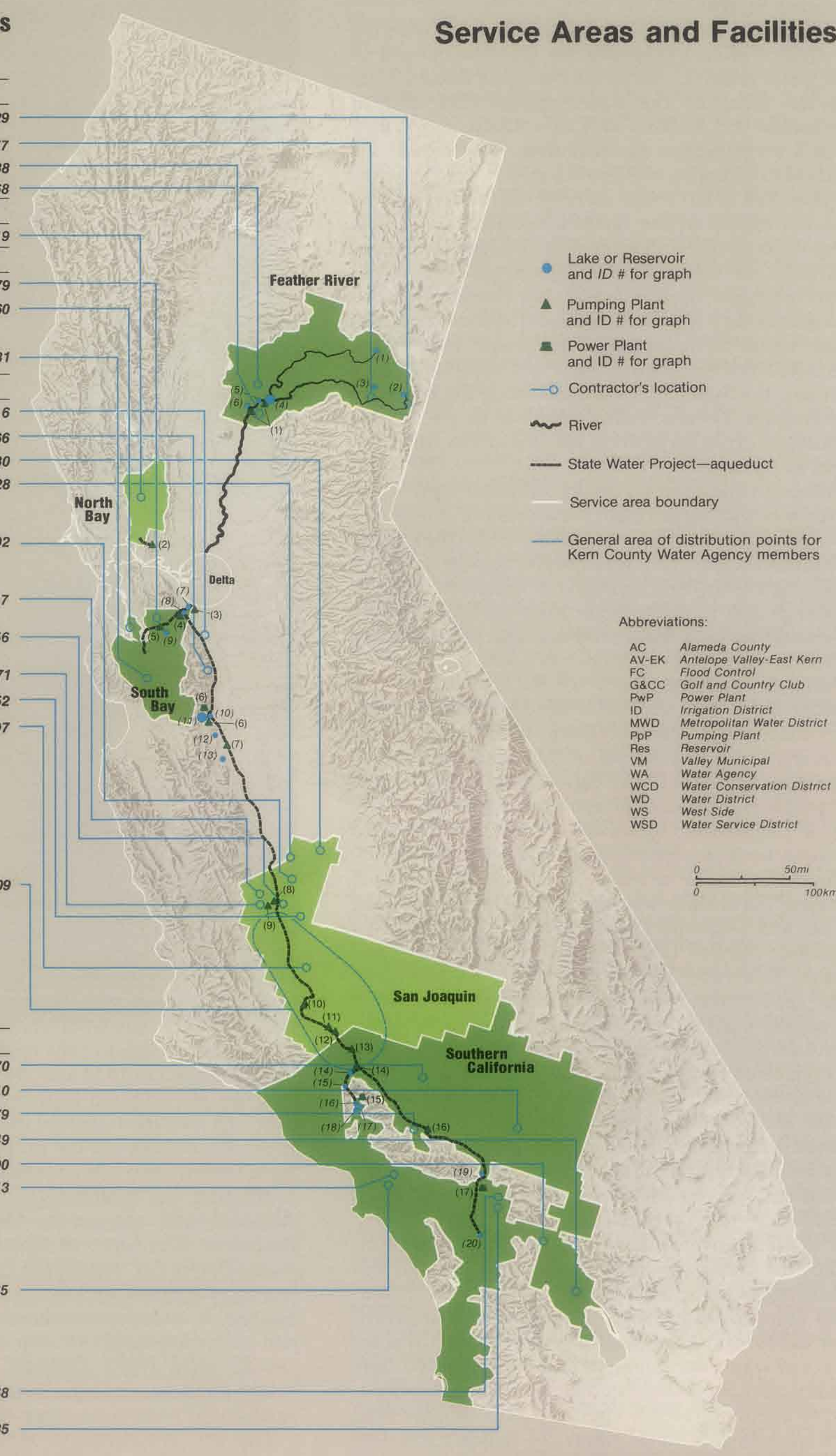
The width of the flow lines is proportional to the quantity of water, in acre-feet, delivered to that water contractor from October 1974 through September 1975.



WATER CONTRACTORS (Contractor/Acre-Feet)

Contractor	Acre-Feet
Feather River	
Last Chance Crk WD	19,129
Plumas FC&WCD	477
Butte County	238
Thermalito ID	468
North Bay	
Napa FC&WCD	6,919
South Bay	
ACFC&WCD (#7)	17,179
Alameda Co. WD	5,760
Santa Clara Valley WD	103,881
San Joaquin	
Tracy G&CC	6
Oak Flat WD	7,266
Kings County	1,580
Empire WSID	6,528
Tulare Lake WSD	201,202
Green Valley WD	2,217
Dudley Ridge WD	80,356
Devil's Den WD	16,871
Hacienda WD	8,952
Buena Vista WSD	6,397
Kern County WA	788,409
Southern California	
AV-EK WA	6,870
Mojave WA	10
Littlerock Crk ID	779
Coachella WD	6,849
Desert WA	10,900
San Gabriel VMWD	2,713
MWD-Southern California	479,565
Crestline-Lake Arrowhead WA	768
San Bernardino VMWD	5,385

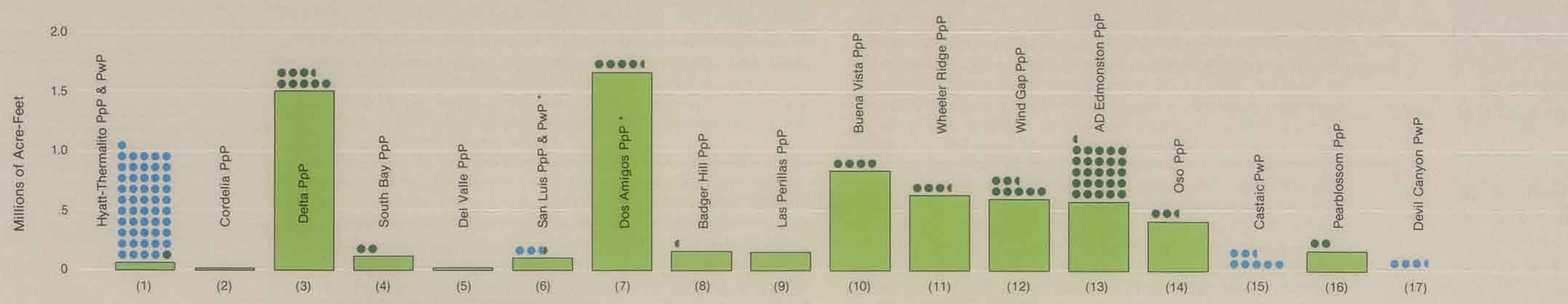
Service Areas and Facilities



Abbreviations:

AC	*Alameda County*
AV-EK	*Antelope Valley-East Kern*
FC	*Flood Control*
G&CC	*Golf and Country Club*
PwP	*Power Plant*
ID	*Irrigation District*
MWD	*Metropolitan Water District*
PpP	*Pumping Plant*
Res	*Reservoir*
VM	*Valley Municipal*
WA	*Water Agency*
WCD	*Water Conservation District*
WD	*Water District*
WS	*West Side*
WSD	*Water Service District*

Energy Generation, Use, and Water Pumped

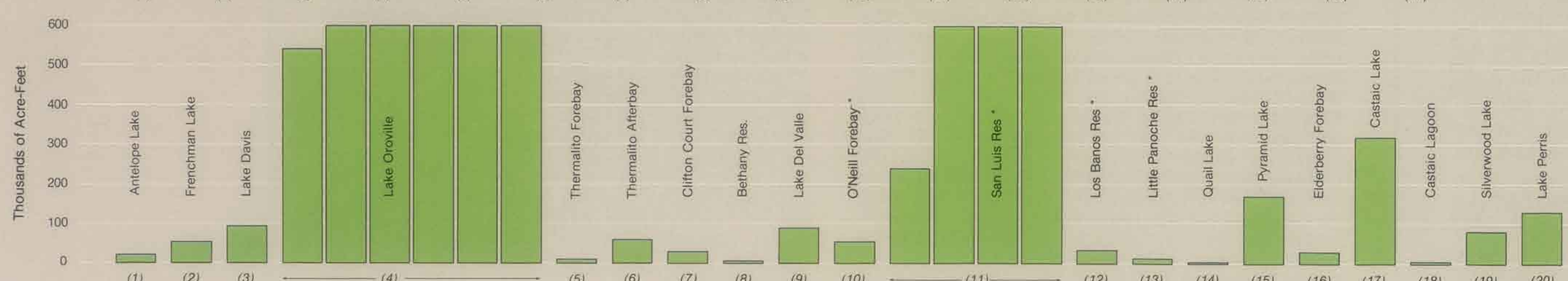


The graph compares the amount of energy generated by power plants along the system with the still larger amount of energy consumed by pumping plants to maintain flows within the system and to lift water over physical barriers. The absence of a symbol for certain pumping plants indicates the energy consumed was less than 25 million kilowatt hours.

- 50 million kilowatt hours of energy generated
- 50 million kilowatt hours of energy consumed
- Total water pumped

*Joint federal/state facility. Only state share is shown.

Reservoir Capacities



Project reservoirs have a total storage capacity of about 6.8 million acre-feet. Seasonal variations in supply and demand produce significant differences in the amount of water stored in a given month. Also, the reservoirs provide different functions for the system. Oroville, for example, retains water near its source in the Sierra; San Luis stores water in transit within the system; and Pyramid holds water for distribution to an urban area.

- Water storage capacity

*Joint federal/state facility. Total capacities are shown.

alternative sources of water such as desalination, geothermal deposits, and wastewater reclamation, although others pointed out that these alternative sources of water were not yet economically available.

Controversy focused especially upon the provisions of the bond measure for financing the project. Of the estimated $2.5 billion total cost of the project, only $1.75 billion would be covered by the sale of bonds. The Burns-Porter Act appropriated to the project portions of the state tideland oil revenues, which project proponents hoped would provide another $500 million by the time these funds were needed for construction. But the Davis-Grunsky Act pledged $130 million from the bond sales for a host of local projects, the promise of which had been crucial in lining up votes for the proposal in the Legislature. Additional promises had been given for so-called "second stage works" which opponents argued would cost the equivalent of all the tideland oil revenues set aside for the project itself.

In an effort to resolve these questions and additional complaints that the discount rate used for evaluation was too low and that the proposal underestimated the effects of inflation, the state retained two independent consulting firms to report on the project's economic feasibility. Two weeks before election day, their published reports gave a qualified endorsement of the plan but noted that the funding was sufficient only if inflation did not further erode the value of the dollar. The failure of this conclusion to resolve the controversy is suggested by the fact that the *Los Angeles Times*, which supported the project, reported that the consultants had given the plan a "sound rating" while the *San Francisco Chronicle*, virulent in its opposition, headed its story on the reports, "State Water Plan Called Impossible."

As the election drew near, MWD's board of directors began to waver in their adamant opposition to the plan. When the Burns-Porter Act first cleared the Legislature, MWD made clear its rejection of the plan by announcing plans to develop a project of its own, tapping the Eel River for the benefit of the South Coast. When this gesture of defiance prompted memories throughout the state of Los Angeles' activities in the Owens Valley, MWD found its position increasingly isolated as communities in the South Coast began individually endorsing the project. Four days before the election, the board reversed its earlier opposition and signed a contract with the state for the delivery of 1.5 million acre-feet of project water. On November 8, the bond issued passed by a margin of 173,944 votes out of a total of 5.8 million cast. Widespread popular support in Sothern California delivered this narrow victory; among the counties of Northern California, the bond issued passed only in Butte County, site of the proposed dam at Oroville.

MODERN OPERATIONS

The 1950s, when the State Water Project was proposed, planned and designed, was a period of widespread expansion for water projects throughout California. While the state was raising funds for its own project, Congress, under the leadership of friends of California water development such as Clair Engle, untied the federal purse strings. In 1949 the Bureau of Reclamation published a study of the Central Valley Basin which detailed no less than 38 future dam sites for multi-purpose projects with connecting canals and power support facilities. And the two decades which followed saw the implementation of many of these proposals.

Unplanned irrigation diversions from the Sacramento River brought an awareness that Shasta Dam did not provide enough capacity to meet the manifold water requirements of the Delta Pool. Folsom Dam, the major facility of the American River Division, was built by the Corps of Engineers between 1948 and 1956 and then taken over by the Bureau, which built Nimbus Dam as a downstream regulating facility. When the Sacramento Valley Canals Unit was sent to Congress by President Harry S. Truman, he tied its construction to a North Coast or Trinity River source for augmenting flows in the Sacramento River. The Trinity River Division, built between 1957 and 1964, carries water from Clair Engle Lake to the Lewiston Dam, then through a 17-mile tunnel through the Coastal Range to Whiskeytown Dam before reaching the Sacramento at Keswick Dam. The San Luis Unit, a combined operation with the State Water Project, also had its inception in the Bureau's Central Valley plans of 1949. Its reservoirs were designed to augment the underground water table on the west side of the San Joaquin Valley where a half million acres of farmland

Future Deliveries of the State Water Project

CONTRACTOR Type of Water	1975 Actual Delivery	1975 Contracted Entitlement	Maximum Annual Contracted Entitlement	First Year of Maximum Entitlement
Feather River Service Area				
1. Butte County				
Entitlement Water	253	1,050	27,500	1990
2. Last Chance Creek Water District				
Regulated Delivery of Local Supply	18,602	——	——	——
3. Plumas County Flood Control and Water Conservation District				
Entitlement Water	405	560	2,700	2016
4. Thermalito Irrigation District				
Regulated Delivery of Local Supply	413	——	——	——
5. Yuba City				
Entitlement Water	0	0	9,600	1990
North Bay Service Area				
6. Napa County Flood Control and Water Conservation District				
Regulated Delivery of Local Supply	6,840	——	——	——
Entitlement Water	0	0	25,000	1990
7. Solano County Flood Control and Water Conservation District				
Entitlement Water	0	0	42,000	1990
South Bay Service Area				
8. Alameda County Flood Control and Water Conservation District - Zone 7				
Entitlement Water	4,618	16,000	46,000	1997
Regulated Delivery of Local Supply	11,702	——	——	——
9. Alameda County Water District				
Entitlement Water	986	20,500	42,000	1994
Regulated Delivery of Local Supply	7,739	——	——	——
10. Santa Clara Valley Water District				
Entitlement Water	88,000	88,000	100,000	1994
Surplus Water	18,470	——	——	——
San Joaquin Valley Service Area				
11. Buena Vista Water Storage District				
Repayment of Preconsolidation Water	6,797	——	——	——
12. Devil's Den Water District				
Entitlement Water	10,700	10,700	12,700	1977
Surplus Water	7,495	——	——	——
13. Dudley Ridge Water District				
Entitlement Water	40,555	40,555	57,700	1990
Surplus Water	40,555	——	——	——
14. Empire West Side Irrigation District				
Entitlement Water	3,000	3,000	3,000	1969
Surplus Water	3,448	——	——	——
15. Green Valley Water District				
Surplus Water	2,217	——	——	——
16. Hacienda Water District				
Entitlement Water	3,758	3,758	8,500	1990
Surplus Water	3,759	——	——	——
17. Kern County Water Agency				
Entitlement Water	410,820	410,820	1,153,400	1990
Surplus Water	410,820	——	——	——
18. Kings County				
Entitlement Water	1,600	1,600	4,000	1987
19. Oak Flat Water District				
Entitlement Water	3,576	3,576	5,700	1990
Surplus Water	3,576	——	——	——
20. Tulare Lake Basin Water Storage District				
Entitlement Water	82,500	82,500	110,000	1990
Surplus Water	132,206	——	——	——
Central Coastal Service Area				
21. San Luis Obispo County Flood Control and Water Conservation District				
Entitlement Water	0	0	25,000	1990
22. Santa Barbara County Flood Control and Water Conservation District				
Entitlement Water	0	0	57,700	1990
Southern California Service Area				
23. Antelope Valley-East Kern Water Agency				
Entitlement Water	8,068	35,000	138,400	1991
24. Castaic Lake Water Agency				
Entitlement Water	0	7,500	41,500	1991
25. Coachella Valley County Water District				
Entitlement Water	7,000	7,000	23,100	1990
26. Crestline-Lake Arrowhead Water Agency				
Entitlement Water	825	1,450	5,800	1990
27. Desert Water Agency				
Entitlement Water	11,000	11,000	38,100	1990
28. Littlerock Creek Irrigation Disirict				
Entitlement Water	520	520	2,300	1990
Surplus Water	356	——	——	——
29. Metropolitan Water District of Southern California California				
Entitlement Water	526,958	555,200	2,011,500	1990
30. Mojave Water Agency				
Entitlement Water	0	15,400	50,800	1990
31. Palmdale Water District				
Entitlement Water	0	5,580	17,300	1990
32. San Bernardino Valley Municipal Water District				
Entitlement Water	13,865	52,500	102,600	1991
33. San Gabriel Valley Municipal Water District				
Entitlement Water	5,450	13,100	28,800	1990
34. San Gorgonio Pass Water Agency				
Entitlement Water	0	0	17,300	1990
35. Ventura County Flood Control District				
Entitlement Water	0	0	20,000	1990
TOTAL STATE WATER PROJECT	1,911,152[1]	1,386,869	4,230,000	2016

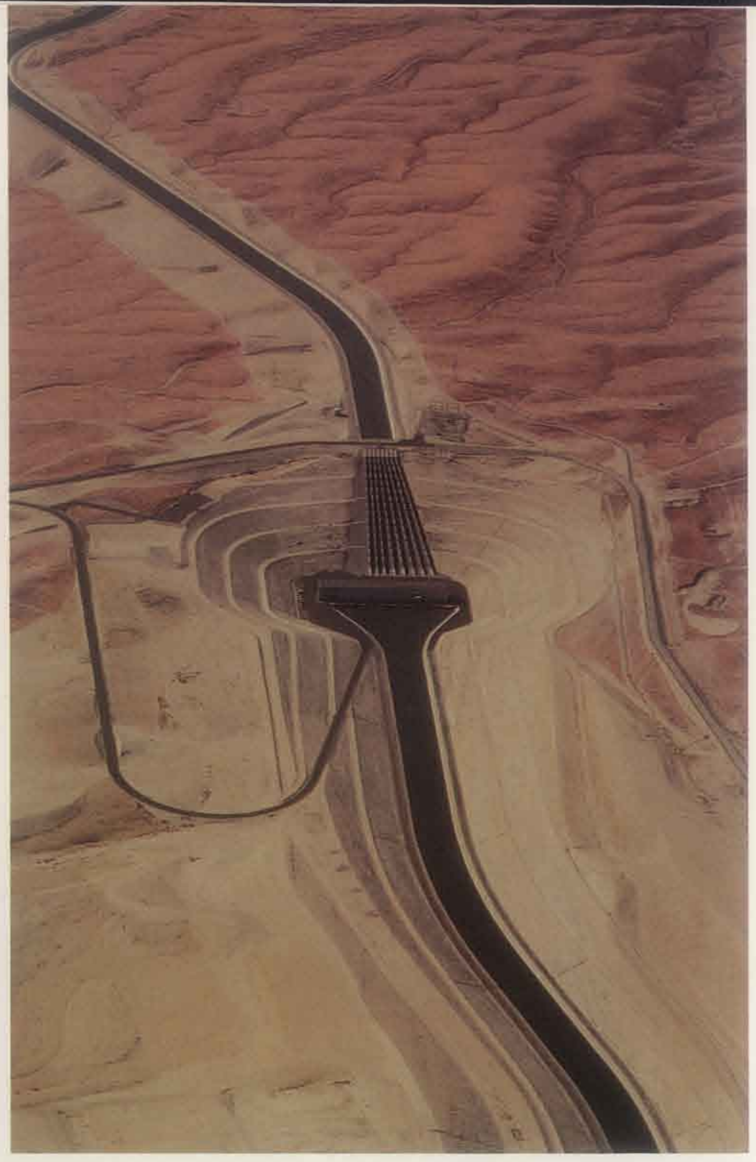
1. This total includes 11,700 acre-feet wheeled for the United States Fish and Wildlife Service to the San Joaquin Valley Service Area.

The configuration of water deliveries shown on the map of the State Water Project is scheduled to change dramatically under the contracts the Department of Water Resources has entered into for the future. This table compares the actual deliveries made to water contractors in 1975 with the amounts to which they were entitled under these contracts in that year. Current deliveries are in turn compared to the maximum amounts to which these contractors are ultimately entitled and the years in which their entitlements will reach these maximum figures. The dates of maximum entitlement shown here are those stipulated in the current contracts; the actual dates when deliveries will reach these maximums may be different and the state is currently seeking to make revisions in some of its contracts.

The state, in 1978, distinguished 15 types of water in connection with the operation of the State Water Project. The four types commonly used in most years are shown here. Entitlement water is the water made available to a contractor under the terms of a contract with the state. Surplus water is the amount that can be made available in any year after entitlement deliveries and the requirements for construction and operation have been fulfilled. Repayments of preconsolidation water involve the repayment of water loaned to the state by local water agencies for purposes of aqueduct construction; these amounts are currently scheduled to be repaid fully by 1985. Regulated deliveries of local supply occur where water derived from local sources but regulated by state facilities is delivered to the contractor by the state; in most cases, the local agency holds water rights within the watershed of a reservoir on the State Water Project.

When the proposed admission of California to the Union threatened to upset the antebellum balance of slave and free states, Daniel Webster sought to allay the fears of southern senators by pointing out that California could never undermine the economy of their states because it was incapable of producing cotton. As the presentation of agricultural water use on the facing page makes clear, however, the construction of the modern water system has transformed the natural conditions on which Webster's assurances were based, and cotton today accounts for a major part of the irrigation water applied each year in California.

The photographs on this page include a construction scene during the building of the State Water Project, a pumping plant west of Buena Vista Lake, and a view of the Carquinez Strait at Vallejo, the heavily industrialized corridor through which the great rivers of the interior flow into San Francisco Bay and the ocean.



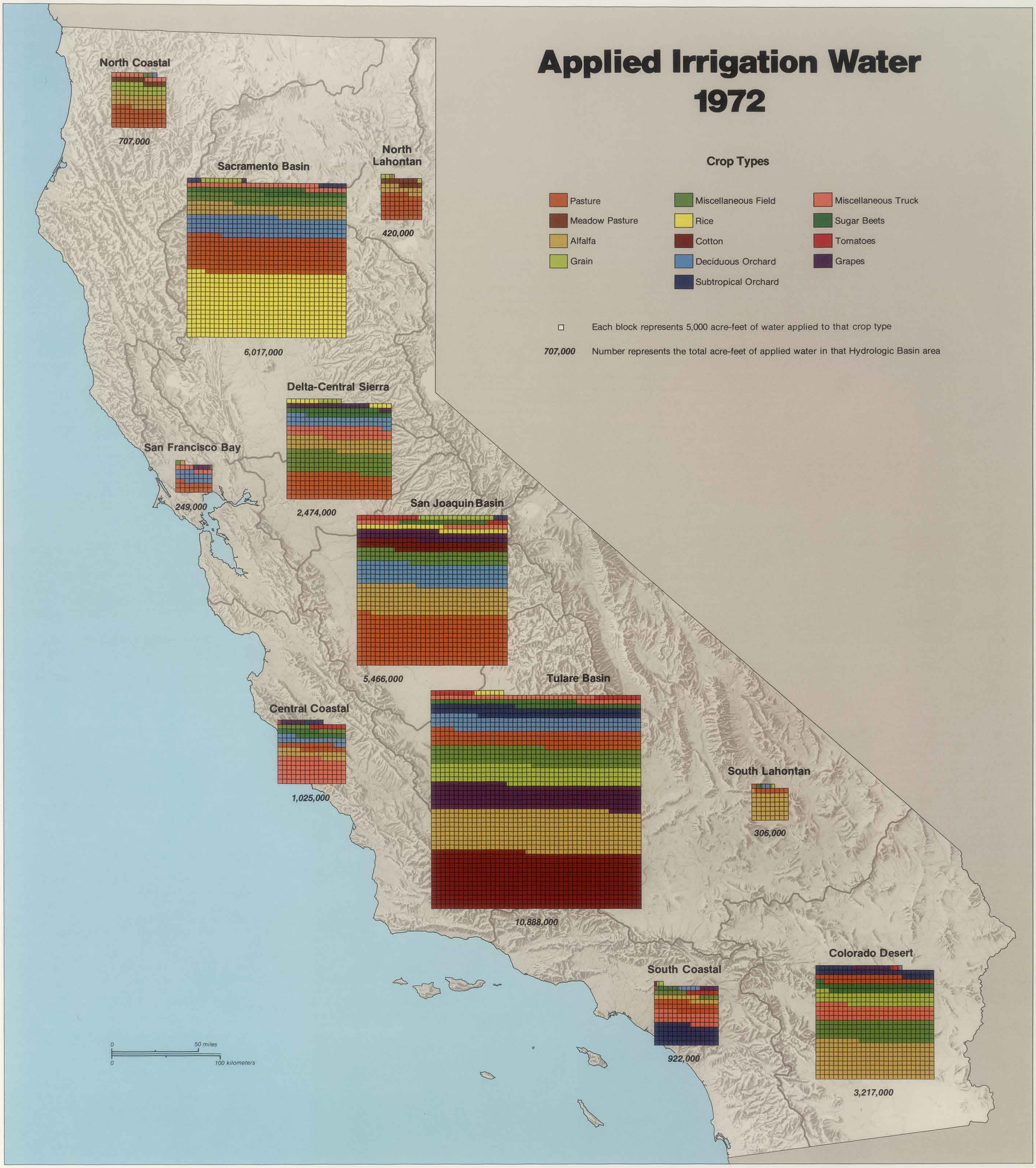
were threatened by subsidence, salinity, and a rising water table.

The San Luis site was included as well in Edmonston's original plans for the Feather River Project in 1951. The agreement for joint construction, ownership, and use of San Luis between the State of California and the United States government marked the first such undertaking by the Bureau of Reclamation and both governments have realized economies of scale as a result. The state paid 55 percent of the construction cost of the facility and the Bureau of Reclamation provided the balance. The giant, 600,000-acre Westlands Water District is the principal contractor for federal water from the San Luis Unit. Although the Congressional authorization for the project in 1960 required arrangements to be made for an adequate agricultural drain for the San Luis water service area, negotiations between the Bureau and the State Department of Water Resources for the joint development of a San Joaquin Master Drain collapsed in 1967 when the state withdrew and the Bureau commenced building its own San Luis Drain. This project is now partially completed from Kettleman City north to a reservoir near Gustine. Although it is planned to reach the southern Delta, lawsuits are promised to protect the Delta from the harmful effects of alkaline salt and nitrogen pollutants which some fear the drain would introduce into the Delta channels.

While these federal projects took shape, the state pressed ahead with the development of its own State Water Project. The first general obligation bonds were sold in early 1964 and sales continued for several years, supplemented by revenue bonds backed by hydroelectric power sales and by the use of $325 million in revenue bonds authorized years before for the original state Central Valley Project. As interest rates in the bond market increased, however, the state could no longer sell the water bonds within the rate limit for general obligation bonds required by the California Constitution. In 1970 the voters approved increasing the interest rate ceiling to seven percent, making the bonds once again competitive. By the spring of 1972, the last of the water bonds available for financing the initial project facilities had been sold.

The first deliveries from the State Water Project were made to Plumas County and to the Livermore Valley in 1962. In 1965 the project reached the Santa Clara Valley. In 1967 both Oroville Dam and the San Luis Dam were finished. In 1968 water began flowing to Napa County and the San Joaquin Valley. And in 1971 the first project water crossed the Tehachapis to Southern California. By the end of 1968 the last contracts were signed for the full project yield of 4,230,000 acre-feet of water per year. And by 1973 the first phase of the State Water Project, the facilities to provide water contracted for until 1980, was essentially complete. The largest area to be served is Southern California with 2.5 million acre-feet. The Metropolitan Water District increased its original contract to two million acre-feet when California lost the Colorado River decision. The second largest area of use is the San Joaquin Valley with 1.3 million acre-feet, most of which goes to the Kern County Water Agency. Contracts with other service areas include 188,000 acre-feet to the southern San Francisco Bay area, 83,000 to the South Coast, 67,000 to the northern San Francisco Bay Area, and 37,800 to the Feather River Area. These contracts presently provide for increasing amounts of water each year until 1990 to provide time for the build-up of demand.

For years critics of the project had predicted financial disaster. But by 1974 the Department of Water Resources could report, "The State Water Project is a financially viable project, producing revenues which are sufficient to pay all costs of operation and maintenance, repay all capital expenditures with interest and eventually producing surplus revenues for any future additions to the State Water Resources Development System that may be authorized." The basic financial concept of the State Water Project is that the costs are paid by those who receive the direct benefits. Water users pay 80 percent of the costs; power users, 13 percent. Funds for recreation and fish and wildlife benefits, amounting to three percent of total project costs, come from the state General Fund. The federal government pays the one percent flood control costs, and the other three percent comes from such sources as interest, rentals, and the sale of excess lands. Water rates are based on a Delta Water Charge, reflecting the construction and operating costs of the conservation facilities necessary to supply water to the Delta Pool, and a Transportation Charge, which includes construction and operating costs of aqueducts and pumping plants to deliver the water from the Delta to the specific



Applied Irrigation Water
1972
Crop Types
Pasture
Meadow Pasture
Alfalfa
Grain
Miscellaneous Field
Rice
Cotton
Deciduous Orchard
Subtropical Orchard
Miscellaneous Truck
Sugar Beets
Tomatoes
Grapes
Each block represents 5,000 acre-feet of water applied to that crop type
707,000 Number represents the total acre-feet of applied water in that Hydrologic Basin area
North Coastal
707,000
Sacramento Basin
6,017,000
North Lahontan
420,000
Delta-Central Sierra
2,474,000
San Francisco Bay
249,000
San Joaquin Basin
5,466,000
Central Coastal
1,025,000
Tulare Basin
10,888,000
South Lahontan
306,000
South Coastal
922,000
Colorado Desert
3,217,000
0
50 miles
0
100 kilometers

service areas. After 1983, when the project's current energy contracts will expire, transportation charges for areas south of the Tehachapis will increase dramatically. All charges, however, include the repayment of principal and interest on the bonds used for financing construction. During the years when surplus water is available, it may be sold for the incremental costs of transporting the water and administering the program. During years of drought when less water is available, the state's contractual commitments for water are decreased.

This system of full-cost financing for the State Water Project contrasts markedly with the methods of financing employed in the Central Valley Project. The Bureau today delivers approximately 6.5 million acre-feet of water for irrigation on approximately two million acres of the Central Valley served by 130 irrigation districts in the project's water service area. Most of these districts have their own distributing systems built under Bureau programs and depend upon the Bureau only for supplemental needs; however, the Bureau of Reclamation constructed distributing canals at reduced expense for the huge Westlands Water District. The demand for federal water is encouraged by the low price of this water, about one-fourth the rate for an acre-foot in the State Water Project service area.

These low rates, of course, are sustained by subsidies such as the interest-free component in reclamation project construction charges. Federal taxpayers as a whole underwrite an estimated 13 percent of the cost of the Central Valley Project. It has also been estimated that public power sales from the Bureau's generating plants subsidize approximately 65 percent of the true cost of irrigation water deliveries. Detailed economic analyses of the project's operations, however, vary widely in their conclusions depending upon the discount rates chosen, the separable costs of the project that are attributed to irrigation, and the selection of items that are counted as expenses for the project's beneficiaries. Thus, while irrigators are chargeable by official estimate with 63 percent of the project's reimbursable costs, some studies indicate that they in fact repay only 17 percent, while power users pay 72 percent and municipal and industrial users about 10 percent. Ever since the completion of the Contra Costa Canal serving residential and industrial customers along Suisun Bay, however, the Central Valley Project has found an increasing demand for its water in an expanding urban market. Coalinga is one of the most recent cities which has come to rely on project water. In 1975 a reported 147,000 acre-feet of Central Valley Project water served California's urban and industrial areas.

The total capital investment in the Central Valley Project as of June 30, 1976, was $1,718,907,425. Another two billion dollars would be required to complete the project if all the authorized units such as the Auburn-Folsom South Unit, the San Felipe Division, and other major units were finished. No terminal date has been attached to these projections, however, and inflation may at some future time make these additions prohibitively expensive. Completion would bring the benefits of irrigation water to a total of three million acres of prime Central Valley agricultural land while at the same time making a million acre-feet of water available to municipal and industrial users.

Since the advent of the 1970s, however, environmental concerns have combined with the increasing costs of project development to impose restraints upon the rapid course of water development that marked the 1950s and 1960s. An early sign of these changing conditions was the intense reaction sparked by a 1967 report of the U. S. Army Corps of Engineers proposing construction of a dam on the Middle Fork of the Eel River at Dos Rios. Water from this project would travel through a 21-mile state-financed tunnel to the Sacramento Valley for use in the State Water Project. A vigorous campaign was waged against both the economic and environmental aspects of the proposed dam and in 1971 Governor Ronald Reagan joined in opposing plans for the Dos Rios Dam, thus forcing its suspension. A decision by the State Water Resources Control Board that same year required the State Water Project to release water for the protection of the environment of the Delta. This decreased the amount of water available to meet contractual obligations. The following year the Legislature passed the California Wild and Scenic Rivers Act of 1972, prohibiting the construction of dams or diversion facilities, except for local needs, on those free-flowing North Coast rivers which were once considered as future water sources for the State Water Project.

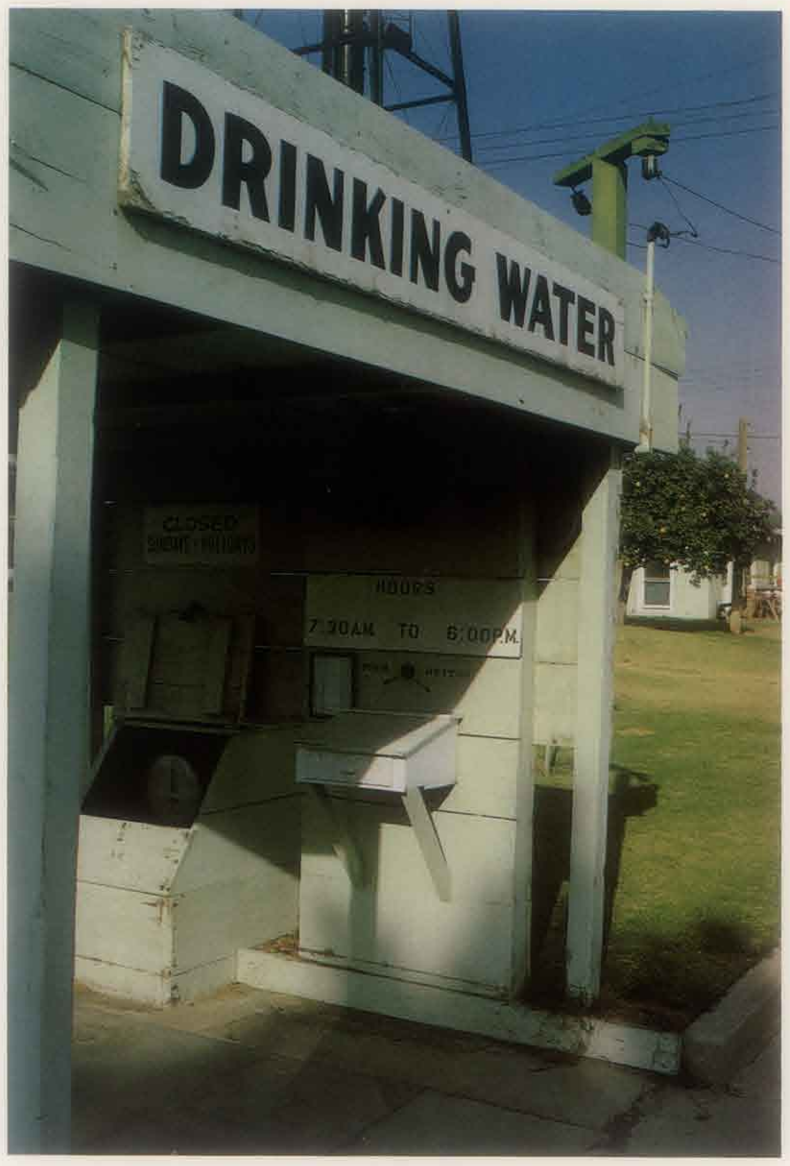
Increased attention to water quality standards in the Delta has also pitted the Bureau of Reclamation against the California State Water Resources Control Board. The Bureau must secure from this board permits to water rights for unappropriated water to be impounded by every new Bureau of Reclamation dam. The regional director for the Central Valley Project went on record in 1957 stating that the Bureau's responsibility for controlling salinity intrusion in the Delta channels was limited to the waters adjacent to the pumping stations for the Contra Costa and Delta-Mendota canals. Some thought this stance a betrayal of federal obligations going back to the Hyatt Report of 1930. The board's decision in 1971 to require both the State Water Project and the Central Valley Project to release fresh water in the Delta so as to give protection to fish and wildlife beyond the previous agricultural, municipal, and industrial water-use standards placed significant constraints upon the Bureau's plans for operation of the New Melones and Auburn dams. Although the federal government went to court to test the authority of California to limit its water rights and operations in these and related cases, the United States Supreme Court in 1978 upheld the board's power to impose requirements upon the operation of the New Melones Dam so long as these requirements do not conflict with the purposes for the dam which Congress specified in its authorization.

The prospects for eventual completion of all the Central Valley Project's planned facilities are thus somewhat doubtful. The New Melones project, although proceeding, has met with persistent opposition. Completion of the Auburn Dam has been held up by concerns over seismic safety. Construction of the San Felipe Division to divert water from the San Luis Reservoir to Santa Clara and San Benito counties has long been delayed by environmental impact studies and a lack of funding. The future activities of the Bureau in California may consequently involve not so much new construction as greater emphasis upon water management. This could be achieved through efforts aimed at more closely integrating the Bureau's operations with those of the Corps of Engineers, improved management of groundwater basins, enhancement of wastewater reclamation, new efforts at water conservation, and a re-examination of the Bureau's present agricultural water pricing system. The National Water Commission in 1973 recommended that water management functions take priority over further construction by the Bureau of Reclamation with emphasis directed toward increasing the efficiency of water use in the western states.

In the case of the State Water Project, the great question for the future involves the development of the proposed Peripheral Canal, which was initially proposed by Bureau engineers as a means of conveying water for export and was adopted by the Department of Water Resources in 1965 as a means also of repelling tidal salinity intrusion in the Delta. In 1974 the Department of Water Resources released a draft environmental impact report on the Peripheral Canal which met with considerable opposition. A delay in the schedule for building the canal was announced and the following year, under a new administration, the Delta Alternatives Review Program was established to reconsider the need for the canal or a different Delta transfer facility. This study was later expanded to include other water issues.

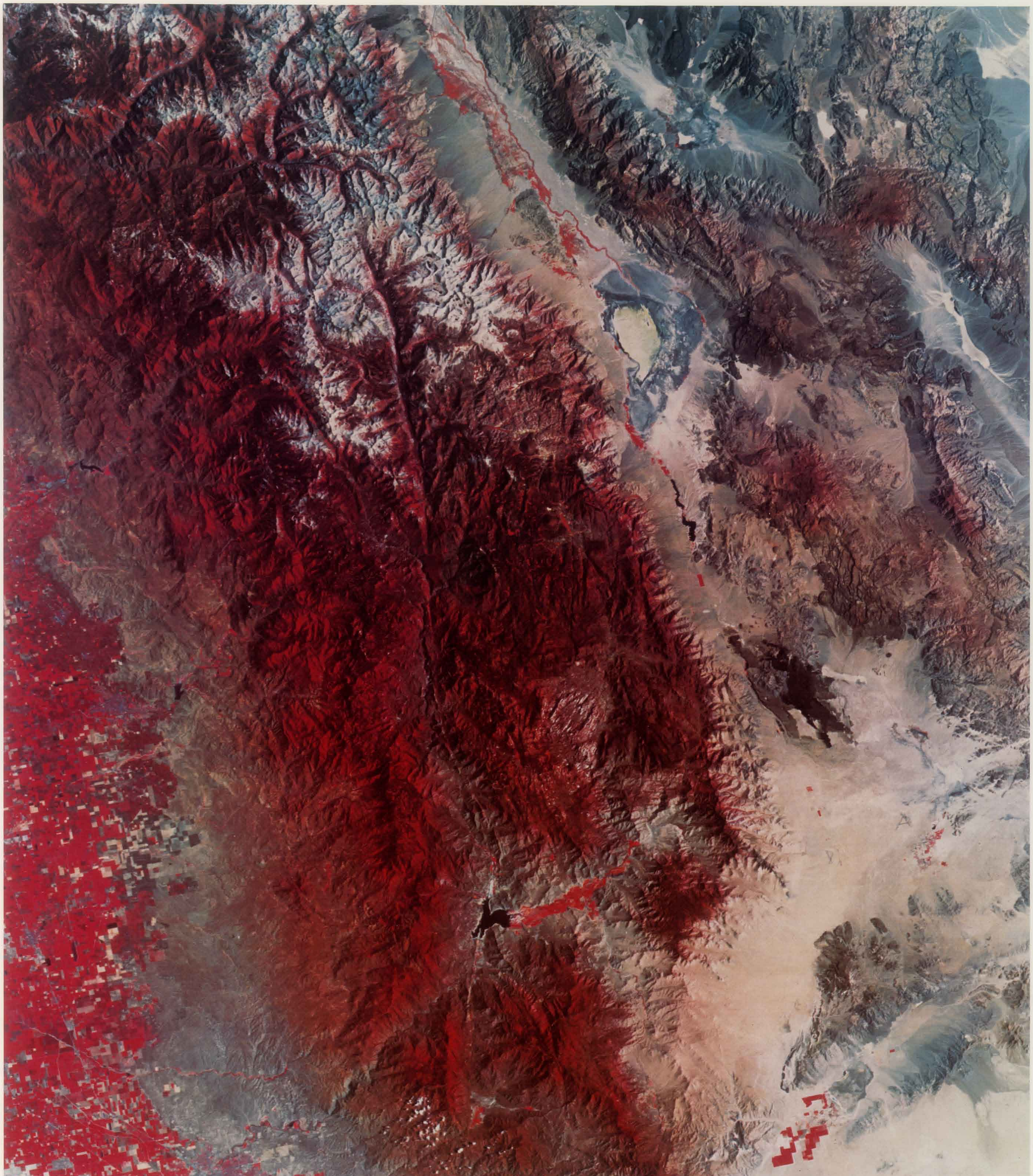
In 1977 the Department recommended the Peripheral Canal as part of a course of action which also included additional construction of some surface storage facilities; greater emphasis on conjunctive use of surface and groundwater supplies through underground storage in the San Joaquin Valley and Southern California for later withdrawal in dry years; and a series of new programs to encourage water conservation and the greater use of reclaimed water. With respect to the Delta, the plan recommended completing and implementing the Four Agency Fisheries Agreement with other state and federal agencies directly concerned with the Delta; completing a long-term federal Central Valley Project-State Water Project operating agreement; and requiring assurance of federal authorization for the Central Valley Project to release stored water to protect Delta water quality. The Department argues that the Peripheral Canal is the best method of protecting the environment of the Delta while efficiently transporting water for export. While some environmentalists agree, others feel that conveying the water through natural Delta channels, which requires the release of fresh water to repel salt water from the ocean in order to protect the quality of export water, is the only sure way to protect water quality in the Delta.

Congress has not yet appropriated funds for construction of the Peripheral Canal and the Department's overall program still awaits approval by the California Legislature. The severe drought in 1976 and 1977, however, pointed forcefully to the need to provide additional water and power to meet ultimate contract commitments. While the future of the Peripheral Canal is being debated, the Department is working on a Water Action Plan, reviewing specific water issues and suggesting ways to solve them. Thus, for the Department of Water Resources as for the Bureau of Reclamation, the emphasis of earlier years on damming rivers to provide increasing amounts of water has shifted to one which also includes the increased use of management techniques to meet the expanding range of demands that are being placed upon the water supplies now available.



Before the construction of the modern water delivery systems of the Central Valley, residents of Coalinga had to bring their jugs to the distillation plant shown here to purchase their water for household use. Water deliveries have also enhanced the development of sophisticated corporate agricultural operations which farm vast tracts of land using mechanized equipment like the tomato picker at right.

The satellite image on the facing page illustrates in part the interaction of natural and artificial components of the modern water system through the juxtaposition of the Sierra Nevada and the great rain shadow it casts to the east with the intensive agricultural activities which water deliveries have helped to bring about in the San Joaquin Valley at left.



CHAPTER 7

The Operation of the Modern Water System

The preceding sections have traced the sequential development of the major components of the modern water system. Within the brief span of only a little more than a century, Californians have remade the natural waterscape through the construction of a great network of artificial lakes and rivers. The modern water system, however, is more than these physical elements: it is made up as well of the legal and institutional structures we have erected to govern it and the social and economic development it has helped to foster. The wealth we have invested in the transformation of the natural waterscape has worked to make California the most populous and agriculturally productive state in the nation. In the process, however, we have become a culture which is as dependent upon water as the great water-based civilizations of ancient Egypt, Mesopotamia, and the Yang-tse and Yellow rivers. This section treats both the power and the limitations of the modern water system by examining the profound changes this system has wrought in the natural water endowment, the legal and institutional constraints under which it operates today, and the limits which nature nonetheless imposes upon the system through the extreme events of flood and drought.

By draining the land and moving water over great distances, the development of the modern water system has altered the intricate balance of the water environment. The natural infiltration of water into the soil has been reduced by asphalt in our urban areas and increased by repeated plowing in the countryside. Evaporation from reservoirs, cloud seeding, and evapotranspiration from irrigated agriculture affect the flow and concentration of atmospheric water. And intensive pumping of groundwater basins has resulted in land surface subsidence in some areas and induced underground saltwater intrusion in others.

THE ALTERED ENDOWMENT

California today has more large dams with a greater total storage capacity than any other state in the Union. The myriad of surface storage facilities which has been created as a result is displayed on the map of California's major lakes and reservoirs in this section. Although California has a large number of natural lakes, their storage capacity, as the map shows, is considerably smaller than that of the reservoirs. The major exception, of course, is Lake Tahoe, whose great volume vastly exceeds that of all the other lakes and reservoirs shown here. The lakes and reservoirs on this map have been distinguished according to their surface elevations and surface acreage, which are important factors in determining the amount of evaporative loss any surface water storage body will experience. Most of the major reservoirs have been located in the mountains, where the best reservoir sites exist. Building reservoirs at these heights, however, also helps to reduce evaporation and create gravity flows for the generation of hydroelectric power. In the southern parts of the state, where evaporation rates are higher than in the north, reservoirs tend as well to be built deeper with less surface acreage as a way of reducing evaporative losses.

The comparison of unimpaired and measured flows in this section provides probably the most graphic demonstration of the impact of human development on California's major rivers. With dams and diversion structures, we have smoothed out the seasonal peaks of natural streamflows and altered the concentration of sediments and nutrients these rivers once carried. As a result, the modern system of dams, reservoirs, and artificial channels has encouraged erosion in some areas and stopped it in others while slowing or halting the formation of alluvial floodplains in some parts of the state and accelerating their formation in others.

The waterworks of California have also changed the distribution and abundance of virtually every native aquatic plant and animal in the state. No natural landscape in California has undergone a more severe alteration in this respect than its valley bottoms. In 1850 the Central Valley was a vast expanse of alkali flats, grassland prairie, and marshlands composed of tule beds, oxbow lakes, and freshwater bogs. In addition, forests of willow, oak, cottonwood, and sycamore covered an estimated 775,000 acres. The bottomlands of the Sacramento

Smog covers the pine forests of the San Gabriel Mountains.

SUBSIDENCE AND SALTWATER INTRUSION

Groundwater as a source of local supply possesses numerous advantages. Because it is insulated by an overlying mantle of soil and rock, groundwater does not suffer evaporative losses, and its temperature is more uniform, a signal advantage in instances where it is to be used for air conditioning and certain other industrial uses in which water of a particular temperature is required. Most important, in areas where surface supplies are limited, it is often less expensive to pump from a local groundwater basin than pay the costs of imported water. Overdraft by pumpage of a groundwater basin, however, may lead to subsidence of the land surface and, in some coastal areas, the usefulness of a groundwater reservoir may be impaired by saltwater intrusion.

Saltwater intrusion can occur wherever the natural seaward hydraulic gradient is reversed so that conditions favor the landward movement of sea water as when groundwater levels are drawn down below sea level by pumping. This could happen in a groundwater reservoir anywhere along the coast but the problem appeared first in Southern California. As early as 1906 saltwater was found to have moved up the San Diego River from Mission Bay, causing the abandonment of wells in San Diego's Old Town pumping field. Seasonal saltwater intrusion was noted as well in the Tijuana and San Dieguito river basins in San Diego County. And along the San Luis Rey River pumping for agricultural and municipal use had by 1938 drawn groundwater levels below sea level in a trough two to six miles inland from the ocean. In the years since water from the Colorado River became available, groundwater pumping in this area has been reduced and surface water has been used to recharge the groundwater basin, thus enabling the basin to hold its own against saltwater intrusion.

The coastal plain in Los Angeles and Orange counties has been the scene of the most serious occurrences of saltwater intrusion and the most intensive countermeasures in California. For more than 50 years pumping from numerous wells progressively lowered groundwater levels until by 1953 they were below sea level in a large part of the area. Numerous wells near the coast had to be abandoned because of increased salinity, and brackish groundwater appeared as much as eight miles inland. Most of the seawater intrusion occurred in the West Basin of Los Angeles County, where groundwater levels fell to as much as 100 feet below sea level. Although water levels in most of the West Basin were still below sea level in 1970, saltwater intrusion had been repelled by the development of a barrier ridge created by injecting Colorado River water into a line of 93 wells. In Orange County pumping from wells has been substantially reduced and Colorado River water is spread for artificial recharge.

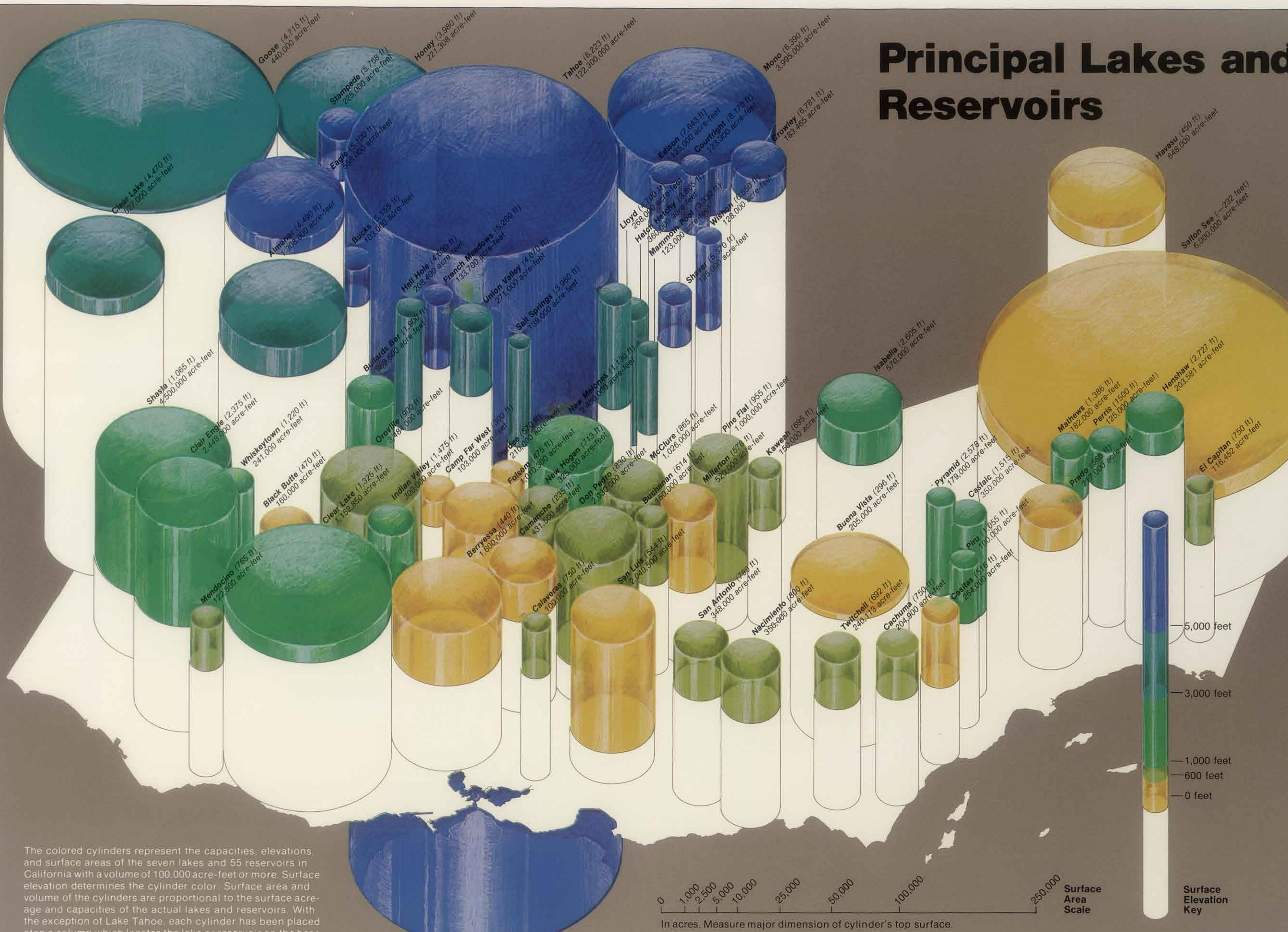
Further north, in Santa Barbara County, fears of saltwater intrusion were widespread during the drought of 1945-55, when the City of Santa Barbara and numerous outlying communities were dependent upon groundwater pumping from three small coastal basins. The intrusion did not occur because these basins are separated from the ocean by impermeable materials, which did not permit the migration of sea water.

In contrast to saltwater intrusion, which is limited for the most part to the coastal areas of California, subsidence can occur wherever overdrafts of a groundwater basin reduce the upward hydraulic pressure that supports the overlying land surface. In the San Joaquin Valley, the site of the most extensive groundwater overdraft in California, subsidence became a noticeable problem by the 1920s. By 1970, an estimated 5,200 square miles of the valley had dropped to a maximum of 28 feet in the area west of Mendota. This subsidence in turn has created a need for expensive repairs to the Delta-Mendota and Friant-Kern canals, which were fractured as the ground beneath them subsided.

The Santa Clara Valley along the southern arm of San Francisco Bay has achieved particular success in combating the problems of subsidence. Abundant artesian water supplies helped to establish the Santa Clara Valley as a principal center of fruit canning and drying in the 1930s. At this time, more than 110,000 acres of the valley were devoted to fruit and nut bearing orchard crops. The water demands of these crops, however, caused groundwater levels to drop over 150 feet in an area where 2,000 artesian wells once flowed and extensive subsidence became evident in 1933. The rate of subsidence declined, however, during the wet years the valley experienced from 1936 to 1943 and groundwater levels in some parts of the valley rose as much as 80 feet.

After World War Two the Santa Clara Valley underwent intensive urban and industrial growth as the area's population increased from 291,000 in 1950 to 900,000 by 1965. The ensuing changes in land use from agriculture to urban development further taxed the local groundwater supplies. The overall volume of land subsidence from 1934 to 1967 is estimated to have been half a million acre-feet, the equivalent of about ten percent of the water pumped in this 33-year period. In some areas, the land surface dropped by as much as twelve feet between 1930 and 1969, causing millions of dollars of damage. The Santa Clara Valley Water District responded by instituting a cloud seeding program and by purchasing water from the Hetch Hetchy project. These deliveries were used both on the surface and to recharge the depleted aquifers. In 1965, water from the State Water Project became available through the South Bay Aqueduct, and the valley's annual imports increased to 120,000 acre-feet by 1970. From 1967 to 1970 water levels in more than a hundred wells rose an average of about 56 feet, and land subsidence was consequently brought to a halt.

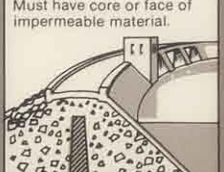
Principal Lakes and Reservoirs



The colored cylinders represent the capacities, elevations, and surface areas of the seven lakes and 55 reservoirs in California with a volume of 100,000 acre-feet or more. Surface elevation determines the cylinder color. Surface area and volume of the cylinders are proportional to the surface acreage and capacities of the actual lakes and reservoirs. With the exception of Lake Tahoe, each cylinder has been placed atop a column which locates the lake or reservoir on the base map. Additional properties of the 55 reservoirs are shown in the table below.

Use Key
- **C** *conservation*
- **I** *irrigation*
- **M** *municipal & industrial*
- **F** *flood control*
- **R** *recreation*
- **P** *power generation*
- **N** *navigation (draft maintenance)*

Rock Fill
Must have core or face of impermeable material.



Dam name (Reservoir name, if different)	Stream impounded	Year completed	Owner	Principal use (see Use Key, right)
New Melones	*Stanislaus River*	1978	Army Corps of Engineers	C I F R P
New Exchequer (McClure)	*Merced River*	1966	Merced Irrigation District	I F R P
Hell Hole	*Rubicon River*	1966	Placer Co. Water Agency	I M R P
Pyramid	*Piru Creek*	1973	Dept.of Water Resources	C I M F R P
Salt Springs	*No. Fk. Mokelumne R.*	1931	Pacific Gas & Electric	P
Courtright	*Helms Creek*	1958	Pacific Gas & Electric	P
Wishon	*North Fork Kings River*	1958	Pacific Gas & Electric	P
Bucks	*Bucks Creek*	1928	Pacific Gas & Electric	I P

Earth & Rock
Unsorted, or sorted to use materials optimally.

Dam name (Reservoir name, if different)	Stream impounded	Year completed	Owner	Principal use
Cherry Valley (Lloyd)	*Cherry Creek*	1956	City & Co. San Francisco	C I M F P
Whiskeytown	*Clear Creek*	1963	US Bur. of Reclamation	I M R P
Terminus (Kaweah)	*Kaweah River*	1962	Army Corps of Engineers	I F R
Buchanan	*Chowchilla River*	1975	Army Corps of Engineers	I F R
Bradbury (Cachuma)	*Santa Ynez River*	1953	US Bur. of Reclamation	I M R
New Hogan	*Calaveras River*	1964	Army Corps of Engineers	C I F R
Clear Lake Reservoir	*Lost River*	1910	US Bur. of Reclamation	I F R
Calaveras	*Calaveras Creek*	1925	City & Co. San Francisco	C M

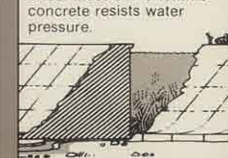
Earth Fill
Inexpensive. Must be protected from erosion and damaging percolation.

Dam name (Reservoir name, if different)	Stream impounded	Year completed	Owner	Principal use
Oroville	*Feather River*	1968	Dept. of Water Resources	C I M F R P
Don Pedro	*Tuolumne River*	1970	Turlock & Modesto IDs	C I M F R P
Trinity (Clair Engle)	*Trinity River*	1960	US Bur. of Reclamation	I M R P
Union Valley	*Silver Creek*	1963	Sacramento MUD	C I M R P
Mammoth Pool	*San Joaquin River*	1960	Southern Calif. Edison	M R P
Castaic	*Castaic Creek*	1971	Dept. of Water Resources	C I M F R P
San Luis	*San Luis Creek*	1967	US Bur. of Reclamation	C I M R P
Casitas	*Coyote Creek*	1959	US Bur. of Reclamation	I M R
Mathews	*trib. of Cajalco Creek*	1938	Metro. Water Dist. So. Cal.	I M
Stampede	*Little Truckee River*	1970	US Bur. of Reclamation	I M F R
L. L. Anderson (French Meadows)	*Mid. Fk. American R.*	1965	Placer Co. Water Agency	C I M R P
Indian Valley	*North Fk. Cache Creek*	1975	Yolo Co. FCWCD	I M F R
Twitchell	*Cuyama River*	1958	US Bur. of Reclamation	I M F R
Nacimiento	*Nacimiento River*	1957	Monterey Co. FC&WCD	C I M F R
San Antonio	*San Antonio River*	1965	Monterey Co. FC&WCD	C I M F R
Santa Felicia (Piru)	*Piru Creek*	1955	United Wtr. Conserv. Dist.	C I M R
Isabella	*Kern River*	1953	Army Corps of Engineers	C I F R
Camp Far West	*Bear River*	1963	South Sutter Water Dist.	C I R
Camanche	*Mokelumne River*	1963	East Bay Mun. Util. Dist.	M F
Vermillion Valley (Edison)	*Mono Creek*	1954	Southern Calif. Edison	P M
Coyote (Mendocino)	*East Fk. Russian River*	1959	Army Corps of Engineers	C I M F R
Black Butte	*Stony Creek*	1963	Army Corps of Engineers	I F R
Long Valley (Crowley)	*Owens River*	1941	City of Los Angeles	M R P
Perris	*offstream*	1973	Dept. of Water Resources	I M R
Prado	*Santa Ana*	1941	Army Corps of Engineers	F
Buena Vista	*Kern River*	1890	Boswell Co. & Tenneco W.	I

Hydraulic Fill
Fill sluiced to site & water-sorted between dikes.

Dam name (Reservoir name, if different)	Stream impounded	Year completed	Owner	Principal use
El Capitan	*San Diego River*	1934	City of San Diego	C I M
Almanor	*North Fk. Feather River*	1927	Pacific Gas & Electric	I R P
Henshaw	*San Luis Rey River*	1923	Vista Irrigation District	C I R

Gravity
Sheer mass of monolithic concrete resists water pressure.



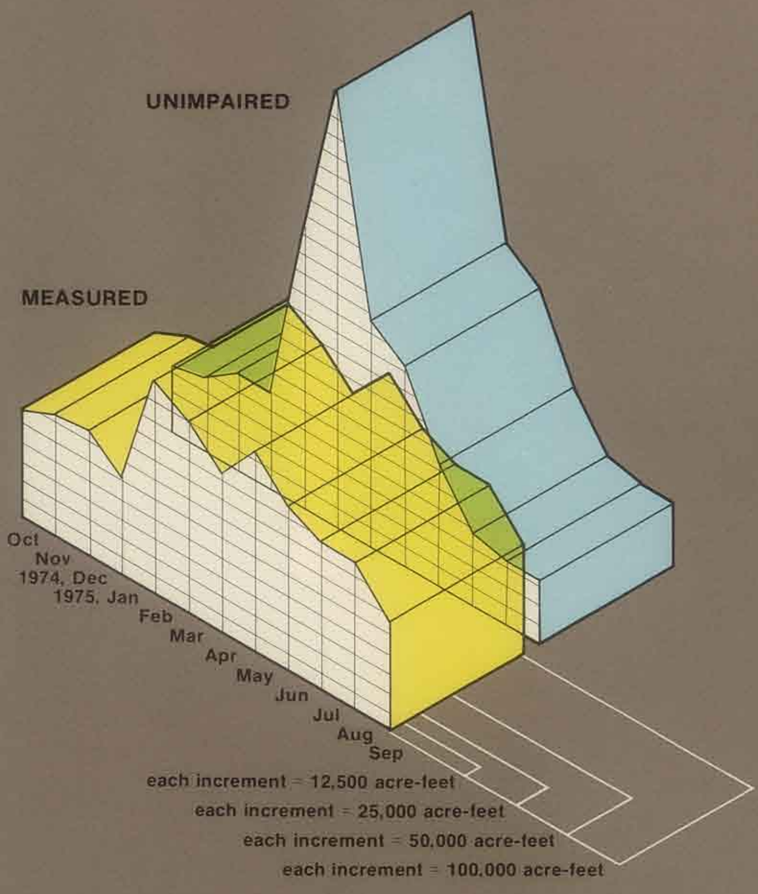
Dam name (Reservoir name, if different)	Stream impounded	Year completed	Owner	Principal use
Shasta	*Sacramento River*	1949	US Bur. of Reclamation	I M F R P N
Pine Flat	*Kings River*	1954	Army Corps of Engineers	C I F R
Pardee	*Mokelumne River*	1929	East Bay Mun. Util. Dist.	M F R P
O'Shaughnessy (Hetch Hetchy)	*Tuolumne River*	1923	City & Co. San Francisco	C M F P
Friant (Millerton)	*San Joaquin River*	1947	US Bur. of Reclamation	I F R
Folsom	*American River*	1956	US Bur. of Reclamation	I F M R P
Shaver	*Stevenson Creek*	1927	Southern Calif. Edison	R P

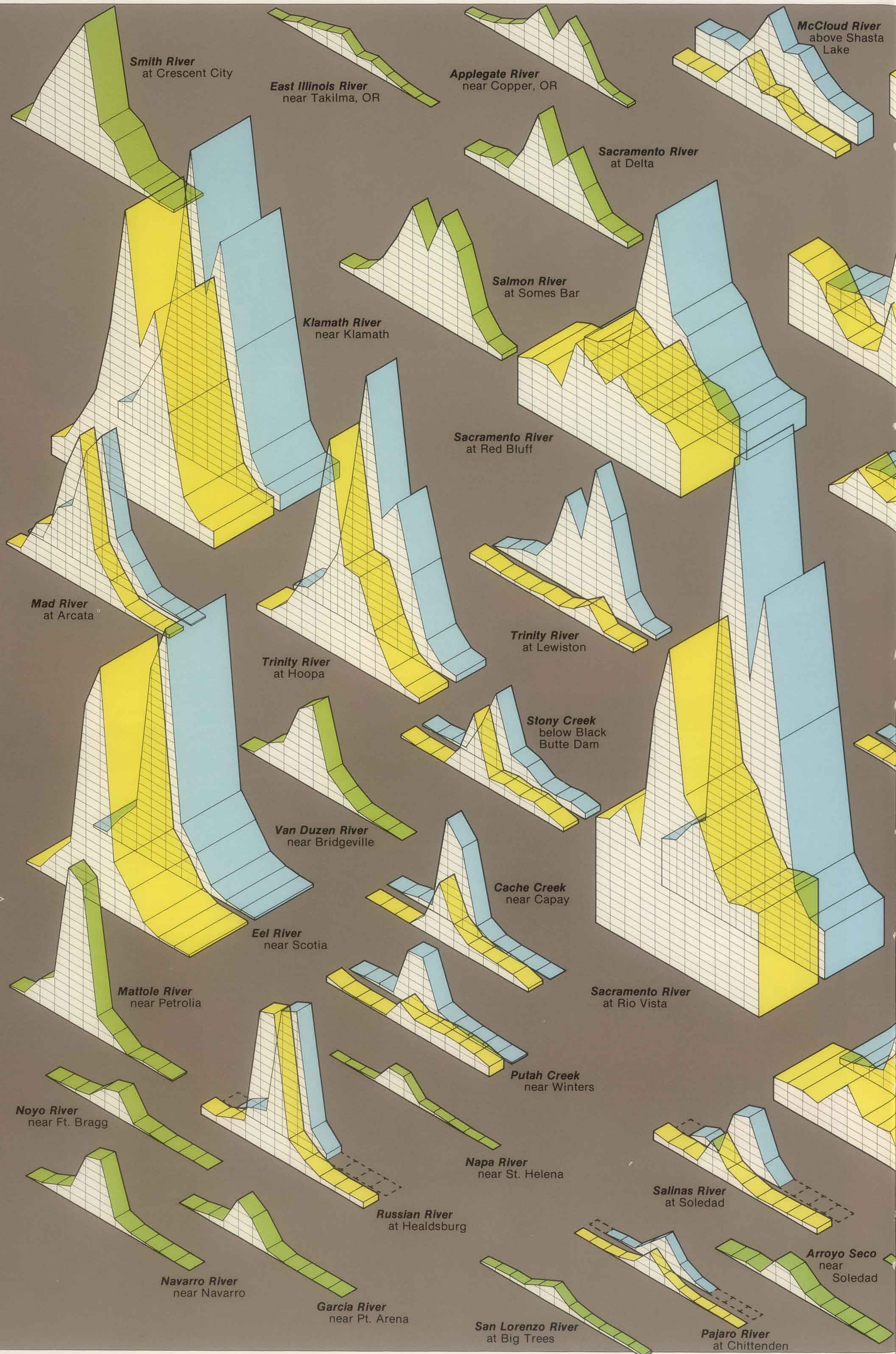
Arch
Thin, curved shell transmits force of water to canyon walls.

Dam name (Reservoir name, if different)	Stream impounded	Year completed	Owner	Principal use
New Bullards Bar (Bullards Bar)	*North Yuba River*	1970	Yuba Co. Water Agency	I M F R P
Monticello (Berryessa)	*Putah Creek*	1957	US Bur. of Reclamation	I M F R
Parker (Havasu)	*Colorado River*	1938	US Bur. of Reclamation	F M R P

Measured and Unimpaired Streamflows

Water Year 1975



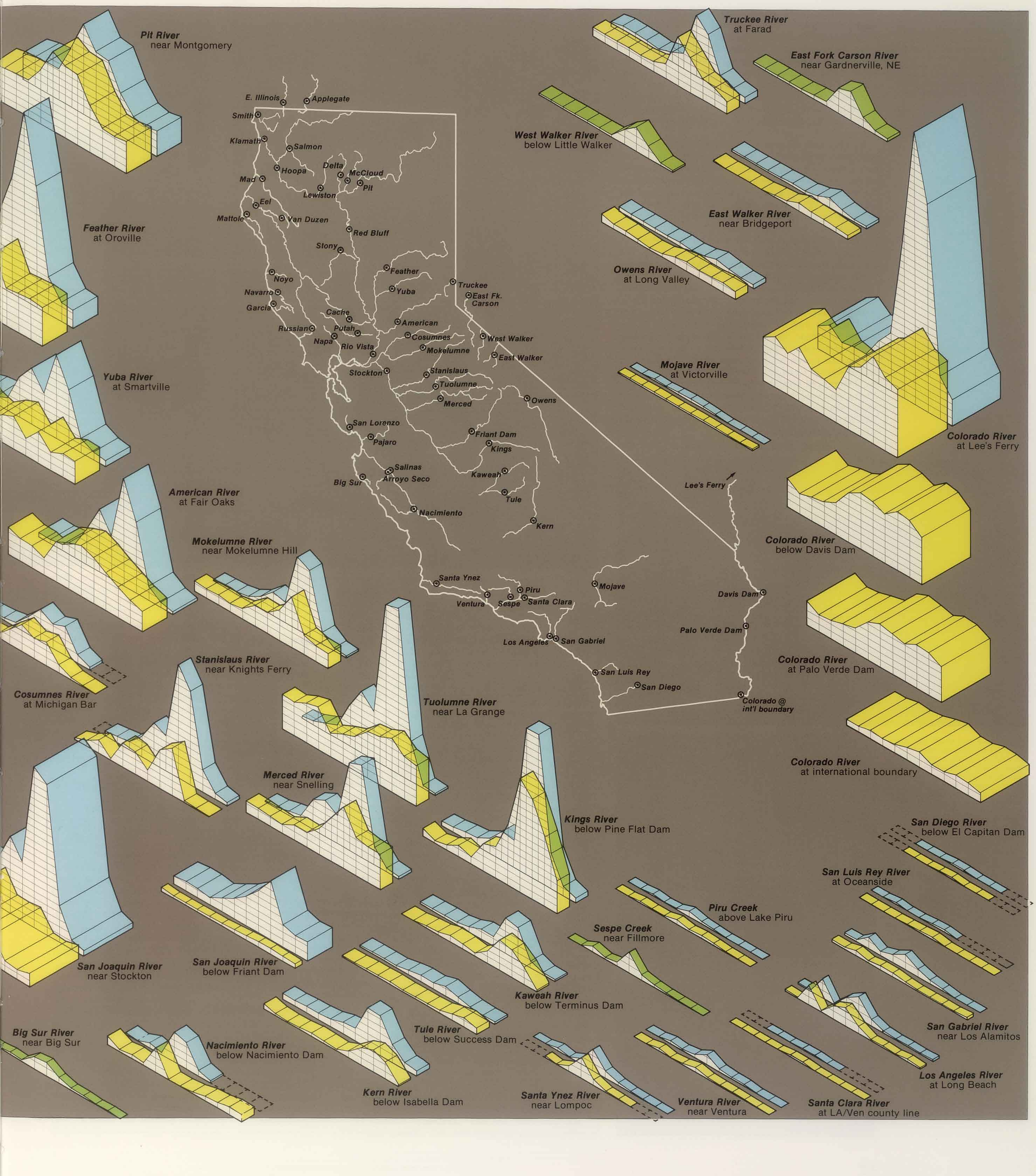


Each diagram pair represents streamflow past a gauging station in the water year October 1974 through September 1975. The nearer of the pair represents the actual flow as measured at the gauging station. The farther diagram represents the hypothetical "virgin" condition as it would have been if there were no artificial diversions or storage facilities.

Green tints have been used wherever the yellow and blue tints overlap and where only an unimpaired flow is shown. Broken lines identify those periods during the water year when water flows were or would have been zero.

Streamflow volumes vary significantly from one river to another. To represent these differences, the values assigned to the horizontal lines measuring volume vary according to the width of the diagram. In the narrowest diagrams, each horizontal line represents 12,500 acre-feet. The wider diagrams employ multipliers of 2, 4, and 8, and in these diagrams, the values of the horizontal lines increase accordingly to 25,000, 50,000 and 100,000 acre-feet.

Except for the Colorado, a single diagram identifies a river which has neither significant regulation nor diversion. For the Colorado, unimpaired and measured flows are shown only at Lee's Ferry, where the amount of water available for lower basin users is measured. Downstream, at Davis Dam, Palo Verde Dam, and the international boundary, only the measured flows have been shown as an index of the succession of diversions to California and Arizona.


Pit River
near Montgomery
Feather River
at Oroville
Yuba River
at Smartville
American River
at Fair Oaks
Mokelumne River
near Mokelumne Hill
Cosumnes River
at Michigan Bar
Stanislaus River
near Knights Ferry
Tuolumne River
near La Grange
Merced River
near Snelling
Kings River
below Pine Flat Dam
San Joaquin River
near Stockton
San Joaquin River
below Friant Dam
Kaweah River
below Terminus Dam
Tule River
below Success Dam
Kern River
below Isabella Dam
Big Sur River
near Big Sur
Nacimiento River
below Nacimiento Dam
Santa Ynez River
near Lompoc
Ventura River
near Ventura
Santa Clara River
at LA/Ven county line
Los Angeles River
at Long Beach
San Gabriel River
near Los Alamitos
Sespe Creek
near Fillmore
Piru Creek
above Lake Piru
San Luis Rey River
at Oceanside
San Diego River
below El Capitan Dam
Colorado River
at international boundary
Colorado River
at Palo Verde Dam
Colorado River
below Davis Dam
Colorado River
at Lee's Ferry
Mojave River
at Victorville
Owens River
at Long Valley
East Walker River
near Bridgeport
West Walker River
below Little Walker
East Fork Carson River
near Gardnerville, NE
Truckee River
at Farad
E. Illinois
Applegate
Smith
Klamath
Salmon
Hoopa
Delta
McCloud
Mad
Pit
Lewiston
Eel
Mattole
Van Duzen
Red Bluff
Stony
Feather
Noyo
Navarro
Garcia
Yuba
Truckee
East Fk.
Carson
Cache
Putah
American
Russian
Napa
Cosumnes
Rio Vista
Mokelumne
West Walker
East Walker
Stockton
Stanislaus
Tuolumne
Merced
Owens
San Lorenzo
Pajaro
Friant Dam
Kings
Salinas
Arroyo Seco
Big Sur
Kaweah
Tule
Lee's Ferry
Nacimiento
Kern
Santa Ynez
Piru
Mojave
Ventura
Sespe
Santa Clara
Davis Dam
Los Angeles
San Gabriel
Palo Verde Dam
San Luis Rey
San Diego
Colorado @
int'l boundary

The impact of human development upon the water environment is especially evident in the southern end of San Francisco Bay. In the photograph at right, the bright green areas are salt ponds, rusty red tints define natural tidal marshes, and brown marks the tidelands which have been diked for reclamation but not used.

and southern San Joaquin rivers and their tributaries supported golden beaver, mink, and river otter. Grizzlies and black bears made seasonal migrations to hunt the salmon and freshwater fish like the thick-tail chub, and Sacramento perch complemented the salmon and sturgeon fisheries of the native peoples. Great flights of ducks, geese, swans, cranes, and shorebirds wintered on the hundreds of thousands of acres of marsh, overflow lands, and waterways in these valleys, the Delta, and around San Francisco Bay.

By 1950 only three percent of the floodplain forests remained, principally in the area between Red Bluff and Colusa. Drainage systems dried up the nurseries of the thick-tail chub and reduced the distribution of California's vernal pools to a few remnants. And the population of beaver, mink, and river otter was depleted by reclamation of their habitat for irrigated agriculture.

Waterfowl and shorebirds have felt the effects of drainage most. They routinely stopped at the Klamath, Buena Vista, and Tulare lakes, the overflow lands south of the Tehachapis, and the non-alkaline natural surface storage areas of Great Basin Lakes, Owens Valley, and the lower Colorado. Buena Vista, Tulare, and Owens Lake rarely exist at all today due to diversion and drainage. The marshlands of the lower Colorado and Owens River have largely disappeared, although the Salton Sea has become a man-made haven for migrating birds. The Klamath Lakes were drained, but have been gradually replaced by a managed wetland. San Francisco Bay and the Delta, however, have lost an estimated 60 percent of their marshland, including the famous Alvarado Marsh in the South Bay which has been given over to salt evaporation ponds.

No creature is a better "barometer" for the existence or destruction of California's riparian woodlands than the yellow-billed cuckoo. Originally, the cuckoo nested in willow and cottonwood forests in most of the valleys of the Coastal Range from San Diego County to Sebastopol in Sonoma County. It flourished as well throughout the Central Valley from Bakersfield to Redding, in the Owens Valley, and along the Colorado River. The cuckoo's breeding habitat disappeared as groundwater levels fell because of pumping, streamside vegetation was cleared for flood control and farming, marshland drained for extensive agriculture, and forests cut for wood. Only 35 to 68 pairs were reported in the Sacramento Valley in 1977. Although another population may nest consistently on the lower Colorado, the cuckoo is considered a rare bird in California today.

In place of the yellow-billed cuckoo and other riparian song birds such as the Bell's vireo, willow flycatcher, and yellow warbler has come the cowbird, a parasite which leaves its eggs in the nests of other birds to be hatched and fed. Until 1900, only one cowbird had been seen in all the Sacramento Valley. With the spread of irrigated agriculture, however, the cowbird population has been vastly expanded and flocks of up to 10,000 birds have been counted along the river in recent years.

The native members of the salmon family provide a similar index of the effects of the modern water system upon the state's fish and fisheries. Rainbow trout once abounded in virtually all of the Sierra and Cascade streams. King salmon inhabited most of the larger foothill tributaries of the Sacramento and San Joaquin rivers up to elevations of 3,000 or 4,000 feet. King salmon were also abundant in the larger coastal rivers and creeks. And silver salmon and steelhead trout inhabited most of the coastal streams of California in increasing numbers from south to north.

Sedimentation from hydraulic mining in the nineteenth century damaged the salmon runs along the Yuba, American, and Feather rivers. The excavation of railroad lines by dynamiting along the banks of the Sacramento left barriers of rock and debris which proved impassable for many fish. By 1883 the spring run of king salmon on the McCloud River as well as the hatchery that tried to compensate for detrimental activities downstream were both closed. And by the 1920s, dams on the Stanislaus, Tuolumne, and San Joaquin rivers closed the access of king salmon to a major portion of their spawning grounds.

Any barrier across a stream or river that prevents the passage of salmon reduces their population. But the barrier does not have to be a concrete wall. Barriers are also created by increasing temperatures, reducing the concentration of dissolved oxygen in the

Inland Commercial Fishing

Common Name	Native or Year Introduced	Commercially Fished	-Status- Active or Year Commercial Fishing Ended
American Shad	1871	Sacramento-San Joaquin System	1957
Asiatic Clam	1870-90	Sacramento-San Joaquin System	Active
Bull Frog	1870's	Statewide	Active
Carp	1872	Sacramento-San Joaquin System; Clear Lake; Lake Almanor and other reservoirs	Active
Crayfish	Native and introduced 1900-25	Lake Tahoe Sacramento-San Joaquin System	1970 Active
Lahontan Cutthroat Trout	Native	Lake Tahoe	1917
Lake Trout	1889	Lake Tahoe	1917
Mullet	Native	Salton Sea; Colorado River	1952
Pond Turtle	Native	Sacramento-San Joaquin System; Tulare Lake	Can be taken for scientific and educational purposes only.
Roughfish (Greaser, Blackford, Hardhead)	Native	Clear Lake; Sacramento-San Joaquin System	Active
Sacramento Perch	Native	Sacramento-San Joaquin System	1957
Sacramento Pike or Squawfish	Native	Sacramento-San Joaquin System	1951
Salmon (all species)	Native	Smith; Klamath; Eel; Mad Russian; Sacramento-San Joaquin System	1934 1957
Steelhead (Rainbow Trout)	Native	Smith; Klamath; Eel; Mad; Russian; Sacramento-San Joaquin System; Central Coastal Streams	1927
Striped Bass	1879	Sacramento-San Joaquin System	1935
Sturgeon (White and Green)	Native	Sacramento-San Joaquin System	1917
White Catfish	1874	Sacramento-San Joaquin System	1953

Inland fishing was at one time an important commercial activity in California. Salmon, steelhead, and other species were extensively fished in the rivers of the North Coast and in the Sacramento-San Joaquin Delta. More than 25 canneries were operating in the Delta when the industry reached its peak at the turn of the century. In the early decades of the twentieth century, however, the industry declined rapidly due to overfishing of the resource, siltation, pollution, shipping activities, and the construction of dams and water diversion facilities. This table summarizes those species that were once or are still taken commercially. Although the commercial fishing of many inland species has been halted, many of these species can still be taken by sport fishermen or under special exceptions such as those granted to certain Indian tribes on the Klamath River.

water, and concentrating pollutants through which salmon will not swim. These problems are especially acute in the lower reaches of the Sacramento and San Joaquin rivers. Reduced flows because of diversions and dams can also delay the start of salmon migration. The spring run of king salmon head upstream when spring freshets reach the Delta. These freshets bring increased currents and the odor or taste of the salmon's stream of birth; king salmon follow this "aquatic scent" to their ancestral spawning grounds. In addition, reduced flows and dam diversions can prevent the tributaries to streams from adding their yearly load of sediment to the main channel, where it is washed downstream leaving clean, aerated gravel for salmon young. When the Lewiston Dam prevented the flows of the Trinity River from washing sediments out of the mainstream spawning beds, for example, thousands of salmon were lost as a result.

Dams also hinder the survival of young salmon trying to move downstream. This problem has been hard to quantify, but kills of young have been caused by passage through hydroelectric turbines, by the water quality in some reservoirs, and by predators who wait for the juveniles to bunch up along dam walls. Further downstream, the young encounter agricultural canals and other diversions. If these artificial channels are not screened with a relatively fine mesh (which is unusual because maintenance of clogged screens is costly), the young swim down these diversions to become stranded in the fields. And in the Delta, many young are sucked into the Tracy pumps although some survive to be trucked back to the Delta and a few even descend the Delta-Mendota Canal.

Hillside erosion and channelization cause many physical changes to rivers that discourage salmon survival. The stream bed becomes more uniform and the deep pools needed for summer survival of king and silver salmon and rainbow trout are lost. The undercut banks and fallen trees which provide shelter for juveniles disappear. And the lack of trees also reduces shade, allowing temperatures to fluctuate more widely.

Numerous local, state, and federal agencies have joined forces to combat these influences and protect fish populations through the development of hatcheries and management programs that affect not only dam operations but also modern logging practices and a wide range of industrial, municipal, and agricultural waste discharges. Artificial hatcheries, however, cannot duplicate the productivity of natural spawning areas.

Modern water technology has brought great wealth to California and its people, but this technology has also had serious environmental consequences that would require large expenditures of public funds to rectify. The opportunities for the development of coordinated programs for the resolution of these and other environmental and social conflicts, however, have been greatly complicated by the vast array of public agencies which are involved in the administration of water today in California.

WATER DISTRICTS IN CALIFORNIA

The responsibility for the day-to-day management of water in most of the state is vested in more than 3,700 public and private agencies with administrative authority over some aspect of water supply, delivery, use, and treatment. Special districts organized under general enabling statutes make up the majority of these agencies. Although state statutes currently provide for 17 different classes of special district for water management, there are as well a number of districts—the Kern County Water Agency as a prominent example—which have been established under special legislative acts which apply uniquely to their operations. These special act districts have been classified into three functional categories and combined with the other districts formed under general enabling statutes in the table of district organization in this section.

These local agencies range from small agricultural districts representing only a handful of landowners to mammoth entities like the Westlands Water District, Kern County Water Agency, and Metropolitan Water District which exercise broad powers over large segments of the state's land and population. The proliferation and configuration of special districts and the assignment of their responsibilities, however, reflect many of the economic and social changes that have shaped the history of water development in California.

Water District Organization

Type of District	Year Organized: 1880-89	1890-99	1900-09	1910-19	1920-29	1930-39	1940-49	1950-59	1960-69	1970	No Date	Dissolved	Total in 1970
Community Service						1		38	56	14	1	2	108
Flood Control & Water Conservation								2	1		5		8
Harbor & Ports							1						1
Municipal Improvement								2	2				4
Maintenance								2	8	1	25		36
Reclamation				1	3						5		9
Recreation & Parks									5		1		6
County Service Area									19	8	6		33
Municipal Utility					1	1		1					3
Public Utility					7	10	25	7	2		1		52
California Water					1	2	9	69	72	4	5		162
County Water				3	9	8	18	77	72	8		11	184
Metropolitan					1								1
Municipal Water				1			2	29	17	2		3	48
Water Agency or Authority								11	9	1	4		25
Water Conservation					2	1	1	3		1	2	2	8
Water Replenishment								1					1
Water Storage					2	1	1	3	1				8
County Waterworks				2	5	4	4	30	21	2	24	2	90
Irrigation	5	1	2	23	44	4	8	8	1	1	10	2	105
TOTALS	5	1	2	30	75	32	69	283	286	42	89	22	892

Reclamation districts were the first to be authorized, when the state's swelling population in the 1860s created the need to reclaim the marshes, swamps, and tidelands that were seen as obstacles to widespread settlement. As agriculture assumed its central role in California's economy, irrigation districts organized under the Wright Act of 1887 and its succeeding amendments became the predominating form of special district. With the concentration of the state's population in urban centers and the consequent movement toward municipal control of water resources after the turn of the century, however, came a series of legislative acts authorizing the formation of municipal and county water districts in 1911 and 1913.

The adoption of the municipal and public utility district acts in 1921 marked a shift in approach which recognized water management as only one part of an integrated program for the provision of utility services to the public. Drought conditions in the middle of the 1920s intensified the problems of matching water supply to rising demands in many parts of the state. Prompted in part by the particular problems of groundwater overdraft which the Santa Clara Valley experienced in this period, the Legislature placed a new and special emphasis upon the management of limited water resources through the enactment of the water conservation acts of 1927, 1929, and 1931.

Since the 1930s the emphasis in new water district formation has been placed upon the authorization of entities with broader powers and areas of activity than was accorded in the earlier statutes. The Community Services District Law of 1951, for example, extended a general authority for the provision of public services to meet the needs of California's growing suburban population in areas which lacked municipal organization. This general trend toward liberalizing the purposes for which districts may be formed has brought in turn a spectacular rise in the proliferation of districts. Whereas an estimated 214 water utility districts of one sort or another were organized in all the years prior to 1950, 283 new districts were incorporated in the 1950s and another 285 in the 1960s. These relatively new districts formed since 1950 now constitute a majority of the more than 900 water utility districts operating in California. Most were organized under the broad governmental powers accorded to county water districts, California water districts, and community services districts.

With this trend toward the assumption of broad governmental powers by new districts has come an increasing reliance upon property ownership as a qualification for voting on bonds and the election of district officers. Residency and the "one-man-one-vote" rule govern the elections in public utility,

In the 1960s one Los Angeles politician campaigned for public office on a pledge to turn the Los Angeles River blue by painting the concrete channel through which it flows today. In the photograph above a salt-laden slough winds through the Suisun Marsh.

irrigation, and county water districts. The directors of county service areas and districts for the maintenance of ports and harbors, among others, are appointed by county boards of supervisors. The California Water District Act of 1913, however, grants to the district electors one vote for each dollar of the assessed value of their land. The provisions for elections in water storage districts and water conservation districts are also weighted in favor of property ownership. It has been estimated that approximately one-fifth of all the water utilities in California currently require property ownership as a qualification for voting in district elections. A total of 310 districts—more than half of the districts formed between 1950 and 1969—operate under these restrictions on the electoral franchise.

In part, this preference for recognizing property ownership in district elections reflects the emergence of large-scale corporate agriculture in the development of naturally water-deficient areas on the west side of the San Joaquin Valley and other areas of Southern California. This system of agricultural organization, characterized by vast land holdings owned by distant corporate interests, contrasts markedly with the smaller, owner-occupied farms which proliferated in the nineteenth century along the stream-fed areas of the eastern San Joaquin Valley. In certain extreme cases, the property ownership requirements for district elections can render a public district little more than the agent of a few corporate interests. Four or five major landholders in the Westlands Water District, for example, can swing a majority of all the votes in the district. In the Tulare Lake Basin Water Storage District, where four corporations farm nearly 85 percent of the district's land area, the J. G. Boswell Corporation alone controls enough votes to determine the outcome of district elections while 189 other landowners command only a little more than two percent of the district's acreage and exercise a proportionately small influence in the election of district officers. And, when the Irvine Ranch Water District was organized as a California water district in 1961, the Irvine Company owned fully 98 percent of the district's land, while the remainder was divided among 31 different owners.

Although statutory provisions requiring that directors of the Imperial Irrigation District must themselves be district landowners have been declared unconstitutional in California, the related requirements for property ownership as a qualification to vote have been upheld by the United States Supreme Court. The J. G. Salyer Land Company brought suit against the Tulare Lake Basin Water Storage District after its property was flooded in 1969. The flood could have been contained and Salyer's property protected, but this would have interfered with the agricultural operations of the J. G. Boswell Corporation on land within the Buena Vista Lake Basin to which the flood waters would have been diverted. Since Boswell held a majority of the votes within the district, the district's board of directors never activated its flood control system to save Salyer's property. In its majority opinion, the Supreme Court denied Salyer's complaint on the grounds that the district's powers were not so broad as to qualify as being truly "governmental" and that the district's activities, therefore, "fall so disproportionately on landowners as a group that it is not unreasonable that the statutory framework focuses on the land benefited, rather than people as such."

LEGAL CONSTRAINTS: THE LAW OF RIGHTS

As important as the panoply of local, state, and federal agencies may be in the provision of water services, the ultimate authority over the distribution and management of California's water resources has resided with the judiciary ever since the earliest days of white settlement. An earlier section of this volume traced the struggle over riparian versus appropriative rights up to the time that the constitutional amendment was adopted in 1928 recognizing the interest of all the people in the state's water resource. Since that time, California's dual system of riparian and appropriative doctrines has continued to evolve and the courts have established specific rules governing each type of right.

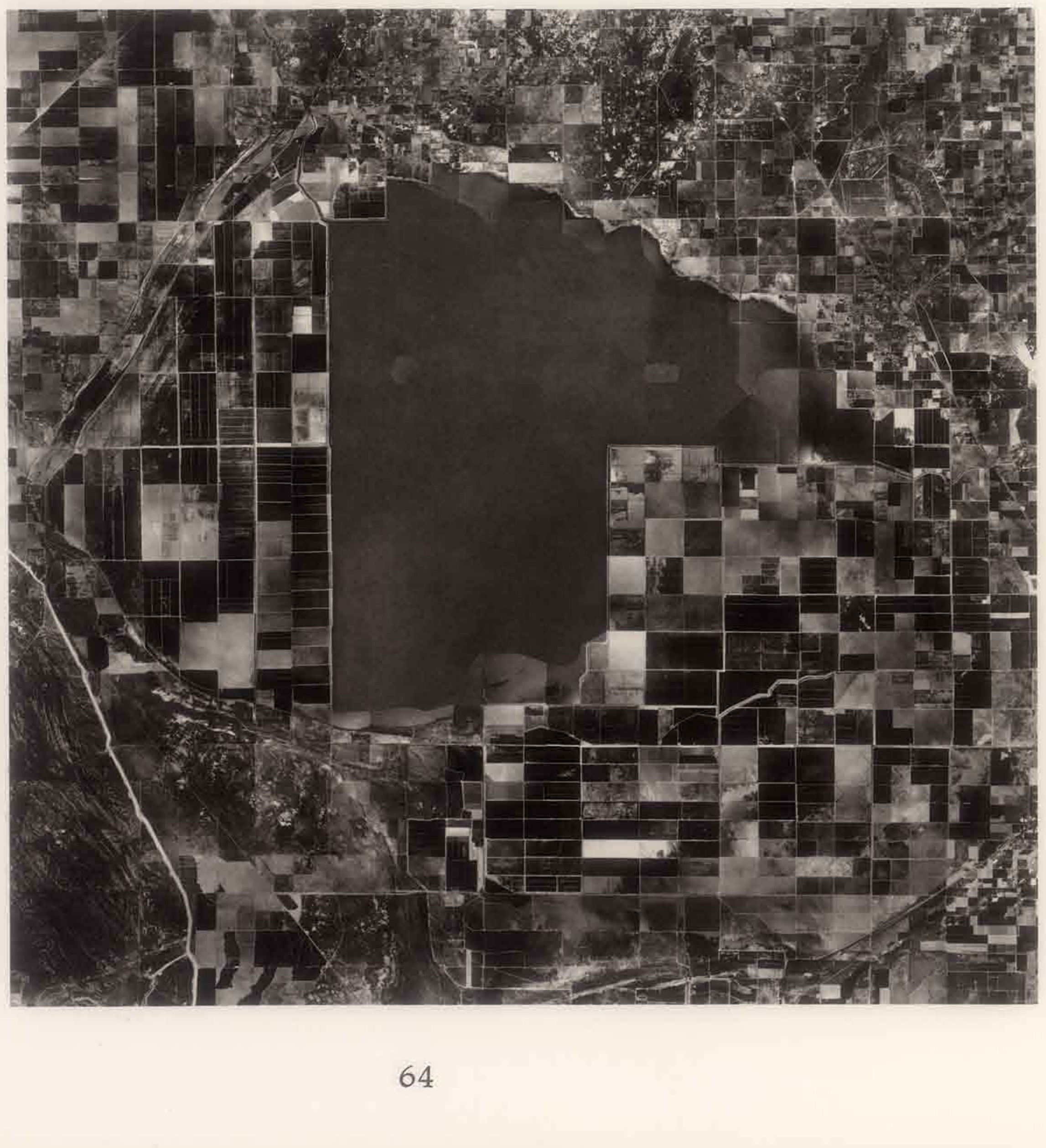
In the frequently quoted statement that Arizona's adoption of the English common law, which had recognized the supremacy of riparian rights, "is far from meaning that the patentees of a ranch on the San Pedro are to have the same rights as owners of an estate on the Thames," Chief Justice Oliver Wendell Holmes Jr. capsulized the central tenet of the law of waters in the western United States. In California, one of the most fundamental controversies has concerned the definition of riparian land, and three major tests have emerged. First, some part of the land in question must actually touch the stream (except in the infrequent case where a deed has preserved the riparian rights of the portion separated from it). Second, only that portion can be riparian which lies within the watershed of the stream, although any portion draining into another stream may be riparian to that other stream. In the case of tributaries, a special application of this watershed test requires that land adjoining one tributary of a river does not have a riparian right to water extracted from another tributary upstream from the junction of the two tributaries. Finally, once any portion of the riparian land loses its riparian character by being separated in title from the portion touching the stream, it can never again be riparian, not even if it is later joined in title to land which remains riparian.

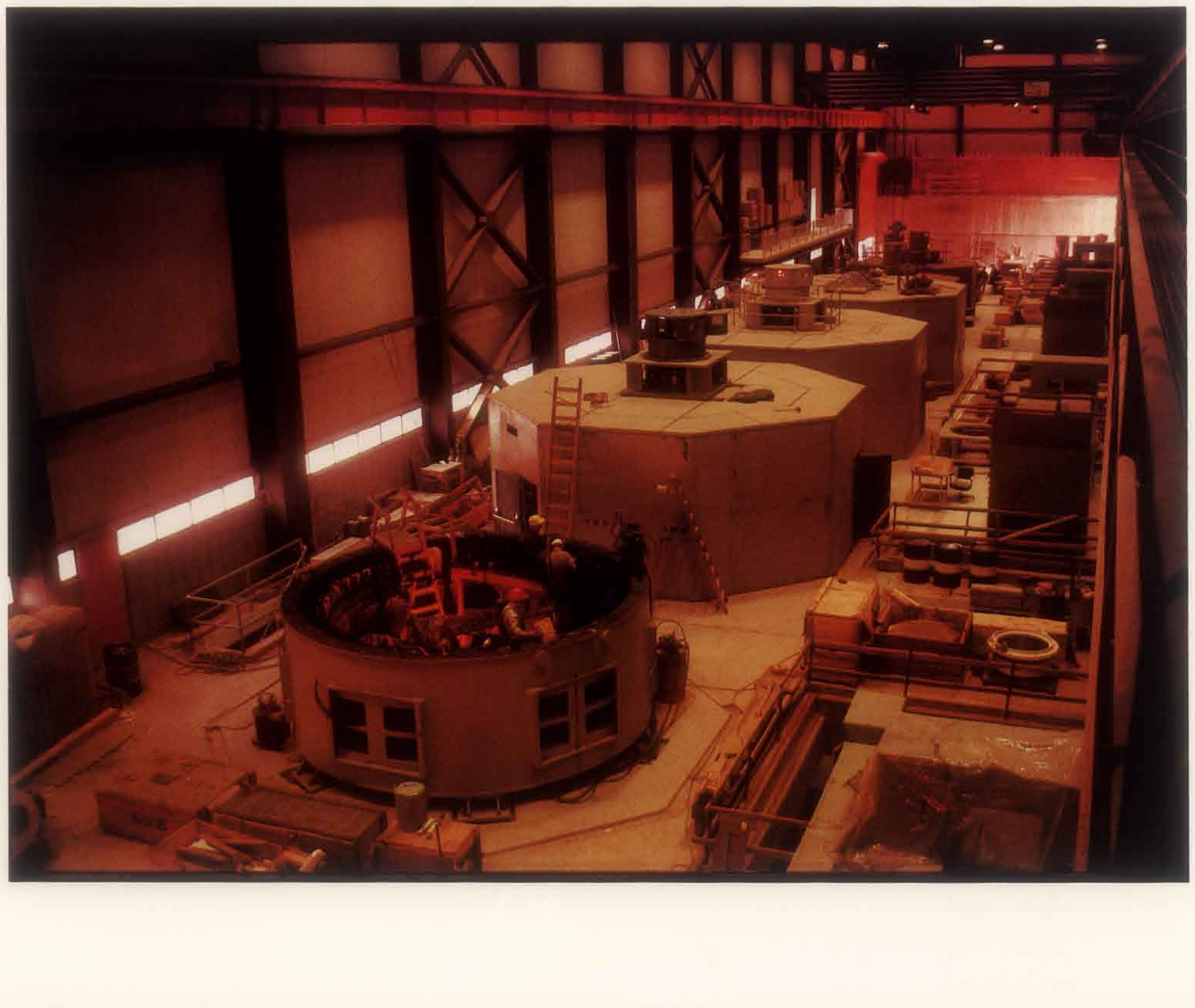
Although the parties to a sales transaction may provide for the continued use of water by a severed tract of land, this chain-of-title test has steadily reduced the amount of riparian acreage in California as land is continually subdivided and sold. Thus, in a city bordering on a river, only the owners whose land touches the river would ordinarily have riparian rights in it; the owners in the next block away from the river would not. Even if a riparian owner with a house facing the river bought the lot behind to serve as a back yard and joined it in title with the lot which touches the river, there would be a right to take water from the river for the front lawn but not for the garden in the newly acquired back yard. Nor does it make any difference that the entire city adjoins the river; riparian rights are a matter of land ownership, not municipal boundaries. The city may take water for riparian use on its own riparian land, as for a park or a city facility located next to the river, but when the city supplies water as a municipal utility to non-riparian land, even within the city limits, it acts as an appropriator.

Ordinarily riparian rights apply only to the natural flow of streams and it is not essential to the riparian right that the land in question touch the stream at all times. The California courts recognize an important distinction, however, between two kinds of floods. The perennial, predictable Central Valley flood waters, whose source is the gradual melting each year of the Sierra Nevada snow pack, are subject to riparian rights. Sudden, unpredictable flash floods, however, whose source is runoff from rainstorms, are not subject to riparian rights. The theory is that these latter flows are too uncertain and too fleeting to be utilized as they occur; only through storage can they be put to beneficial use.

Storage has itself been a major area of riparian litigation involving the question of what constitutes a proper riparian use. In England and the United States during less populous and less industrialized times, water on riparian land was commonly used by the owner and his family. Water for commercial crops was usually a matter of rainfall. With the industrial revolution, water was needed more and more for business purposes, and increasing urbanization created a demand for the recognition of the needs of public utilities. Also, in the western United States, the climate was such that irrigation became a necessity for agriculture. The courts were called upon, therefore, to interpret the doctrine of riparian rights and decide whether some or all of these new uses were permissible. In reaching its decisions, the court often cited two principles underlying the riparian doctrine: first, that the riparian owner is entitled to

The fluctuating surface area of Tulare Lake once extended to cover an estimated 700 square miles of the Central Valley. Modern diversion structures keep the lake basin dry in most years because the lands that were formerly under water are so valuable for agriculture. The photograph below was taken during a flood in October 1969, which inundated 139 square miles causing an estimated $20 million in damage. The faint lines on the land surface which can be seen encircling the inundated area trace the ancient shoreline of Tulare lake. The photograph at right shows the interior of the State Water Project's Delta Pumping Plant.





the "natural advantages" of his situation; second, that the respective riparian owners along a stream are entitled to have the stream flow "as it was accustomed to flow."

Although it was urged by some that in applying these principles commercial use should not be permitted, particularly where such use involved a significant reduction in the flow of the stream, California law ultimately recognized any reasonable beneficial use. Thus, water for large herds of cattle, as opposed to domestic stock, may be taken pursuant to the riparian right, and water may also be used for the irrigation of commercial crops. Even electric generation is permissible. It can readily be seen that these rulings were as important as recognition of the riparian doctrine in the first place. Had irrigation, for example, been held to be a prohibited use, then California agriculture would have had to turn to appropriation as a source of water, and the battle between the riparian and appropriative doctrines might have had a different result.

Two special rules were developed as a result of the decision to permit riparian owners to take water for any reasonable beneficial use. First, it has been necessary in some cases to face the fact that there is not enough water available in a particular stream for all possible riparian uses. The California Supreme Court has held that the rights of riparian owners as among themselves are correlative, and when there is a deficiency of supply to satisfy all the riparian demands at a given time, the court may make an equitable apportionment of the supply. The cases which have reached this point have been few, however, and the rules for determining what is equitable are not specific. Second, in California at least, the notion that certain riparian uses are more natural than others has resulted in a rule that for personal domestic purposes an upstream riparian owner may take as much water as necessary, even if it has the effect of depriving riparian owners downstream of any share of the supply.

The principle that a riparian owner is entitled to the natural advantages of his situation appears to have been determinative in decisions which refuse to recognize a right to store water pursuant to riparian right. Storage contemplates use at a time when the water would not naturally be present. On the other hand, impounding water in order to create a pressure head for irrigation is not storage and does not constitute use at an unnatural time; it merely makes it possible to lift and distribute the water for immediate use, and the short lapse of time involved is incidental to the delivery process.

One of the most frequently mentioned criticisms of the riparian doctrine is that riparian rights are not transferable. The right is not "appurtenant" to the land, it is "part and parcel" of the land. Thus, it passes automatically with any conveyance of the land, and it may not be severed from the land and conveyed separately. Nature does not always bestow her blessings in the most sensible manner; the most efficient and desirable place to use the water of a particular stream may be on land that is not riparian. With most economic resources, the answer is simply to buy the resource from the owner and transport it to the more profitable location. But in the case of a riparian right, the very character of the owner's property in the water makes such a transaction legally impossible. The riparian owner does not own the water but only the right to use it on riparian land.

A way around this restriction on transferability has been recognized: a riparian owner may not convey his water right, but he may agree not to exercise it. In fact, a deed purporting to convey the right is construed by the courts as an agreement not to exercise the right. The purchasing appropriator, therefore, must buy off enough riparian owners to make sure that the uses of the remaining riparian owners leave the amount of water he needs. Such a purchaser does not, however, acquire the priority of the seller, but only the elimination of that seller's demand upon the stream. This is especially important if there have been earlier appropriations; the new appropriator who "purchases" a riparian right will be junior to those earlier appropriations, even though the riparian seller had priority over them.

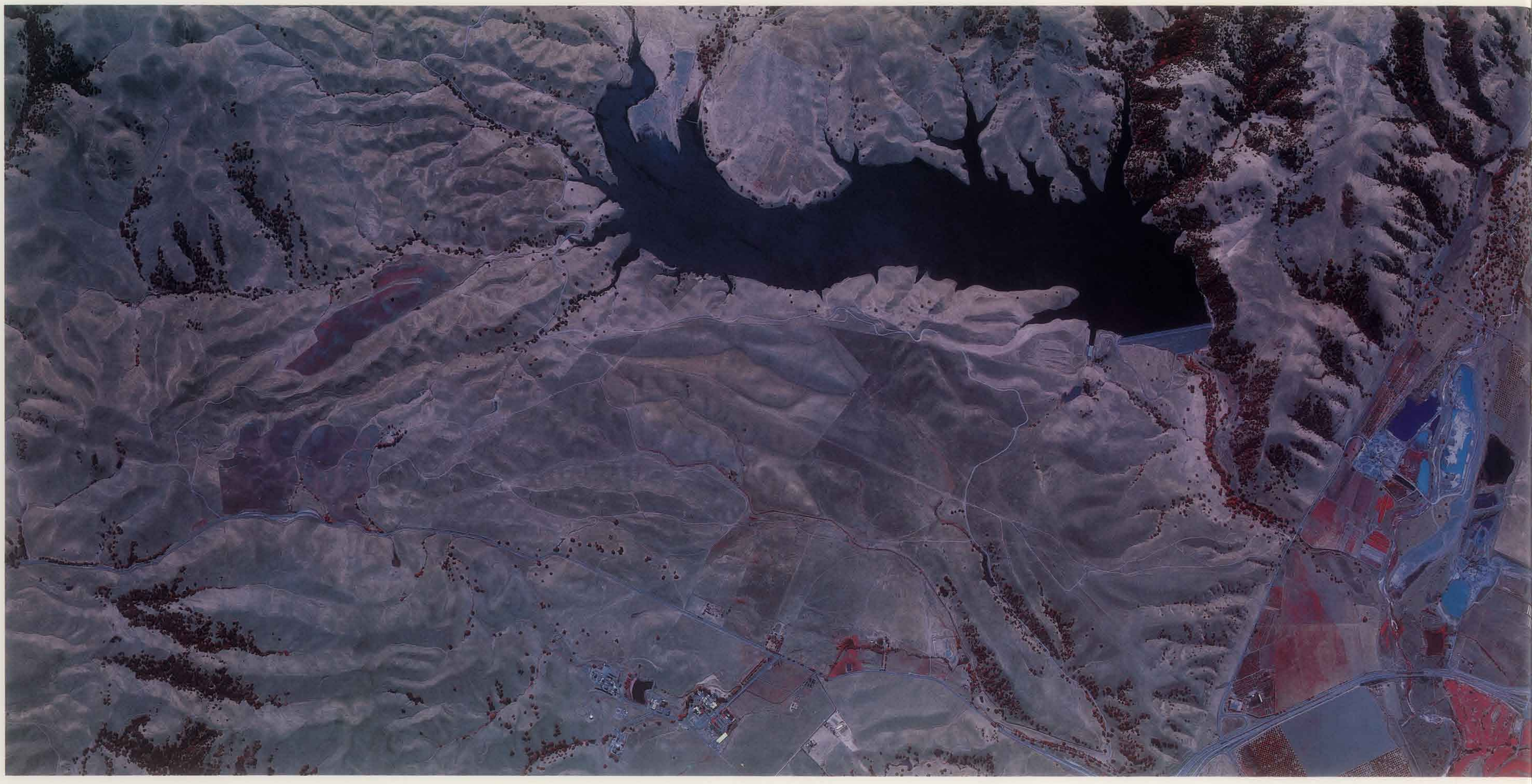
Perhaps the most heated criticism of the riparian doctrine has been directed against the rule that the right is not lost by nonuse. One important result is that prospective appropriators are discouraged from making use of water which flows by idle riparian land; they realize that at some future time the prior riparian rights of such undeveloped land may be exercised and that anyone appropriating water in the meantime may be cut off. In theory this criticism merely reargues the underlying principle of the appropriation doctrine that first in time should be first in right. Although efforts have been made to cut off unused riparian rights, these attempts have been criticized as a denial of due process. Although the question is once again pending in the California Supreme Court, the court has held in the past that the 1928 constitutional amendment had the effect of protecting this perpetual feature of the riparian right because the amendment was aimed at limiting the riparian right to reasonable purposes and its authors had inserted a disclaimer of any other restriction on the right.

Even though riparian rights are, with certain exceptions, recognized in California as "prior and paramount" to appropriative rights, the majority of California's waters today are utilized pursuant to appropriation. There are two major categories of appropriative rights. First, as against the public lands of the United States, appropriative rights have priority. When unreserved public land is transferred to a private owner, that land acquires riparian rights which are superior to later appropriations; but it is important to remember that any appropriative rights perfected before the transfer will continue to have priority, even against the new riparian owner who acquired the land from the United States. Second, water which is "surplus" to the needs of riparian owners may be appropriated. If the riparian owners cannot, or do not, use the entire supply, they cannot object when the water they do not use is taken by others. The rules of appropriation then apply in determining the priorities among these subordinate users.

Each appropriative right is for a definite quantity of water and has a definite date of priority. Although the right is perfected by actual use for reasonable beneficial purposes, there can be complications in determining the priority of rights between two prospective appropriators. At one time posting a notice at the site of a project was required, but later statutes called for the recording of a notice of appropriation. The appropriator must be diligent in bringing a project into operation; but once begun, the project will not necessarily be limited to the amount of water first applied to it. And so long as the appropriator is diligent in developing the facilities, he may continue to increase the actual appropriation over a period of years, gradually building up to the maximum stated in the original notice. This doctrine helps to protect many large municipal projects, which are planned and built to a larger capacity than is presently required in the expectation of substantial municipal growth in the future.

Appropriations may be made for use on any land and for any reasonable beneficial purpose. Thus, an appropriator is not restricted to use on land adjoining a stream or land inside the watershed of the stream. Nor is an appropriator prohibited from storing water for use at a later time. However, an appropriation must be reasonable in both use and method of use, and, if it is not reasonable, a junior appropriator may be able to assert a prior right. Considerable debate, for example, has attended the question of the

The South Coast has been the scene of the state's most complex controversies over groundwater in part because the area's need for water so far exceeds the natural supply. In this photograph, the principal rivers of the basin appear as narrow concrete channels crossing the metropolitan area. The Los Angeles River curves through the middle of the photograph emptying into Long Beach Harbor. To its right are the San Gabriel and Santa Ana rivers.



In this photograph of the San Antonio Reservoir, the "borrow pits" dug in the course of the reservoir's construction appear at the far right as permanent features on the landscape of the Sunol Valley.

reasonableness of flooding as a method of irrigation, since it may have the effect of requiring more water than a different method.

The law regarding the use of agricultural return flows, in fact, illustrates another important principle of appropriation: that an appropriator may change the place and type of use so long as the change is reasonable and does not prejudice other rights. When water is used for irrigation, a substantial portion of it is not consumed by a crop and instead sinks into the ground or returns to a nearby stream where it is available for further appropriation. If a second appropriator establishes a right to this return flow, even though it is junior in priority to the first appropriation, the first appropriator may not change his operations in order to direct the return flow to another location where it would not be available to the second appropriator. This does not mean that an appropriator may not appropriate his own return flows as a part of his project; nor can the first appropriator be forced to continue his diversion just to satisfy the second appropriator. But, so long as the first appropriator continues to divert water in the original way and allows the return flow to pass beyond his control, then the second appropriator's right to that return flow must be respected.

As in the case of riparian rights, an appropriator does not own the water itself, only the right to use it in a certain way. Unlike a riparian right, however, an appropriative right may be lost by nonuse. And an appropriative right may be sold or otherwise transferred. This constitutes a major advantage over the riparian right, for it permits the economic flexibility ordinarily associated with property rights—the ability to change from one owner to another, from one purpose to another, even from one region to another. Nevertheless this transferability is subject, of course, to the rule that there can be no prejudice to other existing rights.

Substantial changes in the California law of appropriation were made by the Water Commission Act of 1913. Although portions of this act have been set aside by the courts, its most important surviving provision gave exclusive jurisdiction to a state agency to determine whether a proposed appropriation should be allowed. This authority is vested today in the State Water Resources Control Board. Under this statutory procedure, an intending appropriator must file an application, and the time of filing establishes the priority date if the application is approved. The board is not bound to approve the application, however, and it may instead approve a competing application which has been filed later. Upon approval, a permit is issued which authorizes the taking of water and establishes a time limit within which the project must be completed and the water actually put to use. The board may also impose a wide range of other conditions relating to the use of the water. When water is actually used in accordance with a permit, a formal license is issued and any subsequent changes in use or place of use are subject to board approval.

THE DECLINE OF PRIVATE RIGHTS

The period since World War Two has seen the rise of water resource planning by large public agencies and a corresponding decline in the importance of private water rights. The seeds of this change were planted much earlier and grew from the same social, economic, and political changes which both developed from and made possible the construction of the modern water system. Rules of law and institutional arrangements which were adequate to resolve water disputes between small groups of farmers and miners have come to be seen as insufficient for California's modern urban societies. Out of this perception came the impetus for the municipal ownership of water resources, which laid the institutional foundation for the construction of the Hetch Hetchy and Owens Valley water projects. These same principles of "public entrepreneurship" gradually extended to support water projects involving groups of cities, groups of states, and ultimately the federal government itself.

In the Central Valley Project water rights were perfected by the United States in a format of historic appropriation. At the private or local consumer end of the chain, however, water rights became a matter of special contract. Federal requirements relating to acreage limitations and water pricing control thus characterize the nature and utility of the modern rights encompassed in the Bureau of Reclamation's contracts. Similarly, the rights of the Metropolitan Water District on the Colorado River were originally thought to be based upon appropriative doctrines. Assignments and transfers of earlier appropriative rights were assiduously documented and an agreement was achieved after long negotiation setting forth the priorities and rights on the Colorado River between California agencies. Yet, when the United States Supreme Court finally resolved the lower Colorado River dispute in *Arizona v. California,* classical concepts of appropriative rights were of no avail. In effect, the court ruled that, with the adoption of the Boulder Canyon Project Act in 1929, the Colorado River had been converted to a delivery facility under the direction of the Secretary of the Interior. For all practical purposes, no rights in the waters of the Colorado River below Hoover Dam were acquired after 1929, except as they might be represented through contracts with the Secretary.

California has not followed the example of those areas of the eastern United States served by the Tennessee Valley Authority, where the power to adopt management programs embracing whole watersheds has been vested in a single administrative agency. But the practice of public entrepreneurship has invaded the field of local water system operations and with it has come a shift in the ownership of local water rights from private individuals, mutual water companies, and investor-owned utilities to public districts and municipal corporations. This transformation in turn has helped to bring about the adoption of judicial techniques better suited to enhance area-wide water resource planning.

This process is most clearly illustrated in the legal conflicts over groundwater rights in Southern California. Area-wide planning for water resources obtained an early start in Los Angeles under Spanish law. In a long succession of cases beginning in 1881, the California Supreme Court determined that the Spanish government intended in founding the Los Angeles pueblo to dedicate to it the entire flow of the Los Angeles River. As the boundaries of the city expanded, the pueblo right expanded with them. At the turn of the century, the court held that this right to all the waters of the river as needed for reasonable purposes carried with it the right to the underground waters of the San Fernando Valley, which are the

Marinas like the one shown here at Stockton are common features of the artificial waterscape of the twentieth century.

principal source of the river. This same rule was made applicable to the City of San Diego's rights on the San Diego River in 1930.

When Los Angeles realized at the beginning of the twentieth century that the flows of the Los Angeles River would not be sufficient for its future needs, water was imported from the Owens Valley, and for many years thereafter the city no longer needed the total local supply. During this period other cities and private parties began to share fully in the waters of the San Fernando Basin. But as Los Angeles' needs continued to increase, these other parties were cut off. Their claim that their use had ripened into a prescriptive right against the city was rejected by the California Supreme Court on the ground that they were entitled to use the water only when the city did not need it and when their taking, therefore, would not be adverse. The pueblo water right, moreover, was held to be a public trust and consequently a right not subject to prescription.

The fact that supplemental water became available through the Metropolitan Water District in 1941 seemed to promise that none of these other parties would have to go without water. But the advent of water from the Colorado River only complicated the problem of groundwater rights in the South Coast. The cost of the imported water significantly exceeded the cost of pumping local groundwater. As a result, Southern California's groundwater basins by the end of World War Two were being increasingly mined of the water in storage over and above the renewable safe yield of the basins involved. An urgent need was thus created for a method of effectively utilizing the delivery system which had been funded and constructed by the joint efforts of the 13 cities which constituted MWD.

Groundwater law at that time, however, provided no demonstrable solution to the problem. Originally, following the English common law, California recognized a law of capture: anyone with land lying over a groundwater basin could extract water and use it on any other land. In 1902, however, this early California rule was overturned on the ground that the English law on the subject is not suited to conditions in California. The California Supreme Court substituted a rule of correlative rights, analogous to riparian rights, by which an overlying owner was held to have a right, in common with other overlying owners, to extract and use groundwater from the basin for reasonable beneficial purposes on the overlying land. As with the riparian right, the overlying owner is said to be entitled to the natural advantages of his situation. Appropriations of groundwater are allowed and in most respects are like surface appropriations. One major difference is that the statutory licensing procedure is applicable to groundwater only in the rare instance where the water flows through known and definite subterranean channels.

It can be factually difficult at times, however, to determine just what is overlying land, particularly if there is more than one basin or subbasin involved and if there is a suggestion of interconnection. At the edges of a basin there may be land which is overlying when the basin is full but not when it has been pumped down. Legally, the definition of overlying land is easier than in the case of riparian land in that there is only one test: the land either lies over the basin or it does not. The watershed or drainage area is not considered; only land actually on the surface of the basin qualifies. But each pumper, by developing a cone of depression at his well, is able to change the gradient of the water table in the basin and thereby to cause water from any part of the basin to be drawn toward that location. It is physically possible, therefore, for one pumper to affect adversely the supply of all the other users, regardless of their relative location on the surface of the basin.

In addition, the amount of water available from a groundwater basin can be deceptive. Some very large basins can be pumped for many years without harmfully lowering the groundwater level. Overpumping which might damage or exhaust a basin can be controlled by operating within the limits of the basin's safe yield. This technique involves the selection of a typical weather cycle of wet and dry years and the determination of the average supply to the basin from rain and runoff in that period; depending on circumstances, such cycles may range from three years to several decades. With certain exceptions, this average is the safe yield. The amount of any excess over the amount used is surplus and is available for appropriation. As the culture of the land overlying the basin changes, however, more water may be used and the surplus may eventually disappear. When the annual draft on the basin exceeds the annual safe yield, the owners of prior rights have a cause of action to enjoin the overdraft.

Although the early groundwater cases effectively defined the relative rights of overlying owners and appropriators, and resolved disputes between a limited number of competing appropriative rights, none addressed the problem which confronted water planners in the South Coast in the 1940s of balancing and integrating imported supplies and local waters. Their problem was one of area-wide resource planning, and their objective was to control groundwater extractions so as to bring operations in the local basins within the limits of a safe yield. Because deficiencies in local supplies could be made up by imports, a plan for the equitable sharing of the higher cost of the imported water was the key.

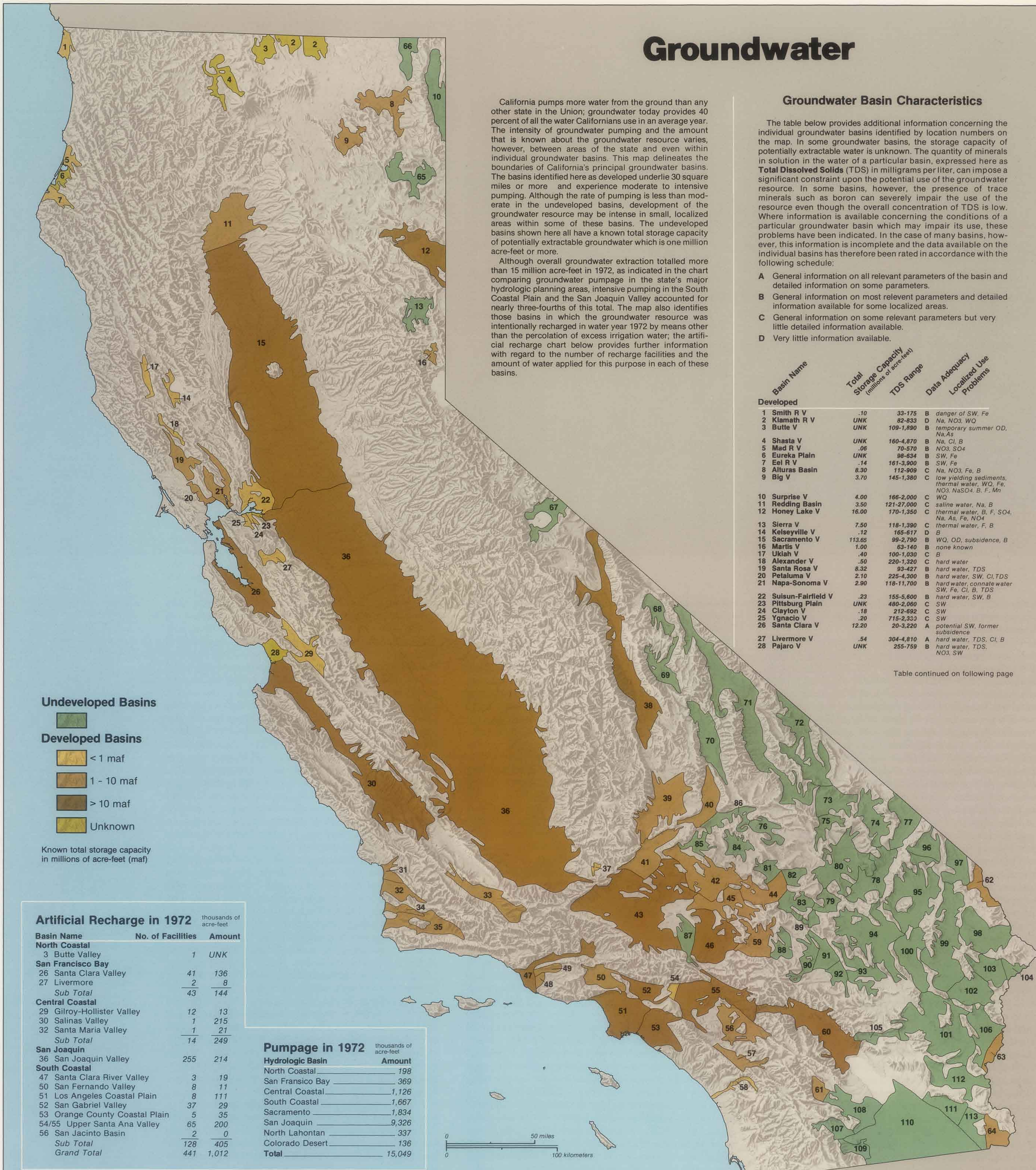
In the late 1940s, attempts were made to develop plans for coordinating local and imported water supplies in a way that would be compatible with private and public rights in the context of establishing principles of water law. The result was a series of plenary water cases involving substantially all of the parties using a groundwater basin. In the first of these basin adjudications, *City of Pasadena v. City of Alhambra,* the hydrologic condition of overdraft in the Raymond Basin was recognized, the major water users were all appropriators, and supplemental imported water was available through MWD. The central problem was to determine who would be required to restrict their groundwater extraction and take more imported water. Reference was made by the court to the State Water Rights Board for a determination of the physical facts, and it was stipulated in open court that the use of each party was adverse to the rights of every other party. From that stipulation, the California Supreme Court developed a doctrine of "mutual prescription." Simply stated, every party's rights to use of the waters of the Raymond Basin were dependent upon each party's highest five years of continuous extraction. All rights thus determined were of equal priority and these rights were then proportionally reduced so that the total extractions from the basin equalled its long-term safe yield. Cities, water districts, public utilities, and other major appropriators were thus placed in a position of equality in their access to groundwater supplies.

As a matter of orderly and equitable planning, all parties were forced to take a proportional share of their water needs from the more expensive imported supply of MWD. This solution by resort to "mutual prescription" sidestepped the complexities of appropriative rights based on the principle of "first in time, first in right." Urban development in the Raymond Basin made unnecessary the resolution of the interplay between major overlying rights because such rights are exercised for agricultural purposes, which were not significant in that basin in the 1940s. This case and those which soon followed in other basins are a testament to the ingenuity of lawyers and hydrologists. They present as well, however, a study in what might be called "dinosaurism"—a process in which a huge and impressive entity is created whose very size and clumsiness threatens its demise.

The second major basin adjudication was in the West Basin of Los Angeles County where continued extractions of groundwater were inducing seawater intrusion along the coastal portion of the basin. The parties to that plenary adjudication took almost 15 years, including two court references, before reaching agreement on a form of judgment essentially following the mutual prescription doctrine of the Raymond Basin case. In the 1950s, a plenary adjudication of rights on the Santa Margarita River consumed over a decade to achieve a judgment that solved nothing. In the Mojave River Basin, over ten years of litigation ended in outright dismissal and abandonment when agreement could not be reached. And the City of Los Angeles litigated its pueblo right and its rights to store imported water in the San Fernando Basin in *Los Angeles v. San Fernando* for more than 23 years, an undertaking that would have bankrupted a lesser litigant.

The cost of these plenary adjudications was proving monumental. The legal and engineering professions had built an expensive prototype and the limit, in terms of adversary litigation, had been reached. The beast had grown so big it threatened to exhaust its source of sustenance. It was in this context that resourceful people in the water industry converted the cumbersome process of court adjudication into a

Groundwater



California pumps more water from the ground than any other state in the Union; groundwater today provides 40 percent of all the water Californians use in an average year. The intensity of groundwater pumping and the amount that is known about the groundwater resource varies, however, between areas of the state and even within individual groundwater basins. This map delineates the boundaries of California's principal groundwater basins. The basins identified here as developed underlie 30 square miles or more and experience moderate to intensive pumping. Although the rate of pumping is less than moderate in the undeveloped basins, development of the groundwater resource may be intense in small, localized areas within some of these basins. The undeveloped basins shown here all have a known total storage capacity of potentially extractable groundwater which is one million acre-feet or more.

Although overall groundwater extraction totalled more than 15 million acre-feet in 1972, as indicated in the chart comparing groundwater pumpage in the state's major hydrologic planning areas, intensive pumping in the South Coastal Plain and the San Joaquin Valley accounted for nearly three-fourths of this total. The map also identifies those basins in which the groundwater resource was intentionally recharged in water year 1972 by means other than the percolation of excess irrigation water; the artificial recharge chart below provides further information with regard to the number of recharge facilities and the amount of water applied for this purpose in each of these basins.

Groundwater Basin Characteristics

The table below provides additional information concerning the individual groundwater basins identified by location numbers on the map. In some groundwater basins, the storage capacity of potentially extractable water is unknown. The quantity of minerals in solution in the water of a particular basin, expressed here as **Total Dissolved Solids** (TDS) in milligrams per liter, can impose a significant constraint upon the potential use of the groundwater resource. In some basins, however, the presence of trace minerals such as boron can severely impair the use of the resource even though the overall concentration of TDS is low. Where information is available concerning the conditions of a particular groundwater basin which may impair its use, these problems have been indicated. In the case of many basins, however, this information is incomplete and the data available on the individual basins has therefore been rated in accordance with the following schedule:

- **A** General information on all relevant parameters of the basin and detailed information on some parameters.
- **B** General information on most relevent parameters and detailed information available for some localized areas.
- **C** General information on some relevant parameters but very little detailed information available.
- **D** Very little information available.

	Basin Name	Total Storage Capacity (millions of acre-feet)	TDS Range	Data Adequacy	Localized Use Problems
Developed					
1	**Smith R V**	.10	33-175	B	danger of SW, Fe
2	**Klamath R V**	UNK	82-833	D	Na, NO3, WQ
3	**Butte V**	UNK	109-1,890	B	temporary summer OD, Na,As
4	**Shasta V**	UNK	160-4,870	B	Na, Cl, B
5	**Mad R V**	.06	70-570	B	NO3, SO4
6	**Eureka Plain**	UNK	98-634	B	SW, Fe
7	**Eel R V**	.14	161-3,900	B	SW, Fe
8	**Alturas Basin**	8.30	112-909	C	Na, NO3, Fe, B
9	**Big V**	3.70	145-1,380	C	low yielding sediments, thermal water, WQ, Fe, NO3, NaSO4, B, F, Mn
10	**Surprise V**	4.00	166-2,000	C	WQ
11	**Redding Basin**	3.50	121-27,000	C	saline water, Na, B
12	**Honey Lake V**	16.00	170-1,350	C	thermal water, B, F, SO4, Na, As, Fe, NO4
13	**Sierra V**	7.50	118-1,390	C	thermal water, F, B
14	**Kelseyville V**	.12	165-617	D	B
15	**Sacramento V**	113.65	99-2,790	B	WQ, OD, subsidence, B
16	**Martis V**	1.00	63-140	B	none known
17	**Ukiah V**	.40	100-1,030	C	B
18	**Alexander V**	.50	220-1,320	C	hard water
19	**Santa Rosa V**	8.32	93-427	B	hard water, TDS
20	**Petaluma V**	2.10	225-4,300	B	hard water, SW, Cl,TDS
21	**Napa-Sonoma V**	2.90	118-11,700	B	hard water, connate water SW, Fe, Cl, B, TDS
22	**Suisun-Fairfield V**	.23	155-5,600	B	hard water, SW, B
23	**Pittsburg Plain**	UNK	480-2,060	C	SW
24	**Clayton V**	.18	212-692	C	SW
25	**Ygnacio V**	.20	715-2,330	C	SW
26	**Santa Clara V**	12.20	20-3,220	A	potential SW, former subsidence
27	**Livermore V**	.54	304-4,810	A	hard water, TDS, Cl, B
28	**Pajaro V**	UNK	255-759	B	hard water, TDS, NO3, SW

Table continued on following page

Artificial Recharge in 1972

thousands of acre-feet

Basin Name	No. of Facilities	Amount
North Coastal		
3 Butte Valley	1	UNK
San Francisco Bay		
26 Santa Clara Valley	41	136
27 Livermore	2	8
Sub Total	43	144
Central Coastal		
29 Gilroy-Hollister Valley	12	13
30 Salinas Valley	1	215
32 Santa Maria Valley	1	21
Sub Total	14	249
San Joaquin		
36 San Joaquin Valley	255	214
South Coastal		
47 Santa Clara River Valley	3	19
50 San Fernando Valley	8	11
51 Los Angeles Coastal Plain	8	111
52 San Gabriel Valley	37	29
53 Orange County Coastal Plain	5	35
54/55 Upper Santa Ana Valley	65	200
56 San Jacinto Basin	2	0
Sub Total	128	405
Grand Total	441	1,012

Pumpage in 1972

thousands of acre-feet

Hydrologic Basin	Amount
North Coastal	198
San Fransisco Bay	369
Central Coastal	1,126
South Coastal	1,667
Sacramento	1,834
San Joaquin	9,326
North Lahontan	337
Colorado Desert	136
Total	15,049

	Basin Name	Total Storage Capacity (millions of acre-feet)	TDS Range	Data Adequacy	Localized Use Problems
29	Gilroy/Hollister V	.93	276-2,560	B	OD, TDS, B
30	Salinas V	10.30	251-3010	B	hard water, SW, TDS
31	Arroyo Grande V	1.70	117-2,900	B	possible SW, TDS Cl, SO4
32	Santa Maria R V	2.00	200-3,200	A	possible SW
33	Cuyama V	2.10	206-5,000	B	WQ
34	San Antonio Creek V	2.10	129-38,600	C	TDS
35	Santa Ynez R V	2.70	179-24,034	B	possible SW, TDS
36	San Joaquin V	570.00	64-10,700	B	OD, subsidence, saline connate waters, Na, Cl, SO4, B, NO4
37	Tehachapi V	.35	364-1,037	C	none known
38	Owens V	38.00	90-470	B	hard water, F, B, Na, As
39	Indian Wells V	5.12	141-232,000	B	Cl, B, TDS
40	Searles V	2.14	11,900-420,000	C	WQ
41	Fremont V	4.80	349-100,000	B	WQ
42	Harper V	6.98	316-14,700	C	WQ
43	Antelope V	70.00	123-7,700	B	OD
44	Lower Mojave R V	5.10	190-2,340	B	OD, WQ
45	Middle Mojave R V	8.05	145-3,900	B	OD, WQ
46	Upper Mojave R V	26.53	16-2,760	B	OD, WQ
47	Santa Clara R V	30.00	278-33,500	A	OD, SW, Mg, SO4, Cl, NO3, B, TDS
48	Pleasant V	1.89	134-92,270	B	OD, Mg, SO4, Cl, NO3, TDS
49	Los Posas V	4.25	130-4,927	B	Cl, B, TDS
50	San Fernando V	3.40	222-2,120	A	WQ
51	Coastal Plain of L.A.	31.73	144-34,800	A	OD, SW, Cl, SO4, TDS Fe, Mn
52	San Gabriel V	10.44	107-1,000	A	OD, NO3, TDS
53	Coastal Pln/Orange Co.	40.00	138-36,500	A	TDS, SW, OD
54	Upper Santa Ana V	.75	180-796	A	NO3, TDS
55	Upper Santa Ana V	16.00	60-1,900	A	OD, NO3, TDS
56	San Jacinto Basin	6.11	278-3,910	D	NO3, Cl, TDS, B, Na
57	Temecula V	1.20	250-700	B	SO4, Cl, Mg, NO3, TDS
58	San Luis Rey V	.24	83-14,300	C	SW, connate water, Mg, SO4, Cl, NO3, Fe, TDS
59	Lucerne V	4.74	97-10,140	C	TDS, NO3, Cl, SO4, F, B, OD
60	Coachella V	39.00	147-3,180	B	OD, F, SO4, TDS, B
61	Borrego V	1.30	300-2,150	C	Mg, NO3, F, SO4, Cl, TDS, Na
62	Needles V	1.10	831-1,500	C	SO4, Cl, F, TDS, Na, OD
63	Palo Verde V	4.96	856-11,000	C	F, Cl, TDS, SO4
64	Yuma V	4.60	935-14,700	D	Mg, SO4, Cl, Mn, TDS, Na
Undeveloped					
65	Madeline Plains	2.00	86-2,330	C	Fe, B, Cl, SO4, NO3
66	Goose Lake V	1.00	66-571	C	F, B, Na
67	Mono V	3.40	60-2,060	D	TDS, B, Na
68	Eureka V	2.07	?-554	D	none known
69	Saline V	2.43	790-3,760	D	F, Cl, SO4, TDS, B, Na
70	Panamint V	3.40	282-272,000	D	WQ
71	Death V	11.00	300-300,000	C	F, B, Cl, TDS, Na
72	Middle Amargosa V	6.80	490-2,300	D	F, B, SO4, Na
73	Lower Kingston V	3.39	5,380-8,540	D	WQ
74	Upper Kingston V	2.13	344-1,080	D	F, B, Cl, TDS, SO4, Na
75	Riggs V	1.19	344-8,540	D	none known
76	Bicycle V	1.70	608-?	D	none known
77	Ivanpah V	3.09	231-2,230	D	WQ
78	Kelso V	5.34	272-570	D	WQ
79	Broadwell V	1.22	470-1,260	D	WQ
80	Soda Lake V	9.30	242-3,350	C	Na, F, TDS
81	Coyote Lake V	7.53	312-2,480	C	F, TDS
82	Caves Canyon V	4.15	198-1,270	D	WQ
83	Troy V	2.17	278-3,310	C	WQ
84	Superior V	1.75	284-2,260	C	WQ
85	Cuddeback V	1.38	395-4,730	C	WQ
86	Pilot Knob V	2.46	389-1,510	D	WQ
87	El Mirage V	1.76	320-14,100	C	WQ
88	Johnson V	1.30	342-3,134	C	SO4
89	Lavic V	2.70	?-1,680	D	F, Cl
90	Ames V	1.20	75-1,408	C	TDS, F, Cl
91	Deadman V	1.27	172-982	C	none known
92	29 Palms V	1.42	86-1,180	C	F
93	Dale V	2.00	1,070-304,000	C	WQ
94	Bristol V	7.00	289-298,000	D	WQ, F
95	Fenner V	5.60	287-872	D	none known
96	Lanfair V	3.00	230-2,000	C	SO4, TDS
97	Piute V	2.40	UNK	D	SO4, F, Na
98	Chemehuevi V	4.70	351-1,090	D	SO4, CL, F, TDS, Na
99	Ward V	8.70	394-21,600	D	saline water, TDS, SO4, F, Cl
100	Cadiz V	4.30	615-2,000	D	WQ
101	Chuckwalla V	9.10	274-12,300	C	SO4, Cl, F, TDS, B, Na
102	Rice V	2.28	661-2,690	D	Cl, TDS, F, SO4, B
103	Vidal V	1.60	450-1,060	D	SO4, Cl, F, TDS, Na
104	Calzona V	1.50	450-1,060	D	SO4, Cl, F, TDS
105	Orocopia V	1.50	460-1,500	D	F, TDS
106	Palo Verde Mesa	6.84	856-11,000	C	AS, Sn, F, Cl, SO4, TDS, B
107	Vallecito/Carrizo V	2.50	220-1,378	D	Mg, SO4, Cl, TDS, Na F
108	Ocotillo V	5.80	498-3,161	D	Cl, F, SO4, TDS, Na
109	Coyote Wells V	1.70	442-8,660	D	WQ
110	Imperial V	14.70	694-3,560	D	deposits of low permability, WQ
111	Amos V	2.90	370-1,600	D	WQ
112	Arroyo Seco V	7.00	330-1,690	D	Mn, Cl, TDS, Na
113	Ogilby V	2.90	370-1,600	D	WQ

Key to Abbreviations in Table

As - Arsenic	NO_3 - Nitrate
B - Boron	OD - Overdraft
Cl - Chloride	R - River
F - Fluoride	Sn - Selenium
Fe - Iron	SO_4 - Sulfate
M - Magnesium	SW - Seawater Intrusion
Mn - Manganese	UNK - Unknown
Na - Sodium	V - Valley
$NaSO_4$ - Sodium Sulfate	WQ - Water Quality

tool for implementing already agreed upon management plans. In three subsequent adjudications, an answer to the size and cost of the Raymond Basin and West Basin prototypes was found in negotiation and agreement by the parties outside of the courtroom. Although the settlements were ultimately confirmed by a judgment of a court and placed under watermaster control, no real adversary trial was thereafter resorted to.

Such litigation by mutual agreement was not easily accomplished. In San Gabriel Basin, the case involved over 100 parties; in Central Basin, about 600; and in Chino Basin, over 1,300 defendants. Substantive water law and ordinary legal procedures did not simplify solution; to the contrary, the determination of all rights in the strict sense of California's water rights law would have meant total failure. The system of rights which emerged from these settlements consequently does not conform to historic categories of California's water rights. Rather, they emphasize equities and social and economic acceptability. Thus resource planning began to overshadow the intricate and heretofore inviolable field of water rights. In some instances, the resort to court was entirely avoided. By legislative action, water districts were given the power to tax all extractions from the groundwater basin for the purpose of obtaining funds to buy imported water to recharge the local supply. This results in individual access to the groundwater supply solely by reason of a political management decision without regard to individual "water rights."

The California Supreme Court's decision in *Los Angeles v. San Fernando* in 1975 further enhanced the standing of public agencies in the context of traditional rights. As a result of the Raymond Basin case, all pumpers within a groundwater basin were encouraged to increase the volume of their appropriations in order to establish their rights under the doctrine of mutual prescription. In the San Fernando case, however, the court removed the prize from this so-called "race to the pumphouse" by ruling that no private pumper can obtain prescriptive rights within a groundwater basin as against any public entity. This unanimous decision had the effect of placing the private pumper at a distinct disadvantage in any basin where public entities are also involved. More importantly, it would appear as a result that the doctrine of mutual prescription will be limited in its future application only to those instances where all of the pumpers in an overdrafted basin are private appropriators or where all appropriators consent to its enforcement as a basis for mutual agreement.

If the era of water resource planning appears to have achieved the elimination or reduction in importance of historic disputes over private water rights, resource planning from a statewide perspective has given birth to other major problems. Rather than individual disputes, the problems now relate to regional or intergovernmental struggles over the allocation and transfer of water supplies between areas of surplus and deficiency within the state.

The aqueduct systems which transfer large quantities of water from one watershed area to another, for example, generally operate on the assumption that their appropriations extend only to surplus waters. Such appropriations may be protected by congressional authorization where the waters arise on public lands, as in the case of the Hetch Hetchy project of the City of San Francisco, or through the purchase and acquisition of substantially all private lands, as in the case of Los Angeles' rights in the Owens Valley. But the areas in which these exported waters originate have been historically concerned with the specter that a major aqueduct system once constructed tends to preempt the supply that it exports and to preclude future local development. That concern led to the adoption of "area-of-origin" statutes which qualify and limit the operations of the Central Valley Project, the State Water Project, and other recent transfer projects. The implications of area-of-origin legislation have not been fully tested in the courts, but as the demands for water increase, the pressure will continue to build to restrain historic exports and preclude future exports of water regardless of economic feasibility or social necessity.

Environmental statutes in recent years have imposed further restraints upon the operation of the water industry in California. Water resource planners who at one time looked to the state's total "water crop" and contemplated transfers from the abundance of the North Coast to the arid areas of Southern California have seen California's Wild and Scenic Rivers Act erected as a wall sealing off their access to approximately one-fourth of the state's total average annual runoff. At the same time, there is increasing pressure for the protection of in-stream

THE WILD AND SCENIC RIVERS ACT

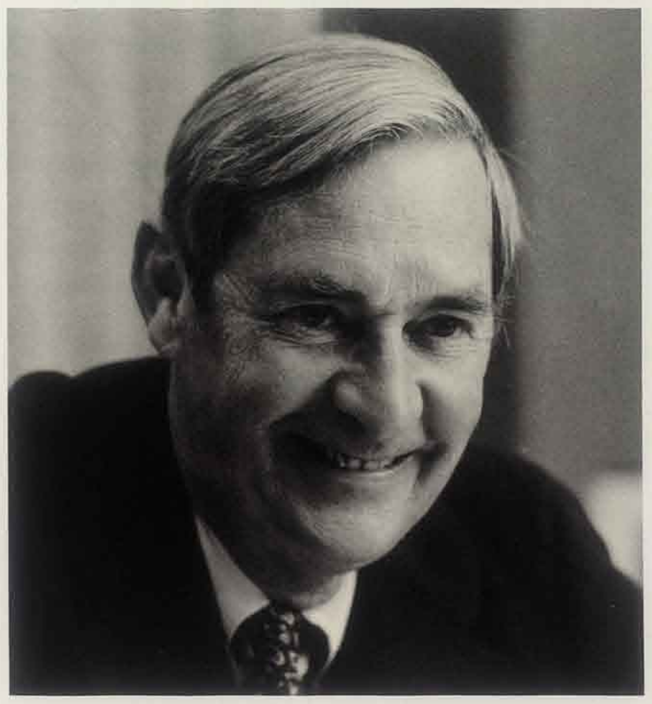
Landmark legislation is often the result not only of compromise but also of a unique combination of personalities and events. Such was the case with the adoption of California's Wild and Scenic Rivers Act, the brainchild of Peter H. Behr, Republican State Senator from Tiburon.

An attorney and former Marin County supervisor, Behr was elected to the State Senate at the end of 1970 following his successful leadership of a statewide petition drive to convince President Richard Nixon to complete the purchase of Point Reyes National Seashore. Although freshman state legislators do not customarily carry major legislative proposals, one of Behr's first acts upon taking office was to introduce his bill to reverse a century of attitudes toward water development in California and preserve the last free-flowing rivers of the North Coast in their natural condition. Still more audacious from the point of view of legislative etiquette, none of the rivers affected by the bill were actually located in Behr's senatorial district as it was then constituted. Instead, the rivers ran through the district of Senator Randolph E. Collier, the most senior member of the Senate and chairman of the powerful Senate Finance Committee, whose long state service had earned him sobriquets as "Father of the California Freeway System" and "Silver Fox of the Siskiyous."

Behr succeeded that first year in bringing his bill through the finance committee but lost it on the Senate floor. Popular support for environmental programs was high, however, and Governor Ronald Reagan's earlier decision to abandon the Corps of Engineers' proposed project at Dos Rios seemed to signal that attitudes at the state level toward water development were changing. When Behr introduced his bill again at the beginning of the 1972 legislative session, Collier responded with a bill of his own which duplicated Behr's in most respects with the significant exception that Collier's proposed legislation did not extend protected status to the Eel River.

The two bills moved in tandem through both houses of the Legislature and reached the governor's desk simultaneously. In the end, however, Governor Reagan gave his approval to the somewhat stronger protections afforded by the Behr bill.

The Wild and Scenic Rivers Act generally prohibits the construction of dams or diversion structures on the entire Smith River and specified stretches of the Klamath, Trinity, Van Duzen, Scott, Eel, Salmon, and American rivers. Although a state statute cannot prohibit a federal agency from developing projects of its own on these rivers, the act does forbid any state agency to lend specific assistance to such an effort. The Department of Water Resources, however, is required to report to the Legislature in 1985 with respect to any needs that may exist for water supply or flood control projects on the Eel River. In addition, the act permits the construction of diversion facilities on these rivers if the state's Secretary for Resources determines that these facilities will serve only local, domestic water needs and that they will not adversely affect the free-flowing condition of the river.



State Senator Peter H. Behr

Conveyance Facilities

1 Tule Lake Tunnel
2 Eastside Canal
3 Westside Canal
4 McArthur Diversion Canal
5 Bella Vista Conduit
6 Spring Creek Tunnel
7 Clear Creek Tunnel
8 Whiskeytown Conduit
9 South Canal
10 Corning Canal
11 Tehama-Colusa Canal
12 Glenn-Colusa Canal
13 Colusa Basin Drain
14 Western Canal
15 Cherokee Canal
16 Main Drainage Canal
17 Eastside Canal
18 Cross Canal
19 North Drainage Canal
20 East Drainage Canal
21 West Drainage Canal
22 Tule Canal
23 Willow Slough Bypass
24 Winters Canal
25 East Park Feed Canal
26 Potter Valley Tunnel
27 Putah South Canal
28 North Bay Aqueduct
29 Cache Slough Conduit
30 Santa Rosa-Sonoma Aqueduct
31 Petaluma Aqueduct
32 North Marin Aqueduct
33 Ygnacio Canal
34 Clayton Canal
35 Contra Costa Canal
36 Delta Cross Channel
37 Mokelumne Aqueduct
38 Folsom South Canal
39 Camino Conduit
40 Swager Ditch
41 Hetch Hetchy Aqueduct
42 Grant Line Canal
43 South Bay Aqueduct
44 California Aqueduct
45 Delta Mendota Canal
46 Modesto Main Canal
47 Turlock I.D. Lat.2
48 Ceres Canal
49 Turlock I.D. Lat.5
50 Turlock Canal
51 Highline Canal
52 Turlock Main Canal
53 Merced Main Canal
54 Le Grand Canal
55 San Luis Drain
56 Outside Canal
57 Main Canal
58 Chowchilla Canal
59 Madera Canal
60 Dry Creek Canal
61 Fresno Canal
62 Fowler Switch Canal
63 Centerville-Kingsbury Canal
64 Liberty Millrace Canal
65 James Canal
66 Crescent Ditch
67 San Luis Canal
68 Coalinga Canal
69 Lemoore Canal
70 Last Chance Ditch
71 Lone Oak Canal
72 Lakeside Ditch
73 Helm-Lewis Ditch
74 Tulare Lake Canal
75 Gates-Jones Canal
76 Wilbur Ditch
77 Blakeley Canal
78 Liberty Farms South Canal
79 Liberty Farms East Canal
80 Lakeland Canal
81 Homeland Canal
82 Pozo Canal
83 Alpaugh Irrig-Dist. Canal
84 Goose Lake Canal
85 Friant-Kern Canal
86 Westside Canal
87 Eastside Canal
88 Calloway Canal
89 Lerdo Canal
90 Pioneer Canal
91 Cross Valley Canal
92 Alejandro Canal
93 Buena Vista Canal
94 Stine Canal
95 Kern Island Canal
96 New Rim Ditch
97 Kern River Intertie
98 Eastside Canal
99 Tehachapi Cummings Pipeline
100a First L.A. Aqueduct
100b Second L.A. Aqueduct
101 Coastal Branch
102 Whale Rock Conduit
103 San Luis Conduit
104 Solvang-Santa Ynez Conduit
105 Tecolate Tunnel
106 Mission Tunnel
107 South Coast Conduit
108 Doulton Tunnel
109 Robles-Casitas Canal
110 Casitas Gravity Canal
111 Rubicon Main
112 California Aqueduct West Branch
113 California Aqueduct East Branch
114 Gage Canal
115 Fallbrook Oceanside Branchline
116 2nd San Diego Aqueduct
117 San Diego Aqueduct
118 La Mesa-Sweetwater Extension
119 Colorado River Aqueduct
120 Coachella Canal
121 Vail Canal
122 East Highline Canal
123 Moss Lateral
124 Occidental Lateral
125 Plum Canal
126 Rose Outlet Drain Canal
127 Acacia Canal
128 Central Main Canal
129 Westside Main Canal
130 All-American Canal
131 Yuma Main
132 Cocopah Canal
133 Reservation Main Drain
134 Eastside Drain
135 Palo Verde Canal

California Waterscape

Cities and Towns

- more than 200,000 population
- under 200,000 population

Selected Conveyance Facilities

- state developed
- locally developed
- federally developed
- dashed lines refer to uncompleted sections

Wetlands

Includes freshwater marsh, brackish marsh, and high water table native pasture.

Coastal Salt Marsh

A wetland subject to tidal inundation and characterized by pickleweed and cordgrass.

Wild and Scenic Rivers

Protected from instream development or diversion pursuant to the California Wild and Scenic Rivers Act of 1972.

Intermittent Lakes and Reservoirs

Lakes and reservoirs which contain some water on a nearly continuous basis.

Lakes and reservoirs that are commonly dry except during years of heavy runoff.

Peak Streamflows

The height of the isometric column represents the greatest **Instantaneous Peak Flow**, measured in cubic feet per second (c.f.s.), recorded on that river during the water year. White increment lines on the columns show 50,000 c.f.s. intervals. A flow of 10,000 c.f.s. is the smallest quantity represented by a "whole" column base. For flows less than 10,000 c.f.s., the column bases are divided proportionately as shown in the graphic key below. Class interval shadings are also employed to group the flows. **Flood Recurrence Frequencies** are indicated by a color code on the top of the column. If the flow does not exceed a 5 year flood, the entire column, including the top, is colored only in its flow class.

Instantaneous Peak Flow
(cubic feet/second)

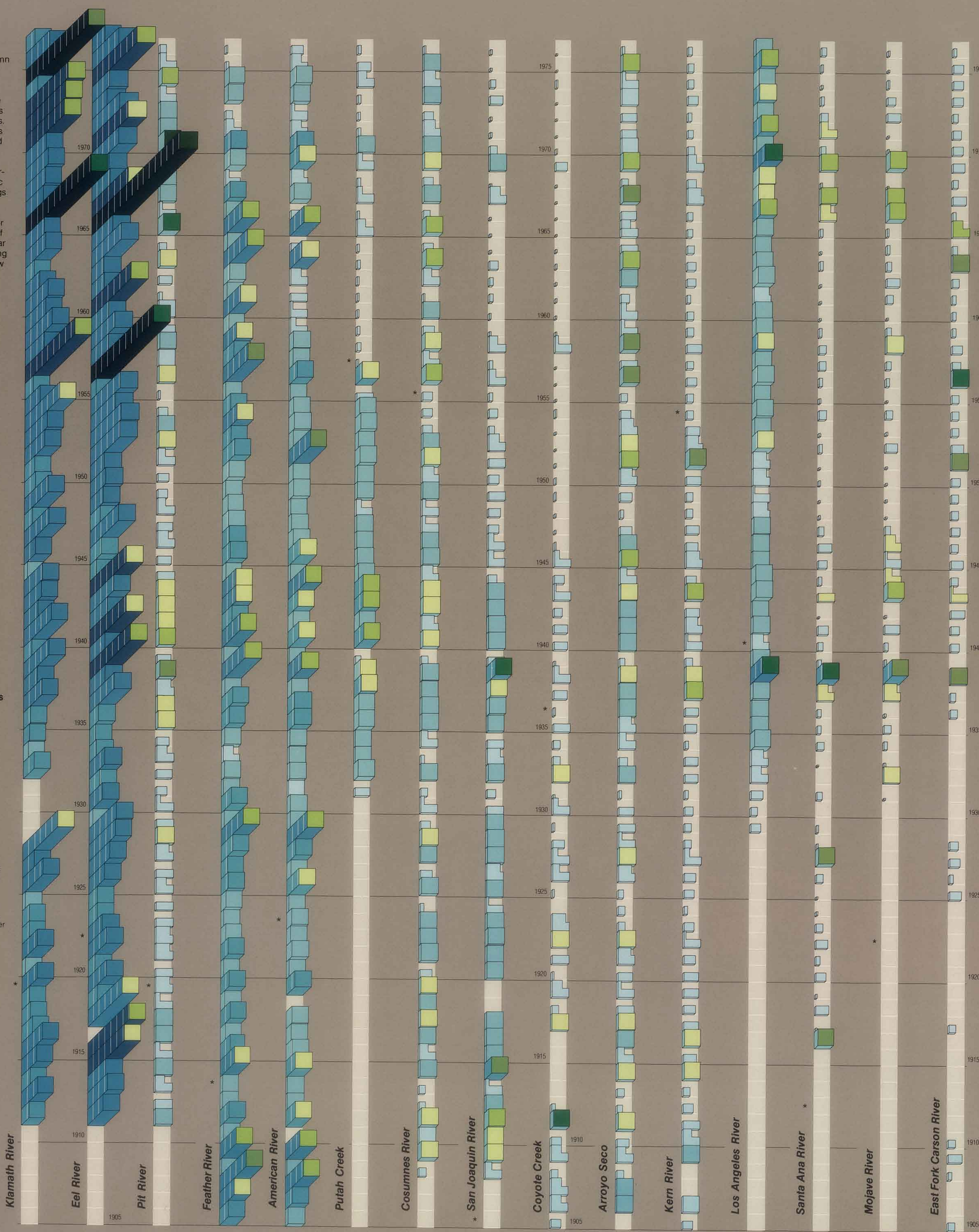
300,000
200,000
100,000

10,000
5,000
1,000
100

10,000 and below
10,001 - 50,000
50,001 - 100,000
100,001 - 300,000
300,001 - 500,000
500,001 and above

Flood Recurrence Frequencies

100 year flood
50 year flood
25 year flood
10 year flood
5 year flood



*First year reservoir capacity sufficient to regulate more than one percent of average annual stream flow.

Flood Recurrence Frequency figures are derived by Pearson Type III computations prescribed by the U.S. Water Resources Council.

Where no column appears for a given year, this indicates incomplete streamflow records.

Comparison of Peak Streamflow Records

This is a summary of the peak flow histories for the fifteen rivers. Each block symbol represents one recorded year, and is colored in the flow class shadings used on the main graphic. The outlined squares denote flows of 10,000 c.f.s. or less. There is no chronological order to the arrangement of the blocks. They are grouped strictly by flow class to relate only the actual number of years within each class that has been recorded on the river since 1905.

uses, which have the effect of interposing fish and wildlife as parties to traditional disputes over the division of water for human needs.

The environmentalist today looks to the 1928 constitutional amendment as a mandate compelling water users to restrict and conserve their use—a concept yet to be fully developed in California's water law. At the same time, water districts and agencies committed to water resource development see the constitutional amendment of 1928 as compelling the application of the state's water supplies to the maximum beneficial use of its people. In either case, water rights and property in the use of the state's water are seen as subservient to the social and political requirements of society.

The era of water resource planning has opened the way toward the use of the water resources of the state in a way that exceeds the imagination of earlier generations. For the first time, State Water Project planners have begun to look to the enormous quantity of unused groundwater storage capacity throughout California as a reservoir, or series of reservoirs, in which the surplus waters of the state from wet years can be stored to meet the demands of drought years. This conjunctive use of groundwater basins represents a major step forward in water resource planning. The way for its implementation was cleared by the California Supreme Court decision in *Los Angeles v. San Fernando*. But the implementation of that mandate will, in all probability, be accomplished by political action and agreement, not by water rights litigation in an adversary sense.

NATURAL CONSTRAINTS: FLOODS AND DROUGHT

Most Californians are primarily concerned with the ability of the modern water system to protect them from the vicissitudes of nature. Floods and drought are potentially disastrous natural events that frustrate our attempts to regulate the hydrologic cycle. Despite contemporary technology and an elaborate system of water management facilities, man has been unable totally to alleviate the effects of these two extreme natural phenomena.

Rainfall-induced floods are a relatively common characteristic of most rivers and streams in California. Even arroyos in the driest parts of the state experience floods periodically. Precipitation is the principal climatic cause of flooding because it dictates the spatial and temporal characteristics of the moisture available within a given drainage basin. A large amount of rainfall received over several days may produce a flood discharge similar to that resulting from a smaller amount of rainfall received very intensely during a few hours. Once precipitation has reached the earth's surface, however, evapotranspiration and antecedent soil moisture become additional factors in determining the proportion of rainfall from a particular storm that will be delivered to the stream channel. The magnitude of precipitation collected at the surface is a function, moreover, of the physical features of the watershed—the basin's area, shape, elevation, soils, and slope. The area of the watershed is commonly recognized as the single most important physiographic factor in determining the magnitude of a flood. In general, as the area of the watershed increases, the surface for collecting precipitation increases and the greater magnitude of intercepted precipitation produces a higher flood flow.

The relationship between watershed area and peak flow is illustrated by the graphic comparison of peak streamflows in this section. The annual peak flows for the Feather River are consistently greater than those for the American River, whose drainage area is only half as large as the Feather River watershed. In Southern California, the peak flows for the Los Angeles River are greater than those for the Santa Ana River which drains a smaller area. There are exceptions to most generalizations, however, and one exception to the relationship between area and flow is evident in the case of the Klamath River. The drainage area of the Klamath is approximately four times larger than that of the Eel River, but the record peak flow of the Eel exceeds that of the Klamath by 1.35 times. Also, the annual peak flow of the Eel has exceeded the annual peak flow of the Klamath in numerous years. This deviation from the general rule illustrates the mutual interdependence of the climatic and physiographic factors that control flood peaks. In these basins, intense rainfall seldom occurs uniformly over all parts of a large basin, but intense rainfall may cover most of a watershed of moderate size. Consequently, the Eel River watershed commonly receives more precipitation from a given storm and produces a higher flood flow even though its area is smaller than that of the Klamath River Basin.

A flood may occur somewhere in California in every month of the year, but some general seasonal characteristics of flooding are identifiable. Rainfall-induced floods resulting from prolonged general storms may occur anywhere in the state from November through March, and the area of flooding may be statewide or localized. The majority of California's most serious floods have resulted from the passage of such general storms. From late spring through fall thunderstorms or other locally intense storms may produce flooding in the Sierra and in Southern California. Thunderstorm floods tend to be of short duration and they are often very localized in their effects. In September and October, tropical storms may produce flooding in Southern California and the Colorado Desert. These storms move eastward out of Mexico north of their usual track and they produce intense rainfall and flooding along their paths.

It is in the period from March through June, however, that snowmelt floods may be expected in streams draining the Sierra. A snowmelt flood differs from a rainfall-induced flood in that the peak flow is usually lower although the flood flow is sustained longer. These conditions occur because the melting of snow moves upslope as thawing progresses from the lowest elevations along the stream channel toward the drainage divide. As the snow retreats upslope, less of the area contributes melted water and the result is a flood flow sustained by the more rapid melting of a decreasing snowpack. However, a cool spring followed by rapid warming will find nearly the entire snowpack still in the mountains and melt rates under these conditions can produce damaging floods. Rivers in the Tulare Basin are particularly noted for snowmelt floods resulting from a combination of unseasonably warm spring temperatures and a heavy snowpack.

When the annual peak flows for the rivers on the peak streamflows plate are compared, it is evident that there is a need for differentiating the peak flows in order to relate them to identifiable flood events and to compare the peak flows for different rivers. The common convention is to identify flows associated with specified flood recurrence intervals or the average span of time within which a flood flow of a given magnitude will be expected to be equaled or exceeded. The recurrence interval identifies a specific flood flow for a particular river, but it does not imply that a ten-year flood represents the same flow on all rivers. For example, a ten-year flood on the Cosumnes River is represented by a flow of 30,000

The intensive logging of forests in the Klamath River watershed visible in the photograph below add to the load of sediment that the river naturally carries. A plume of sediment at the river's mouth appears here as a lighter color sweeping southward along the coast. Mount Shasta is in the background near the center of the photograph.

The principal features of the Eel River floodplain receive prominent display in the photograph on this page. The oxbow lakes and cursive scars that mark the surface of the land to the right of the river's present course of flow define the extent of lateral movement that has occurred in the streambed of the Eel. Loleta is at the left and Highway 101 crosses at the top.

The photograph on the facing page also shows a segment of the Eel River today. Inclusion of the Eel in the state's Wild and Scenic Rivers Act met with opposition from many residents of the North Coast who recalled "killer floods" on the Eel and therefore felt it unwise to prohibit the construction of flood control facilities on the river. As a result of this controversy, a compromise was struck and the act requires a review to be made in 1985 of the continuation of the Eel's protected status under the law.

cubic feet per second while a ten-year flood on the American River is a flow of 108,000 cubic feet per second.

Recurrence interval flood flows are computed by assuming that annual peak discharges for a river may be treated statistically as a series of random events. A flood discharge having a recurrence interval of five years, for example, can be expected to occur once in five years or it has a 20 percent chance of occurring in any year. A 50-year flood can be expected to occur once in 50 years or it has a two percent chance of occurring in any year. Recurrence frequency is an important design and planning tool, but it does not mean that the designated flood discharge occurs at a regular span of five years or 50 years. Five-year floods may occur in successive years and then not recur for ten years or more and 50-year floods may occur in successive years and then not recur for 150 years or more.

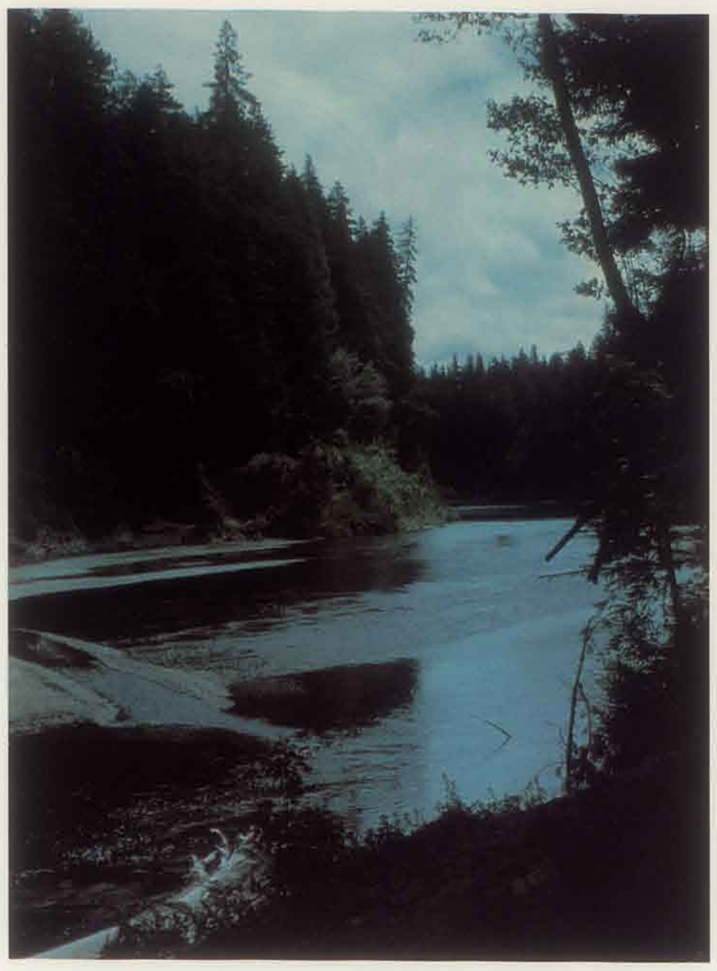
On the peak streamflow plate, only the Eel and Pit rivers have experienced 100-year floods during the period of record shown. Fifty-year floods are more common, but seven of the rivers have not experienced such flood flows since 1905. The Los Angeles River, however, had two 50-year floods during the 32 years between 1938 and 1969. Ten of the rivers have experienced 25-year floods. Arroyo Seco is noteworthy in that it experienced 25-year flood flows in 1956, 1958, and again in 1967. The Klamath River had four ten-year floods during the 62 years shown, but three of these occurred in successive years from 1970 through 1973. In fact, the 62-year record for the Klamath River contains one 50-year flood and one 25-year flood, and both of these floods occurred during the last 12 years of record. These data provide a striking example that floods are capricious even though they tend to conform with expected probabilities over a long period.

Floods due to high tides, tsunamis, and dam failures occur infrequently in California, although such floods are extremely destructive because they often produce a flood flow which overtops flood protection facilities designed to contain rain or snowmelt floods. High tides and wind may produce or contribute to flooding along the lower reaches of rivers whose discharge is at or near flood stage. Tsunamis are a flood hazard along the entire California coastline, but the north coast is the most frequently affected region. The greatest tsunami damage along the California coast in the last 100 years resulted from the wave generated by the Alaskan earthquake in March 1964. Since that time, seven tsunamis have been recorded at Crescent City, but none have approached the magnitude of the 1964 flood wave.

California has been fortunate that with over 1,200 dams in the state, extensive damage due to the failure of major dams has been limited to only a few cases in the state's recent history. Flooding subsequent to the 1928 failure of the St. Francis Dam in the San Francisquito Valley north of Los Angeles cost as many lives as the San Francisco Earthquake. The partial collapse of the Baldwin Hills Dam near Culver City in December 1963 was preceded by an evacuation warning which limited the number of fatalities although flooding caused an estimated $50 million in property damage in the residential area below the dam. And in December 1964, Hell Hole Dam on the Rubicon River was breached by flood water impounded behind the partially completed structure. Fortunately, the flood flow resulting from the failure of Hell Hole Dam was contained downstream by Folsom Dam on the American River.

Earthquakes represent a particularly serious concern for dam safety in most areas of California. The nature of the threat that earthquakes pose to dam safety and flooding was demonstrated by the moderate earthquake which struck the San Fernando Valley in February 1971. The intense ground shaking accompanying the earthquake caused the near failure of the Lower San Fernando Valley Dam and seriously damaged the Upper San Fernando Valley Dam. Approximately 80,000 people living in the area below these hydraulic fill dams would have been affected by flooding if the lower dam had failed.

An earthquake near Oroville Dam in August 1975 called attention to another concern related to earthquakes and dam failures. Evidence is mounting that the construction of dams and reservoirs may trigger seismic activity near a dam. The increased surface load created by the weight of the water in the reservoir and the seepage of water from the reservoir into the underlying strata have been proposed as



LOS ANGELES COUNTY FLOOD CONTROL DISTRICT

In California, the urban flood problem reaches its most serious level within the metropolitan region of Los Angeles. This area is probably subject to a greater potential flood hazard than any other area of similar size and population density in the United States. Furthermore, the flood hazard due to the flow of large volumes of water is compounded by damage due to debris carried from the steep mountain slopes by the flood waters. It has been estimated that the mountain watersheds surrounding Los Angeles when denuded by fire produce as much as 130,000 cubic yards of debris per square mile of watershed during a major storm.

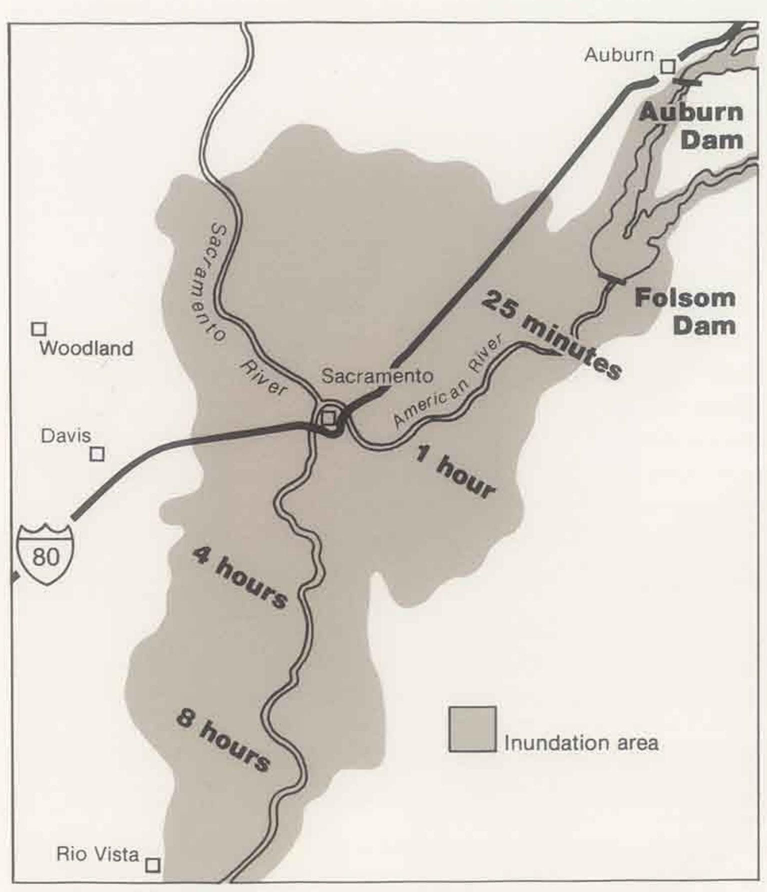
The Los Angeles County Flood Control District was the first flood control district in California to be created by a special act of the Legislature in 1915. Today there are 31 such districts. Because flood control problems seldom coincide with the boundaries of local governments, creation of a flood control district permits county governments to engage in county-wide flood control and water conservation activities which are formulated on the basis of natural watershed boundaries rather than political boundaries. In addition, formation of a flood control district permits the financial burden for flood protection to be distributed equitably among the property owners who benefit from the activities of the district.

The Los Angeles district today is one of the largest special governments in the United States in terms of bonded debt, area of jurisdiction, population, assessed valuation, and the number of its employees. The district is governed by the Los Angeles County Board of Supervisors, and it is charged with responsibility for flood control and water conservation in the southern three-fifths of Los Angeles County. The effectiveness of its flood control facilities was demonstrated during a severe storm in January 1969 when most Southern California counties were declared national disaster areas while the areas within the district's jurisdiction escaped inundation.

In addition to providing flood protection, the district is responsible for conserving flood and reclaimed waters for beneficial use. Impounded flood water is conserved by controlled releases and by enhanced opportunities for percolation of flood water into groundwater reservoirs, either in natural channels or in spreading grounds which have been constructed adjacent to river channels. The conservation of flood water by the district is supplemented by spreading reclaimed water and water imported from the Colorado River and from Northern California. To protect the quality of the water held in groundwater storage, the district operates three barrier projects designed to prevent seawater intrusion into groundwater reservoirs. Injection wells are employed to maintain pressure ridges along the coastline at selected locations, and the pressure ridges prevent seawater from migrating into the inland water-bearing formations. These water conservation activities are essential for maintaining groundwater supplies which provide approximately 40 percent of the water used in Los Angeles County. And the benefits derived from groundwater replenishment and the seawater barriers are especially significant when groundwater pumpage increases during a drought.

potential causes for seismic activity. Conclusive evidence linking reservoir construction and earthquakes is still lacking, but the threat of earthquakes to dam safety and the potential flooding resulting from an earthquake-induced dam failure are major concerns which have delayed construction of the Auburn Dam on the American River.

Most of California's urban and agricultural development has occurred on land subject to periodic inundation under natural conditions. Extensive flood control projects have been constructed to protect much of this land, but complete flood protection or the elimination of floods is an unrealistic goal. In general, current minimum standards attempt to provide protection from a ten-year flood for agricultural areas and from a 100-year flood for urban areas. Flood control is particularly necessary in urban areas because the concentration of population and their dependence on urban services magnifies the problems which accompany flooding.



This map presents a greatly simplified version of the maps prepared by the Bureau of Reclamation detailing the areas that would be inundated in the event of the failure of the Auburn Dam and the times at which the flood wave could be expected to arrive. State law currently requires the preparation of such maps by all agencies with dams subject to state jurisdiction whose failure might endanger populated areas. The Office of Emergency Services keeps a file of approximately 95 percent of the inundation area maps prepared for California.

Flood control programs in California employ a mix of structural and nonstructural measures to prevent or reduce flooding, to prevent loss of life, and to reduce flood damage. The most common structural measures are flood control reservoirs, bypass structures, debris basins, levees, and improved channels. Nonstructural flood control measures include flood forecasting, flood proofing, floodplain zoning and management, and watershed land treatment. Although some type of structural flood control facility has been constructed in each of the eleven hydrologic areas in California, there are significant differences among the regions with regard to the level of development. During the critical period of the flood season, about six million acre-feet of flood control storage is provided by reservoirs whose designated functions include flood control. Large, multi-purpose reservoirs account for more than 95 percent of the total flood control capacity, and 65 percent of the capacity is provided by reservoirs in the Sacramento and Tulare basins. In addition, incidental but often significant flood control benefits are provided by reservoirs which do not have flood control as a designated function.

Over 6,000 miles of levees and improved channels provide varying degrees of flood protection throughout the state. Levee construction has been most actively pursued in the Delta-Central Sierra region and in the Sacramento Basin. These two areas account for 44 percent and 26 percent, respectively, of the total mileage of levees in California. Channel improvements in and around urban areas account for the majority of the mileage in this category. The south coastal region alone contains 76 percent of the total mileage of improved channels in the state.

While flood control structures provide moderate protection from flooding, they do not eliminate the risk or necessarily reduce the threat of flood damage. New developments in unprotected areas, urban and agricultural encroachments into lower elevations along a floodplain, and the inevitable flood which exceeds the design limits of structures are dangers that must be recognized. These are situations in which nonstructural measures may be used effectively. Watershed land treatment measures in both rural and urban areas can be initiated to retard and to reduce runoff so that flood peaks are decreased. Evidence suggests that land-use practices can be especially effective in small watersheds for reducing small flood flows. Floodplain development can be regulated by zoning and management policies and flood forecasting and flood proofing can be employed to reduce losses from floods which exceed the design limits of flood control structures.

Our inability to moderate the extreme conditions of flood and drought may be the single common trait these two events share. Floods have a relatively rapid onset, a short duration, and may recur more than once in a specified period. In contrast, it is often difficult to determine when a drought begins and when it ends. Drought tends to be a long-duration condition when compared to the suddenness of other natural calamities, and drought recurs capriciously. But, whereas floods often produce dramatic changes in the landscape, extensive property damage, and loss of life, drought rarely causes structural damage or loss of human life in California.

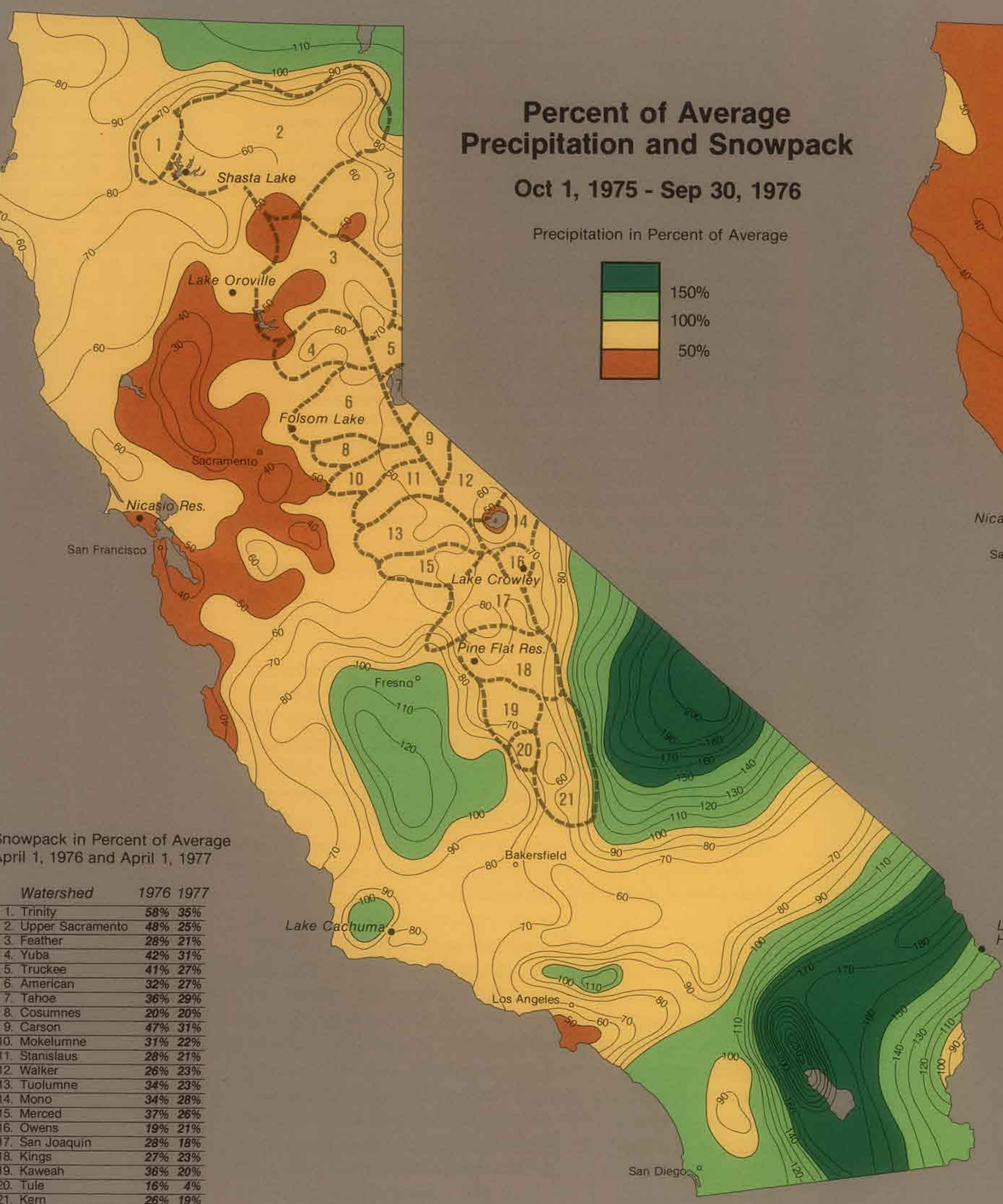
THE DROUGHT OF 1976-1977

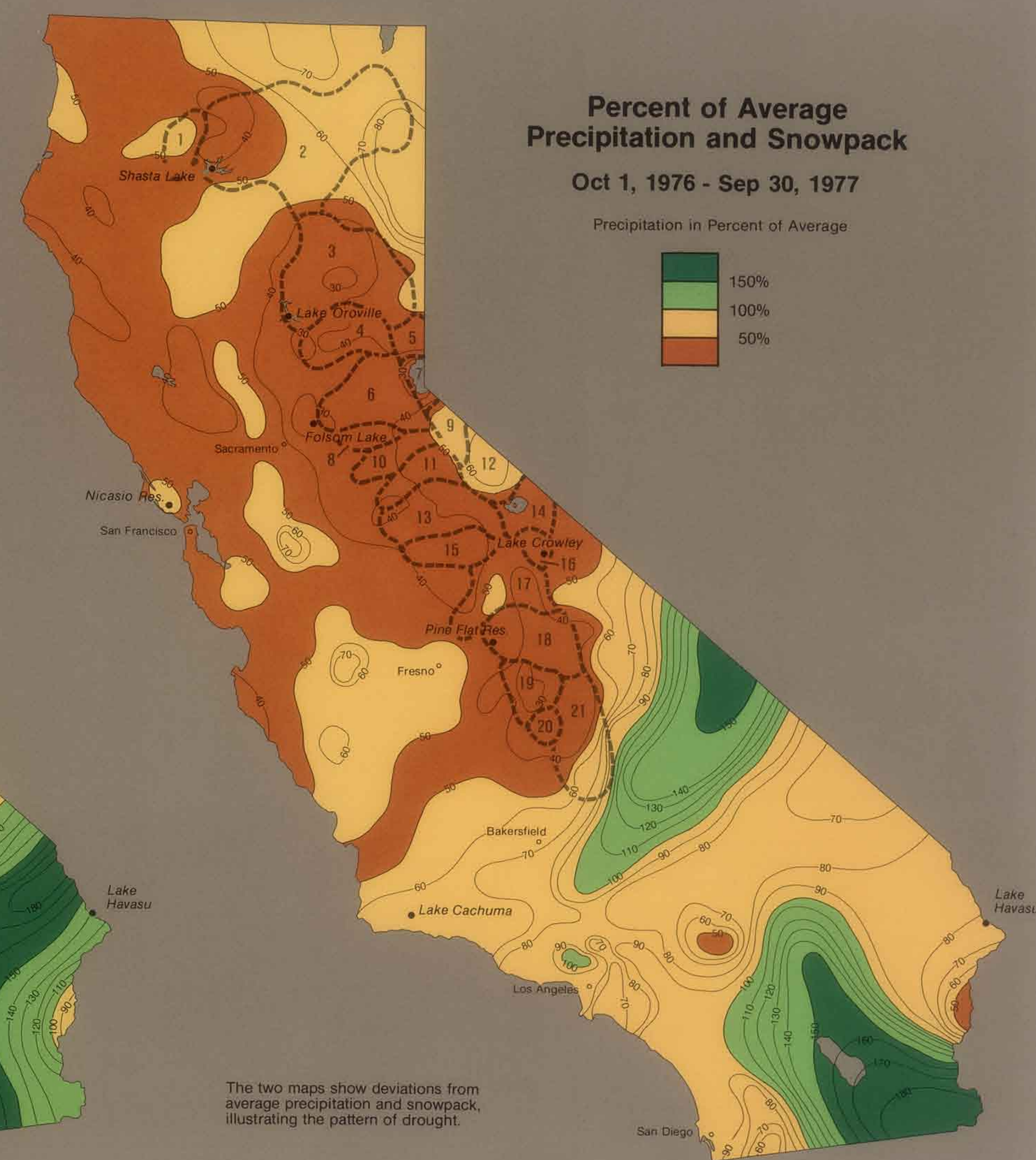
Drought is a multi-faceted natural phenomenon which means different things to different people. Acceptance of a universally applicable notion of drought is impeded by the fact that drought is a relative rather than an absolute condition, and the beginning and ending of drought are difficult to specify objectively. For general purposes, subnormal rainfall is commonly recognized as the single most important factor in the occurrence of a drought, although the magnitude of natural moisture needs is an integral part of the drought concept as well. The inclusion of subnormal rainfall as a component of drought has particular significance in California because it permits drought to be distinguished from the seasonally low rainfall which is characteristic of the summer months throughout the state.

The severity of a drought is measured conventionally by the duration and areal extent of moisture deficiency. In California, the severity of a drought is seldom uniform throughout the state. Although an absence of rainfall is commonly the first hint of a drought, other clues are apparent to the alert observer. The flow of rivers and streams, especially small streams, begins to decline in response to the cessation of runoff which is sustained by rainfall. Evaporation dries the soil surface and transpiration by plants removes moisture from the root zone of the soil. These drying processes are accelerated during rainless periods and temperatures during a drought are often higher than average. The depletion of soil moisture during rainless periods causes plants to wilt and eventually die. Groundwater is the last form of natural storage to display the effects of drought, but groundwater is also slower to respond to the cessation of drought. Groundwater discharge sustains streamflow during rainless periods, but as the duration of the drought extends, the magnitude of water in underground storage decreases and streamflow is reduced. The eventual desiccation of streams during a drought results from the absence of surface runoff and the depletion of groundwater.

For the state as a whole, water year 1976 was the fourth driest year of record and water year 1977 was the driest. These two years in succession produced the most severe drought of this century in California. During the 25 months from November 1975 through November 1977, many locations received little more rainfall than would be expected during an average 12 months. The precipitation map for water year 1977 in

Drought Water Years 1976/1977





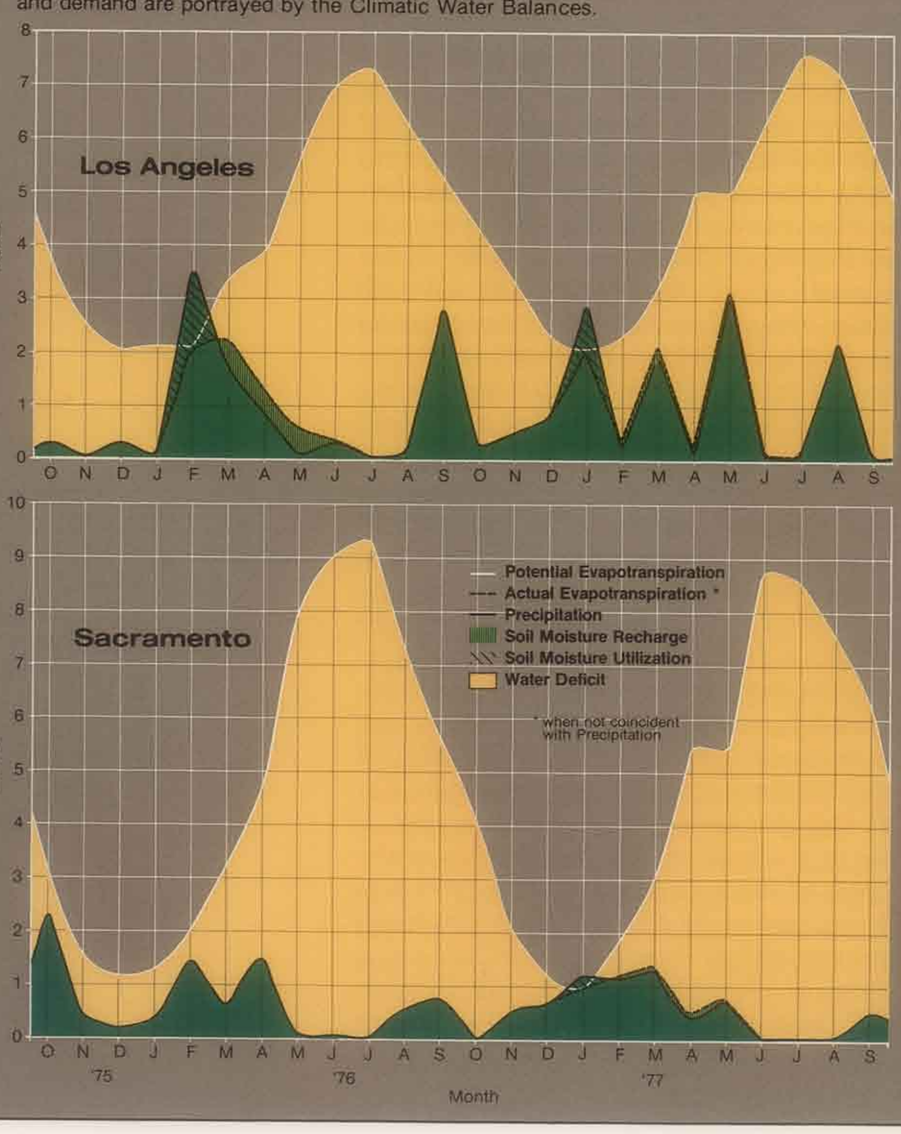
The two maps show deviations from average precipitation and snowpack, illustrating the pattern of drought.

Snowpack in Percent of Average
April 1, 1976 and April 1, 1977

Watershed	1976	1977
1. Trinity	58%	35%
2. Upper Sacramento	48%	25%
3. Feather	28%	21%
4. Yuba	42%	31%
5. Truckee	41%	27%
6. American	32%	27%
7. Tahoe	36%	29%
8. Cosumnes	20%	20%
9. Carson	47%	31%
10. Mokelumne	31%	22%
11. Stanislaus	28%	21%
12. Walker	26%	23%
13. Tuolumne	34%	23%
14. Mono	34%	28%
15. Merced	37%	26%
16. Owens	19%	21%
17. San Joaquin	28%	18%
18. Kings	27%	23%
19. Kaweah	36%	20%
20. Tule	16%	4%
21. Kern	26%	19%

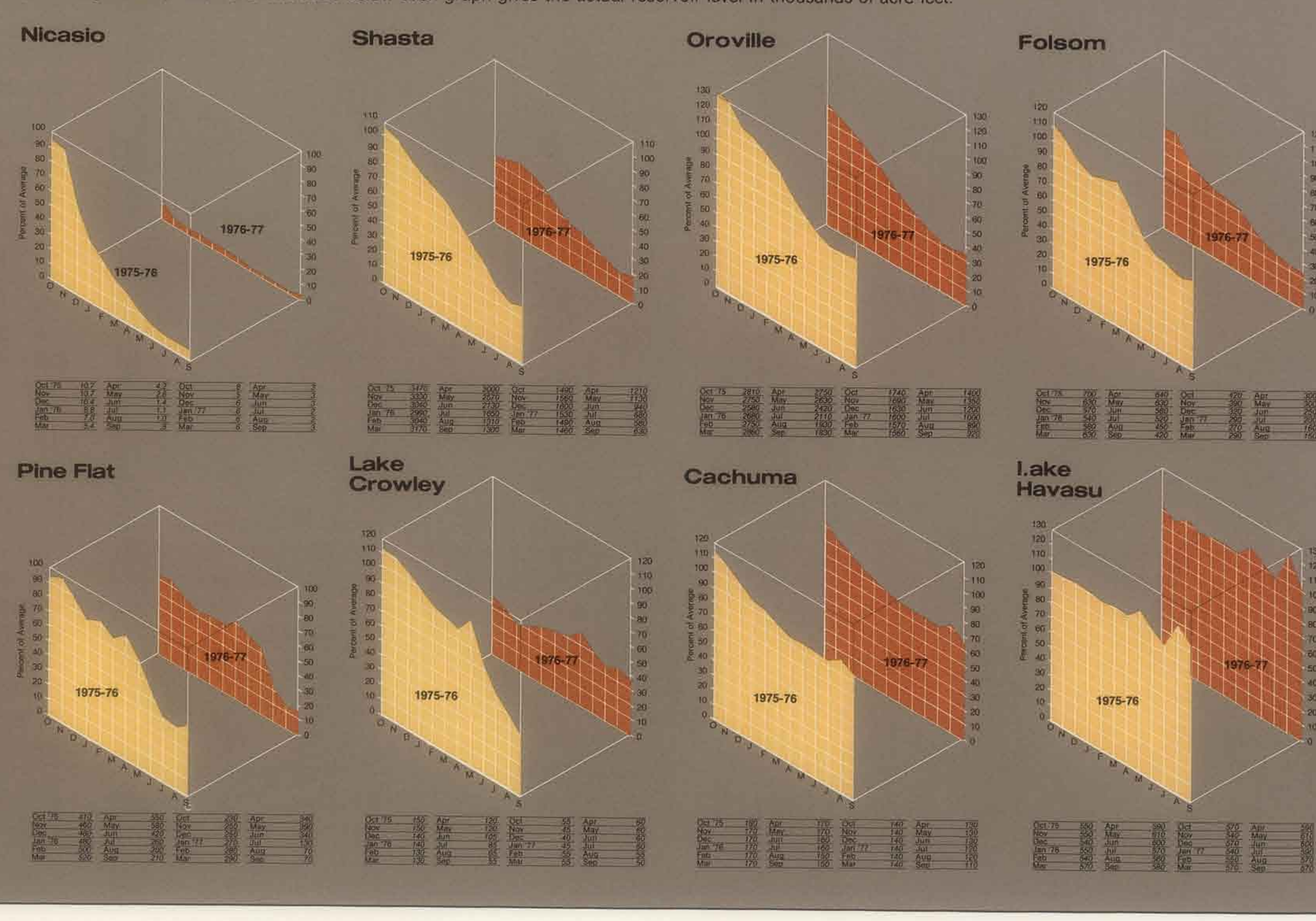
Water Balances

Monthly differences between the natural moisture supply and demand are portrayed by the Climatic Water Balances.



Reservoir Storage

Storage during the drought years is compared to the average monthly storage of these reservoirs during the preceding decade, 1966-1975. The table below each graph gives the actual reservoir level in thousands of acre-feet.



this section shows that precipitation over most of northern and central California was less than one-third of normal. Statewide precipitation for 1977 averaged only 35 percent of normal. Snow accumulation on April 1, 1977, was the lowest in 47 years in all basins except those of the Trinity and Feather rivers, and the water content for this record low snowpack was only 25 percent of normal.

Reduced surface runoff and groundwater discharge during the drought lowered the flow of rivers and streams to record levels. Runoff for the year was only 24 percent of average, and many smaller streams, especially those at lower elevations, ceased to flow. Even rivers regulated by reservoirs eventually carried significantly reduced flows. In October 1977, the Cosumnes River dwindled to a series of stagnant pools of water. The flow of the American River below Folsom Dam was reduced on October 1 to 250 cubic feet per second, while pre-drought releases maintained the river at a low flow of 1,500 cubic feet per second. In September 1977, the level of Lake Tahoe fell below the natural lake rim and the Truckee River, for several miles downstream, was reduced to a flow sustained by sewage effluent and discharge from springs along the river.

Meager runoff during the drought was inadequate for maintaining storage reservoirs at their usual levels, and many reservoirs were drained to their lowest levels since initial filling of the facilities was completed. The changes in reservoir storage during the drought are illustrated by the reservoir graphics on the drought plate in this section. The eight reservoirs shown here were selected as representative examples of statewide reservoir conditions. Declining storage levels are evident for all reservoirs except Lake Havasu, which was sustained by the Colorado River whose flow was little affected by the drought in California. Large reservoirs on rivers whose headwaters are in California, such as Shasta Lake, were severely depleted but maintained carryover storage. Smaller reservoirs, represented by Nicasio, were almost totally depleted. By August 1, 1977, the total storage in 143 reservoirs representing the bulk of California's surface water storage was only 39 percent of the average for that date.

During the drought, many cities and communities were forced to implement emergency measures to meet their essential water needs. The most widespread practices included mandatory conservation, the temporary importation of water from other areas, the drilling of new wells, increased water rates, and water rationing. Ultimately, almost every community in the state placed restrictions on the outdoor uses of water and more than 100 cities adopted some form of mandatory water conservation or rationing. The effectiveness of water conservation programs in selected cities is illustrated by the table of municipal water use. Differences in the reduced consumption of water reflect, among other things, local perceptions of drought severity. The smallest percentage reductions were achieved in Southern California where the availability of Colorado River water eased the drought threat. The largest percentage reductions were achieved by the Marin Municipal Water District and by communities on the Monterey Peninsula. The reduced consumption achieved in Marin was the result of one of the most austere water conservation programs in the state, which limited water to a maximum of 45 gallons per day per resident for all uses and doubled the unit price for water. Not all water price increases during the drought were intended to encourage water conservation however; several water agencies in the San Francisco Bay Area raised water rates to compensate for a substantial decline in revenues resulting from reduced water use by their customers.

Although water agencies in Southern California were less aggressive than those in other parts of the state in striving for reduced water use, four agencies responded to the water needs of Northern California in another way. The Metropolitan Water District of Southern California, San Bernardino Valley Municipal Water District, Coachella Valley County Water Agency, and Desert Water Agency agreed to exchange some or all of their 1977 State Water Project allotments with customers in Northern California. MWD freed 400,000 acre-feet for use in Northern California by increasing its water withdrawal from the Colorado River, and approximately 120,000 acre-feet of this water was delivered to the San Francisco Bay Area. San Bernardino relinquished 39 percent of its entitlement

Shasta Lake during the Drought of 1976-1977

Urban Response to Drought

Municipal Water Use (millions of gallons)

City	Jan. 1, 1976– June 30, 1976	Jan. 1, 1977– June 30, 1977	Difference	Difference in Percentage
Eureka	694	546	−148	−21
Redding	938	816	−122	−13
Alturas	153	140	−13	−8
Chico	2,471	1,969	−502	−20
Subtotal	4,256	3,471	−785	−18
Sacramento	13,156	10,760	−2,396	−18
San Francisco	18,859	13,564	−5,295	−28
San Jose	20,808	15,495	−5,313	−26
East Bay MUD	39,553	25,161	−14,392	−36
Alameda Co. WD	4,912	3,458	−1,454	−30
Stockton	4,828	3,565	−1,263	−26
Contra Costa Co. WD	18,414	14,633	−3,781	−21
Santa Clara	3,789	2,921	−868	−23
San Mateo	2,302	1,492	−810	−35
Daly City	1,440	1,025	−415	−29
Hayward	2,737	1,756	−981	−36
Sunnyvale	3,963	2,859	−1,104	−28
Marin MWD	3,934	1,848	−2,086	−53
North Marin Co. WD	1,160	717	−443	−38
Santa Rosa	2,263	1,424	−839	−37
Subtotal	142,118	100,678	−41,440	−29
Fresno	10,297	7,658	−2,639	−26
Bakersfield	7,539	6,087	−1,452	−19
Modesto	5,016	3,887	−1,129	−23
Merced	2,043	1,385	−658	−32
Monterey Bay	2,652	1,414	−1,238	−47
Sonora-Jamestown	267	200	−67	−25
Subtotal	27,814	20,631	−7,183	−26
Los Angeles	94,983	82,335	−12,648	−13
Long Beach	10,873	9,148	−1,725	−16
San Diego	25,344	23,584	−1,760	−7
Anaheim	8,479	7,530	−949	−11
Riverside	6,755	5,919	−836	−12
Santa Barbara	2,376	1,926	−450	−19
Oxnard	2,802	2,649	−153	−5
Ventura	3,463	2,799	−664	−19
San Luis Obispo	1,041	924	−117	−11
Santa Maria	1,297	1,068	−229	−18
Subtotal	157,413	137,882	−19,531	−12
Total Reported	331,601	262,662	−68,939	−21

for 1977, and the Coachella Valley and Desert water agencies gave up their entire State Water Project allotments. These actions provided another 30,000 acre-feet of water for use in Northern California.

Although agricultural losses due to the drought have been estimated at $510 million for 1976 and $800 million for 1977, most agricultural areas of California had more options available for responding to the drought than water users in most urban areas. In the early months of the drought, agricultural activities most affected by the meager rainfall were dry farming operations, including grain, hay and range crops, ranchers and dairymen. Over 90 percent of the drought losses in 1976 were experienced by nonirrigated agriculture while the needs of irrigated agriculture were generally satisfied in 1976. The State Water Project delivered over two million acre-feet of water in 1976, including 626,000 acre-feet of projected surplus water, the largest single-year delivery of water in the history of the project. The Bureau of Reclamation delivered about six million acre-feet to Central Valley Project customers in 1976 and fulfilled all its contractual commitments. The 1976 deliveries, however, left storage reservoirs seriously depleted, and deliveries to agricultural users in 1977 were reduced by as much as 60 percent for State Water Project customers and by as much as 75 percent for customers of the Central Valley Project.

Agriculture responded to reduced water deliveries during 1977 in several ways. More attention was given to water-efficient irrigation practices, and double cropping was eliminated in many areas, even though these forms of response in some instances had the effect of increasing the costs of agricultural production or decreasing the income from sales. In many areas, the acreage of less water-intensive crops, such as cotton and wheat, was increased, and the acreage of heavy water-using crops, such as rice and sugar beets, was decreased. In the case of processing tomatoes, however, which require more water than most vegetable crops, the acreage was increased in response to favorable market prices. And, as the table of acreage and production shows, on a statewide basis, the acreage of fruit and nut bearing crops, vegetables, and melons actually increased in 1977 while that of field crops decreased. California's overall agricultural production during the drought was in fact only 7.6 percent lower in 1977 than the 1975 record high of 51.7 million tons.

Agriculture survived the drought so well in part because groundwater was used extensively for irrigation to replace deficient surface water supplies. An estimated 10,000 new wells were drilled and by the end of 1977 groundwater pumpage was providing an estimated 53 percent of all the water used by agriculture. As groundwater pumping lowered water tables and created greater pumping lifts, however, the cost of using groundwater increased significantly. And a shortage of hydroelectric energy required the use of more expensive fossil fuels for energy production, which in turn increased the cost of electricity to operate groundwater pumps.

HISTORIC FLOODS AND DROUGHTS

Prior to the drought of 1976-77, the drought which lasted from September 1923 to September 1924 ranks as the most severe period of statewide water deficiency in this century. In all but the interior desert regions, precipitation in 1923-24 was only 40 to 50 percent of average and runoff in the San Joaquin and Tulare Lake basins fell to 25 percent of normal. Drought conditions in this period were complicated by persistant desiccating winds which created dust storms and aided in the spread of forest fires. To make matters still worse, severe frost destroyed much of the state's citrus crop while an unseasonal spate of rain ruined the lettuce crop in the Imperial Valley.

In general, drought conditions tend to be most severe only in limited regions of the state. The drought of 1863-64, for example, had a greater impact on Southern California than the other parts of the state, and the drought of 1929-34 struck the Sacramento River basin with special severity. Similarly, the droughts of 1945-51 and 1958-61 had their principal effects in the Santa Ynez and San Joaquin basins respectively.

Simultaneous statewide flooding is even more rare. The legendary Noachian flood of 1861-62 came closest to affecting the state as a whole, but the records of this event are too incomplete for a certain assessment of the full extent of flooding. The rains began November 10, 1861, and continued almost without ceasing for the next two months. On January 8, 1862, a tropical storm brought warmer temperatures which accelerated melting of the snowpack. As a result, an inland lake 60 miles across formed in the Sacramento Valley and much of what is now the Los Angeles metropolitan area was inundated. Although the rains were less severe in the South Coast, the damage was in some respects much worse than that suffered in other parts of the state, because many of the houses there were built of adobe, which collapsed, and because hundreds of acres of vineyards and farmlands were washed away by rain-engorged streams and rivers cutting new channels to the ocean.

A storm in December 1955 brought extreme flood conditions to the area from the Oregon border to the Tehachapis. Although the recently completed Folsom Dam on the Amerian River protected Sacramento, severe flooding on the Feather and Yuba rivers forced the evacuation of more than 20,000 people from Marysville and Yuba City. More recent storms have produced even higher flood flows than 1955 on many rivers, but the extent of flooding has been more limited. Intense storms in December 1964 and January 1965 were extremely destructive on the North Coast. And the storms of January and February 1969 produced flooding from the Delta southward that rivaled or exceeded the flood stages associated with the rains of 1955.

Agriculture also benefited from water exchanges during the drought. The San Joaquin Valley received about 70 percent of the water freed as a result of MWD's decision to use Colorado River water in place of deliveries from the State Water Project. Agricultural contractors in the San Joaquin Valley consequently received the equivalent of 91 percent of their 1977 State Water Project entitlement rather than the 40 percent they would have received without the exchange. Agricultural users in Northern California received about 30,000 acre-feet of the water relinquished by San Bernardino Valley, Coachella Valley, and Desert water agencies. And in still another case, several rice growers in the southern Sacramento Valley agreed to sell about 10,000 acre-feet of water to farmers in the Friant-Kern service area rather than use the water themselves.

California's response to the drought of 1976-77 required considerable flexibility among the institutions which govern and administer the modern water system. The fact, however, that the drought in Southern California was replaced by destructive flooding in February and March of 1978, which caused 38 deaths and $180 million in damages, emphasizes that total alleviation of nature's extreme events continues to be an elusive goal in California.

This table displays the harvested acreage and production of the principal crop groups in California during the drought of 1976–77 as compared with the two previous years. These figures include both irrigated and dry farm acreage and production. As indicated, acreage and production actually increased in the drought year 1977 for fruit and nut bearing crops, vegetables, and melons.

Agricultural Response to Drought

Year	Field Crops	Fruit and Nut Bearing Crops	Vegetables and Melons	Total
		Acreage		
1974	6,520,300	1,508,010	861,320	8,889,630
1975	6,602,000	1,571,440	921,660	9,095,100
1976	6,590,000	1,634,540	829,466	9,054,006
1977	6,359,000	1,673,890	914,652	8,947,542
		Production (tons)		
1974	24,986,000	8,702,700	11,820,750	45,509,450
1975	28,566,000	9,794,800	13,312,050	51,672,850
1976	28,965,000	9,626,600	11,051,650	49,643,250
1977	25,009,000	9,673,700	13,037,750	47,720,450

CHAPTER 8

The Economics of Water

The study of the economics of water involves the science of efficiency. Because our collective desire for water exceeds the available supply, the fundamental economic question for the allocation of water is how best to use the resources we have. Economic efficiency, which means getting the greatest "net benefit" (benefits minus costs) out of the use of the resource, is accomplished through the operation of a market mechanism wherein buyers and sellers hypothetically come together to register their preferences for the use of the resource. The result of this process is a set of water prices which assures that water will be allocated to those uses for which need is most intense. In this regard, the market is simply an elaborate communication system enabling the myriad of individual preferences to be recorded, summarized, and balanced against one another. In such a theoretical system the allocation of water is treated no differently from any other commodity, and there is no place for the argument that water needs to be treated specially because of its importance to life and the production of goods and services.

Although the market for water shares basic similarities with other markets, it also possesses several distinctive features which distort the normal interaction of supply and demand and alter significantly the ability of the market to achieve purely economic efficiencies. In the first place, the principal commodity in the market, the water itself, has been treated, for the last half century at least, as a free good, a grant from nature which belongs to all the people of California. This public interest in the allocation of water resources assures that social values have had an equal and sometimes predominating play in the market in relation to simply monetary values. As a result, through legislation, water is not assigned just to those who will pay the highest price for it; instead, we have allocated our water resources to accomplish such societal objectives as the support of agriculture or the preservation of some streams in their natural state as wild and scenic rivers.

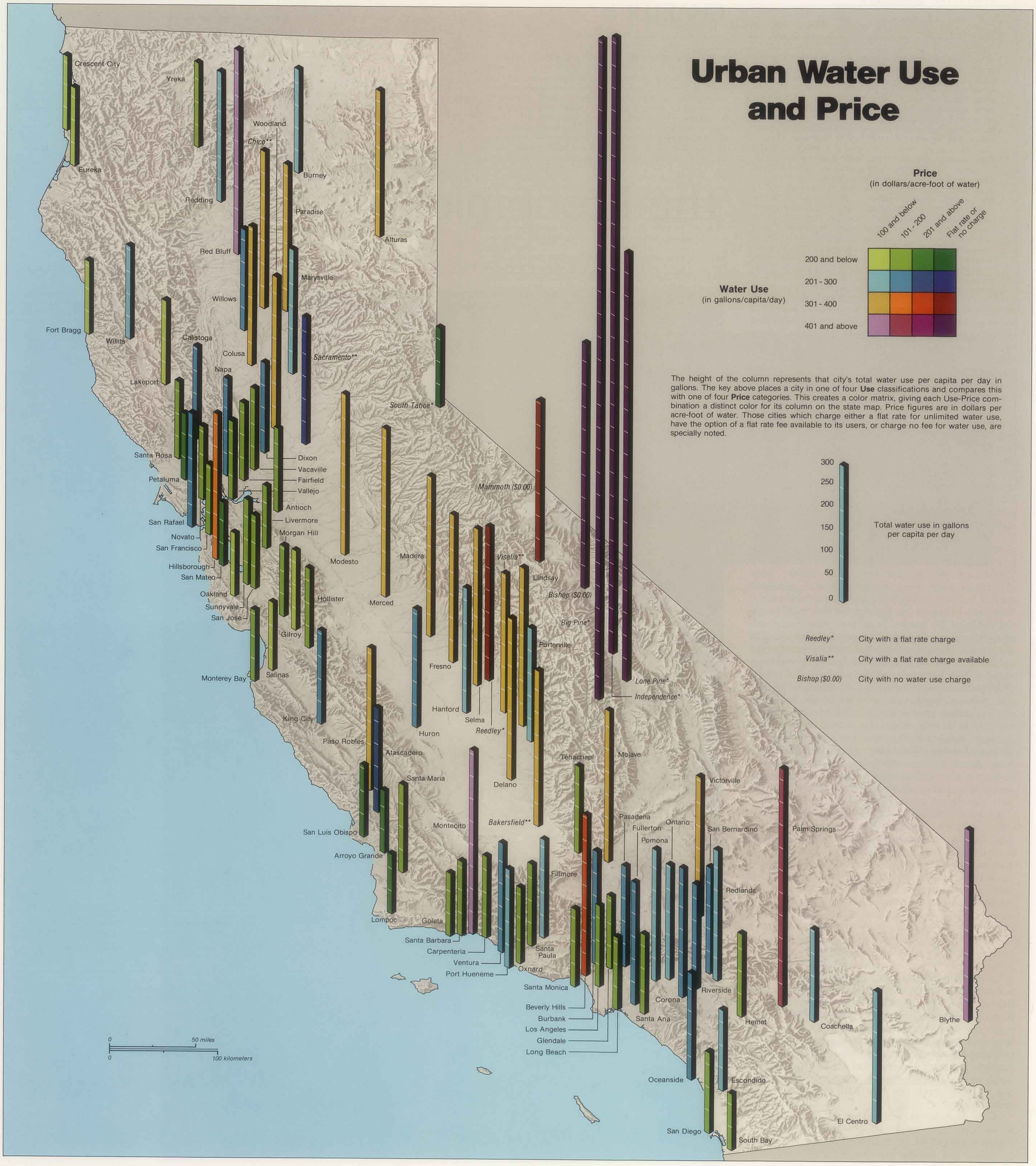
A further ramification of the way in which we treat water as a free good is that no scarcity value is assigned to water in California. Diamonds, in contrast, achieve a high scarcity value and the diamond market works to limit the supply at any given time so that prices will remain high. But when water supplies decline in California, as in a drought, prices do not automatically go up. Instead, when water supplies become scarce or overdrawn, more incentive is given to developing new supplies of water rather than letting the market mechanism raise the price to allocate the water to the highest value use.

An elaborate set of subsidies encourages this behavior. Federal water projects, for example, obtain subsidies through extraordinarily inexpensive financing arrangements and long-term repayment terms which may extend over 30 or 40 years. Where water projects generate hyrdoelectric power, the revenues from energy sales are often applied to subsidize the cost of water delivery. And in many local projects, property tax revenues are used to pay off portions of the development costs of a water system and thereby mask the true cost of water to the consumer.

Water law, by protecting pre-existing rights to water use, also works to preserve current use patterns regardless of scarcity or other changing conditions and thereby prevents the easy reallocation of water to higher value uses. If water is itself

In some areas the disappearance of a pre-existing water source can create economic benefits, as in the case of the mining operation shown here which is extracting commercially valuable salts and chemicals from the dry bed of Searles Lake.

Urban Water Use and Price



The height of the column represents that city's total water use per capita per day in gallons. The key above places a city in one of four **Use** classifications and compares this with one of four **Price** categories. This creates a color matrix, giving each Use-Price combination a distinct color for its column on the state map. Price figures are in dollars per acre-foot of water. Those cities which charge either a flat rate for unlimited water use, have the option of a flat rate fee available to its users, or charge no fee for water use, are specially noted.

treated as a valueless commodity, the right to its use is accorded a very high value indeed in California. In some areas—the Owens Valley, for example, in the 1950s—efforts have been made to tax such rights as though they were property. Rights can be preserved, however, only so long as they are exercised. By protecting water rights, therefore, water law operates not only to prevent the reassignment of water to its highest economic uses but also to keep water in some lower value uses even when the possessor of the right to such use is applying the water only for the purpose of preserving his right. While this is not an argument for overturning all water rights in California, this aspect of the system of rights is significant both for its impact on the water market and for its effects in interfering with the achievement of other societal objectives for water, such as conservation, economic efficiency, or the assignment of water to its highest beneficial uses.

The physical nature of the water delivery systems we have constructed in California constitutes a further restraint upon the transferability of water to its most efficient or desirable uses. These delivery systems represent massive investments and water cannot simply be redirected to a user, no matter how much he is willing to pay, if the user is not located next to an existing water supply or delivery system. Similarly, once a user is hooked up to a water delivery system, he cannot easily take his business elsewhere if he is displeased with the service. In rare instances, however, rights have been transferred within an existing delivery system. This occurred, for example, during the drought year 1977 when legal restrictions were relaxed to allow transfers of water within Kern County. In these circumstances, the water obtained a scarcity value of approximately $75 an acre-foot.

The final element of the water market which distinguishes it from other markets is the monopolistic nature of water supply within individual geographic areas and the consequent need for regulation these conditions create. The capital costs associated with building big delivery and distribution systems like the Central Valley Project, the State Water Project, or the Colorado River Aqueduct assure high barriers to entry into the market, and therefore, basically monopolistic conditions. In some areas where substantial underground pumping can occur with much lower capital investments, competition among pumpers is more likely. But, if the competitors are pumping from the same basin, the results may be preverse and may deplete the groundwater basin more rapidly than is socially desirable.

Regulation in either case is necessary. In the underground pumping case, regulation is necessary to force the level of extraction of the water to be that which is in the long-run interest of society and not to permit windfall profits to accrue to the pumpers. An alternative to regulation of pumpers would be to force monopolistic ownership so that the long-run view is taken using the self-interest motive. But again, regulation would be required to substitute for the competitive market by developing rules and procedures which make a monopoly operate in a way similar to that which would occur in a competitive market.

SUPPLY AND DEMAND

The supply of water available within the market is determined by the underlying costs of production. If these costs cannot be covered, there will be no supply on the market for very long. These basic costs are determined in turn by the production technology involved, the cost of the water or right to its use, the amounts of water involved, the prices of related goods, price expectations about the future, the number of sellers in the market, and any other relevant cost factors, such as the presence of taxes or subsidies. The major determinants of demand include tastes for the product, the number of buyers competing in the market, their income, the prices of related goods (both substitutes and complements) and, finally, expectations about future prices which bear on decisions of whether to buy now or not.

In the figure below, supply is shown as a schedule which depicts the various amounts of a resource the producer is willing and able to produce and make available for sale in the market at each possible price during a specific time period.

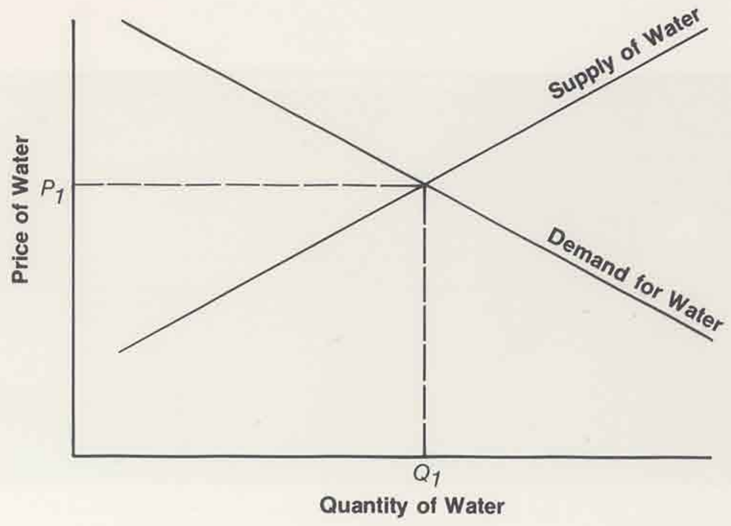


Figure 1
Supply and Demand for Water (Hypothetical)

In reality, however, the lines of price and quantity would be more jagged than smooth as shown in the figure below. Supply is jagged because the lowest cost sources of water (the cheapest dams and distribution systems from a productivity standpoint) are developed first before successively more expensive sources are brought on in the future. Demand is somewhat jagged also, although constant within ranges, suggesting that users will take definite blocks of quantities of water at given prices. Buyers would ideally like to buy a large amount of a resource at a very low price. Unfortunately, this is not possible if the producers are unwilling to produce that amount of the resource at such low prices. In fact, there is only one price at which both demanders and suppliers in aggregate are mutually happy; that is the equilibrium price designated by P^1 when quantity Q^1 is sold.

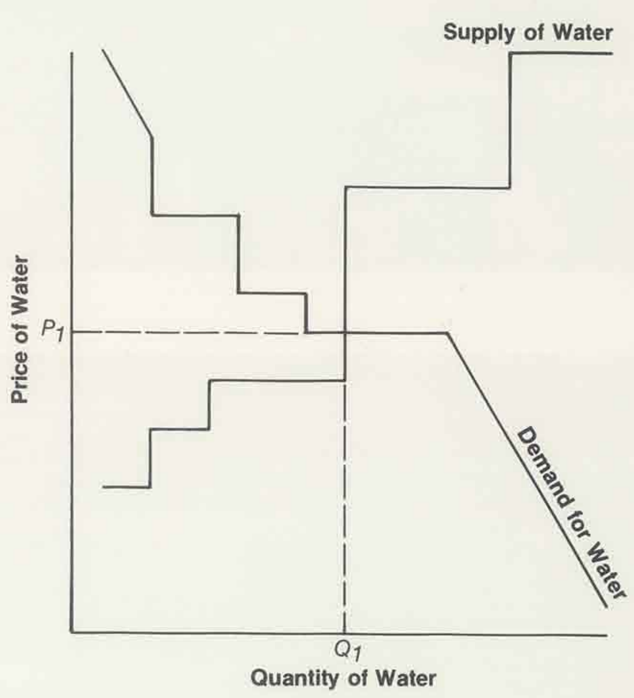


Figure 2

Because water is a public resource in California which has been developed in large part by public agencies, the interaction of buyers and sellers differs somewhat from the private market. When deciding whether or not to build a delivery system like the State Water Project, we the people are both buyer and seller. The effect in terms of the interaction of price and quantity, however, is essentially the same; for, in such a situation, regulation, legal constraints, regional differences, contending environmental and economic interest groups, and our willingness and ability to pay the costs of development, all act in place of the normal operation of supply and demand to fix a unique point at which P^1 and Q^1 will intersect.

The demand for water in California is divided between two principal markets: agriculture, which accounts for approximately 85 percent of all the water used each year; and the urban areas of the state. Agricultural demand varies in accordance with soil characteristics and their effect upon irrigation efficiency, the quality of the irrigation water itself (which determines how much water needs to be used to leach out salts), topography, climate, technology, and the way in which water is used to produce a crop (rice, for example, can be grown by flooding the land to control weeds, which uses a lot of water; less water would be required if weeds were controlled by other means).

The considerable variation in intensity of agricultural water use among adjoining crops is illustrated by the two-page map in this chapter of a section of the San Joaquin Valley. In some areas, crops requiring large applications of irrigation water are grown in the midst of other crops which use far less water; delivery systems must be built, however, with a capacity to serve the heaviest use. The reader may also examine the map to determine comparative efficiencies of water use between the large, corporate land holdings on one side of the valley and small, family farms on the other side. In addition, the map depicts the impact on agricultural land use within the areas of urban development around the City of Fresno.

The demand for water in urban areas is composed of residential, commercial, industrial, and governmental uses. In California, residential demand accounts for about 68 percent of the total urban water usage; industrial, 18 percent; commercial, 10 percent; and governmental, 4 percent. Different water consumption rates among urban areas result from several variables, including the type of climate, the presence of water-intensive industries, the extent of irrigated landscaping, population density, use of water meters, and water prices.

Residential demand for water is composed of interior and exterior uses. Interior water uses include sanitation, bathing, laundry, and cooking; these uses are primarily a function of the size and

Trends in Urban Water Use

	AVERAGE ANNUAL USE (gallons per capita per day)			AVERAGE MONTHLY USE 1966-70 (gallons per capita per day)											
	1941-50	1951-60	1961-70	J	F	M	A	M	J	J	A	S	O	N	D
Eureka	80	104	131	120	123	124	127	134	163	174	162	138	117	111	108
Sacramento	249*	253	264	151	147	174	237	332	385	449	444	380	261	175	158
San Francisco	101	115	135	126	127	129	141	153	157	160	158	157	144	132	125
Fresno	341	333	326	124	129	179	267	435	526	610	574	433	262	162	131
Santa Barbara	125	153	172	108	126	142	168	204	212	238	231	208	174	140	115
Los Angeles (city & harbor)	125	157	160	137	136	143	156	172	180	196	199	182	169	149	137
Los Angeles (San Fernando)	201	205	194	130	131	147	174	213	233	278	279	233	197	154	129
San Bernardino	213	217	226	140	148	163	198	258	298	369	359	295	231	179	139
San Diego	120	123	142	114	117	126	147	171	176	196	200	181	162	134	114

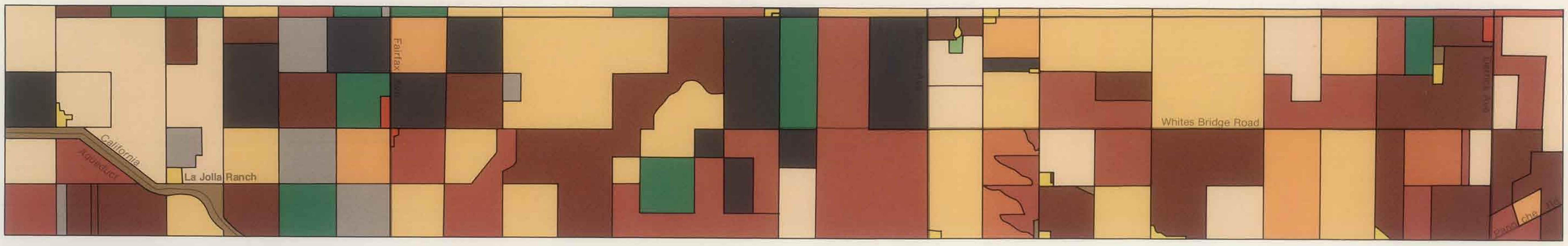
*includes only 1949-50

In addition to the differences between cities in average per capita water use displayed on the map of urban water use and price, municipal per capita water use varies according to the month of the year.

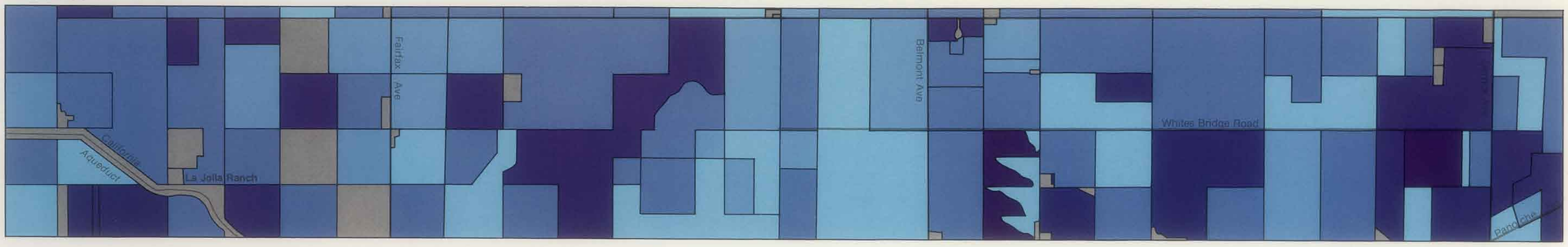
The location of a city is an important factor in determining water use, particularly outdoor uses for such things as garden irrigation. Cities in the coastal zone experience a lower evaporative demand than warmer inland locations. Related to this is the size of the yard and the type of plants which are grown. Suburban areas have larger lot sizes and therefore more plants to water. In addition, exotic plants need more water than native species which are already adapted to California's rainless summers. Urbanized areas with smaller lots, higher population densities, and more cement surfaces will generally have a lower rate of use.

Another important factor is the relative wealth of the members of the community. These differences are reflected in the figures for the selected cities shown in this table. In addition, it can be seen that water use on an average annual basis is increasing, in part as a by-product of the increasing affluence of society as a whole. One study showed that of every thousand dollars added to annual income, a consumer will spend about one dollar more for water a year. This does not seem significant, but in Los Angeles this dollar would buy about 15,000 gallons of water. Consequently a family in Los Angeles earning $30,000 annually may theoretically consume some 300,000 gallons of water more than a family making $10,000.

[1] Crop Types/Land Use

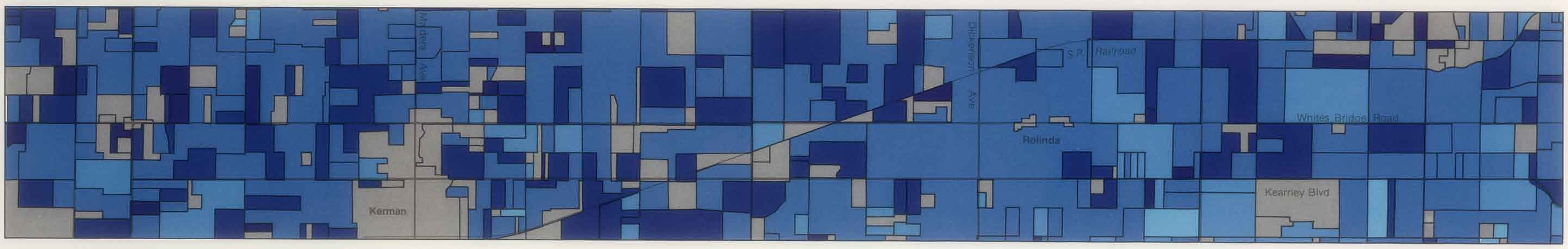


[1] Applied Water

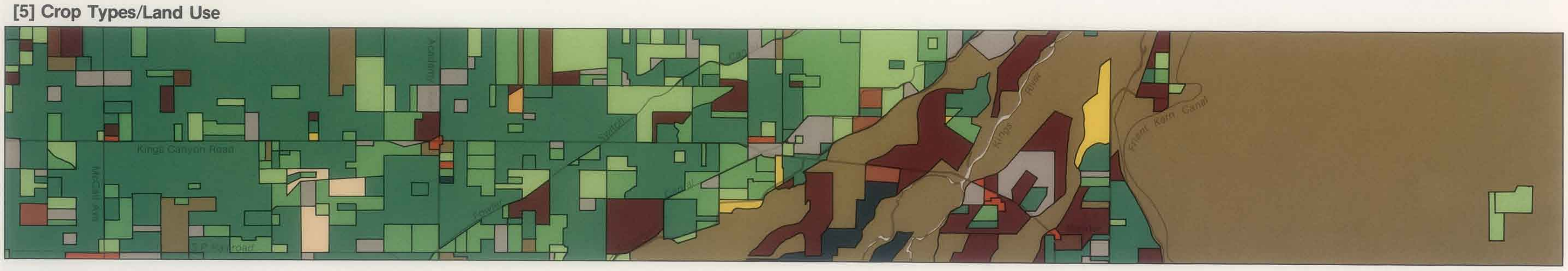


[3] Crop Types/Land Use

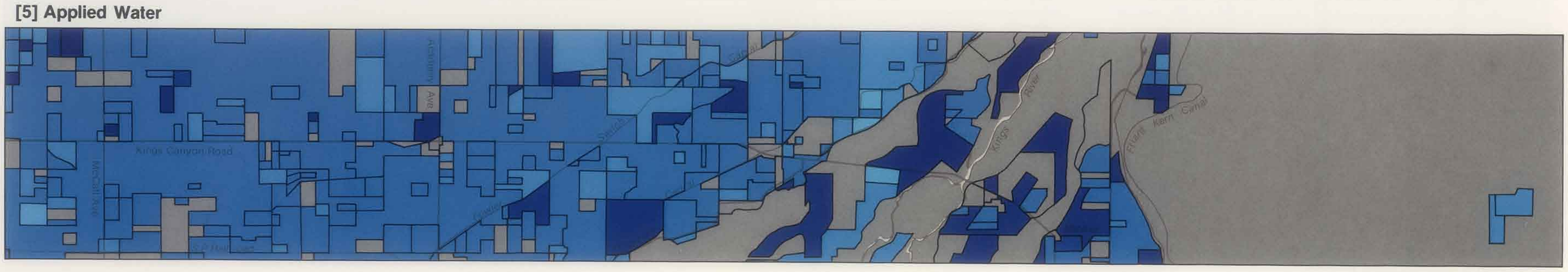
[3] Applied Water



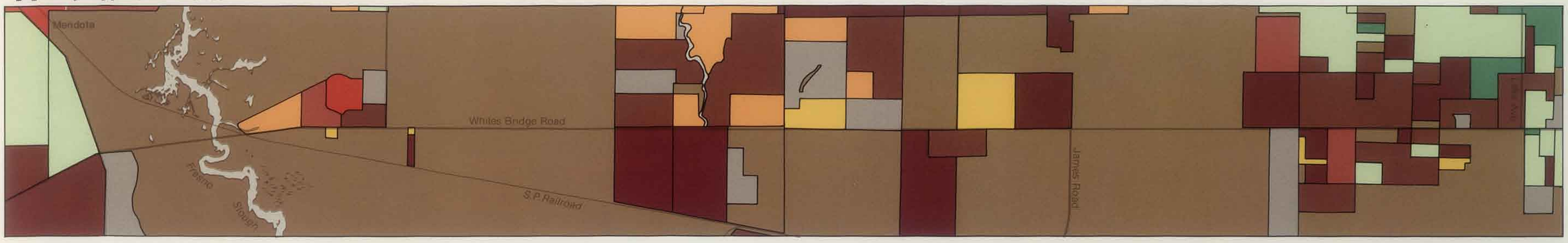
[5] Crop Types/Land Use



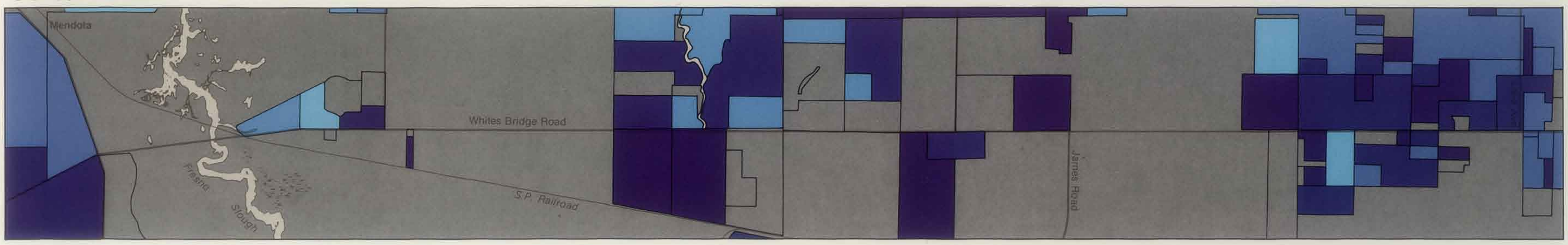
[5] Applied Water



[2] Crop Types/Land Use



[2] Applied Water



[4] Crop Types/Land Use

[4] Applied Water

Crop Patterns and Applied Water

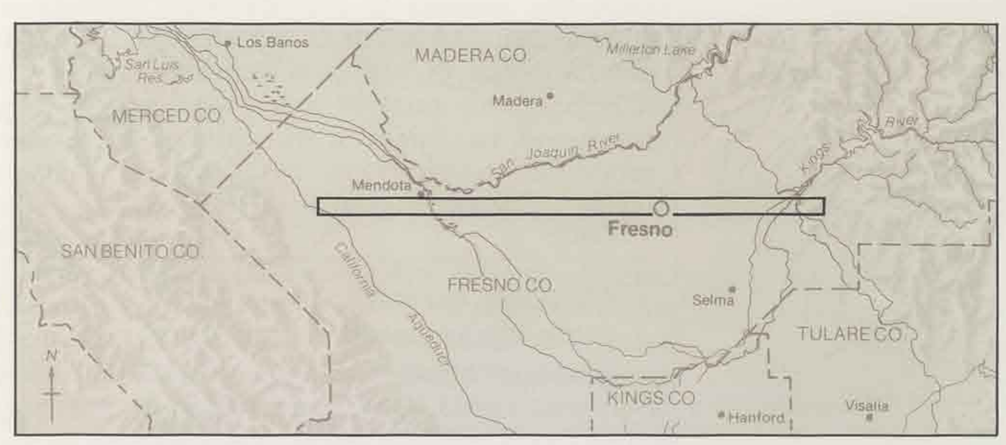
Crop Types and Land Use

- Subtropical Fruits
- Deciduous Fruits and Nuts
- Grapes
- Tomatoes
- Miscellaneous Truck
- Cotton
- Safflower
- Miscellaneous Field
- Rice
- Grain and Hay
- Alfalfa
- Pasture
- Fallow and Idle
- Semiagricultural
- Urban
- Native Vegetation

Applied Water (depth)

- 0.0 - 1.0 feet
- 1.1 - 2.0 feet
- 2.1 - 3.0 feet
- 3.1 - 4.0 feet
- 4.1 - 5.0 feet
- 5.1 - 6.0 feet
- 6.1 - 7.0 feet
- Not Irrigated

Transect Location



This series delineates the wide variations in average applied water use among adjoining crops and land uses within the San Joaquin Valley. Land and water uses are shown separately for each of the five segments of this transect, which traces a two-mile-wide swath across 70 miles of Fresno County. Data are from DWR surveys made in 1969 and 1972.

Key to Transect Alignment

← W [1] [2] [3] [4] [5] E →

Scale

0 1 2 3 kilometers

0 1 2 miles

income of the family. Exterior water uses are for swimming pools, lawns, and gardens; these uses are influenced by precipitation and temperature as well as family income.

Industrial water demand consists of a wide range of uses, including product and equipment cooling, processing, steam generation, sanitation, and air conditioning. Industrial water demand is a function of several variables, including the type and size of the plant, the technology employed by the plant, the cost of water and waste treatment, and environmental guidelines concerning waste disposal. Industrial plants that use large amounts of water include petroleum refineries, smelters, chemical plants, pulp mills, and canneries.

Commercial water demand consists of those uses which are incidental to the operation of the business (such as drinking, sanitation, landscape watering) and those uses which are employed in producing saleable services (such as laundries, car washes, and restaurants). Commercial water demand is dependent upon the income of the area and the extent to which the area provides commercial services to the residents. Precipitation and temperature are minor influences upon commercial demand, except in cases of landscape watering.

Governmental water demand also includes sanitation and landscaping as well as fire control. The extent of such uses is primarily a function of the amount of urban area devoted to public parks and recreation, temperature, and precipitation.

Water price is a variable that can affect all types of water demand. In general, the demand for water should decrease when the price of water increases. The effect of price upon actual water use will vary, however, depending upon rate structure, the use of metering, and the proportion of the total costs of water delivery which are borne directly by the water consumer.

THE THEORY AND PRACTICE OF PRICING

If the water market is to satisfy demand in the most cost-effective way, water needs to be properly priced. One method would entail a two-part tariff such that the capital or fixed costs of a water project are distributed over time among all users in proportion with the amount of project water they actually consume. The variable or marginal costs, such as operations, energy, administration, chemicals, maintenance, and some depreciation should be charged to each user on a per-acre-foot basis in accordance with individual demand. If there are any particular peaking costs or capacity costs incurred by the system for the sake of any group of users, those particular beneficiaries should bear the charges for this additional capacity through a third tier to the tariff system.

Such a pricing system, called short run marginal cost pricing, assures an economically efficient use of the current plant and system, provides a basis for peak load pricing, and delivers the same price signals to the consumer as are received by the utility. Incentives to use water are correct and in line with costs incurred in providing the water. The disadvantages of this approach, however, are several. First, the revenue requirements of the utility may not be satisfied. Secondly, such a system may not provide accurate signals to the consumer of the long-run marginal costs that can be predicted. This is important if consumers are making durable good purchases such as swimming pools or residences with large irrigation requirements, or if farmers are investing in an irrigation system based on current water prices when these current prices will not be in effect over the long term. Also, under short run marginal cost pricing, utilities may not necessarily move toward the best plant mix and technology for the long run. A final disadvantage is that short run marginal cost pricing is efficient only if the prices of labor, energy, and all the other costs of water delivery as well as the prices of all the products and services that result from water delivery are themselves efficiently priced.

Actual pricing policies differ from agency to agency and among the various regions of the state. Urban water delivery systems generally attempt to recoup the cost of transporting, storing, and distributing the water; operating and maintenance costs; and the expense of water treatment. The value of the water itself is usually not included and the methods of calculating depreciation vary widely. Sometimes urban water agencies charge a price which exceeds the cost of service so that excess revenues can be contributed to the local agency's general fund. In other cases, agencies undercollect and are in turn subsidized by local agencies. In general, urban pricing policies have historically attempted to recover as large a part of capital costs as possible through the use of property taxes while charging a service rate which will cover operating costs and the remainder of capital charges. With popular resistance to the property tax on the rise, however, these practices are declining. The use of a basic "meter" fee plus a service rate which fluctuates with actual usage is becoming more common.

The map of urban water use and price displays the considerable range of prices paid for water in 200 urban locations throughout California. Geography and climate play a part in accounting for some of these differences. Some regions, for example, enjoy access to groundwater near the surface, which can be pumped more cheaply than buying imported water. In addition, the water agencies on the South Coast which overlie groundwater basins can purchase imported water for groundwater replenishment at a rate lower than that charged for other urban uses because such deliveries are made on an interruptible basis. The resulting savings are passed on to urban consumers.

Access to groundwater and other local water supplies also has a significant effect upon the differences in agricultural water prices. For very arid regions which have to import water over long distances, the water becomes increasingly expensive, thus making agriculture more costly, other things being equal. When the price of water goes up to farmers, incentive develops at the margin either to rotate crops and plant those which are less water-intensive; to change farming methods so that other resources, such as capital, are substituted for water; or to alter irrigation systems which may require large capital investments in changing over from sprinkling, for example, to drip methods of irrigation. To determine what combination of these events actually occurs, not only is the price of water important, but so too are the prices of the agricultural products themselves. In Orange County, for example, which imports water and also efficiently manages its water basins through pump taxes, agricultural water is comparatively expensive; agriculture survives in part by producing very high value crops, such as asparagus which is exported to restaurants in Japan and France. If the costs of water increase as well as the costs of labor, fertilizer, equipment, seeds, and other essentials, there comes a time, however, when the land simply becomes more valuable in other uses.

To protect agricultural development, federal water policies have sought to keep the price of some agricultural water low through subsidies which are ultimately paid by all taxpayers. Agricultural interests argue that the urban user gets the subsidy back in lower food prices. But most of the subsidy is capitalized in the value of the land and not passed forward to the consumer in terms of lower food prices. Moreover, to the extent that the subsidy does lower food prices, that subsidy is not recaptured solely in California by local water consumers; the benefits of the subsidy are instead exported to all agribusiness consumers in other parts of the United States and throughout the world. Rice grown in California, for example, uses huge amounts of water per acre, but is primarily exported abroad.

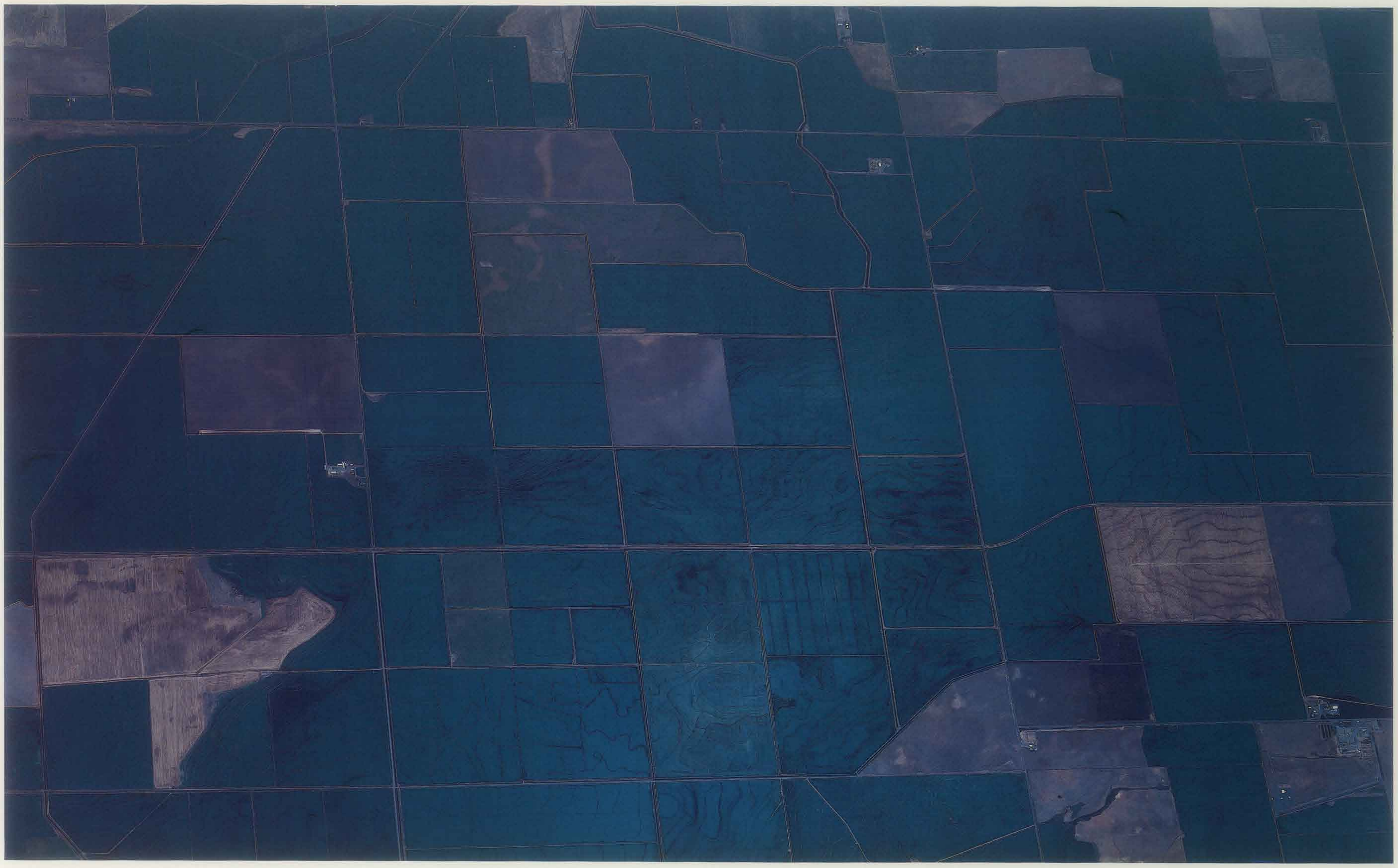
Furthermore, keeping the costs of irrigation water artifically low gives the wrong incentives all the way around. When water is so cheap that it can be used as a substitute for capital and labor, wasteful irrigation technology and highly consumptive crop mixtures may be chosen. Agricultural interests, of course, point out that subsidized agricultural water deliveries permit more rapid growth which confers secondary and intangible benefits to the area. For example, people come to service the agricultural community, jobs are created, and land values go up. While subsidies do cause an economic multiplier effect to increase the growth rate in an agricultural area, the process may benefit some people at the expense of

The pricing systems used in California today assign no scarcity value to water. This was not always the case in the nineteenth century, when water was treated as a private commodity. At the Lyons Well above, for example, desert travelers could purchase 100 gallons for 25 cents or water a two-horse team for a dime.

Comparative Values in Agricultural Production

CROP	IRRIGATED ACREAGE (Acres)	Percent	APPLIED WATER (acre-feet)	Percent	TOTAL VALUE TO PRODUCER (Dollars)	Percent
Alfalfa (hay and grain)	1,341,175	47	6,732,100	54	251,580,000	27
Cotton (lint and seed)	961,700	34	3,874,700	31	305,937,000	33
Grapes (all types)	544,805	19	1,903,350	15	368,106,000	40
	2,847,680	100	12,510,150	100	925,623,000	100

Alfalfa, cotton, and grapes were the top three crops in California in 1972 in terms of irrigated acreage, water consumed, and total value yielded to the producer. Together, these three crops accounted for nearly one-third of the irrigated acreage and applied irrigation water used by the 200 commercial crops California produces. As the table illustrates, however, the crops which occupy the greatest acreage and consume the largest volumes of water are not necessarily those which yield the highest value to the producer.



others. Even though land owners may achieve economic benefits individually, society as a whole pays by having its resources cheapened and a less than optimally efficient system of agricultural production results. These historically given water subsidies could, however, be given in other ways so that the benefits could be wider spread while affording an even higher multiplier effect.

WASTE, EQUITY, AND THE FUTURE

Many people think it equitable that the price of water should be kept very low because water is essential to life. Many problems would arise, however, from such a policy. First, the amount of water actually used for life-sustaining purposes is very small compared to the total uses to which water is put. If society's interest is in achieving an efficient allocation of a limited resource, then water should be priced no lower than its true marginal cost to society. If society believes that beneficial uses exist for the water at prices lower than marginal costs, and that some users should be supplied more water than they could otherwise afford, then the solution is not to make the water inexpensive for everyone because this would result in prices which give incentives to all users to waste water.

Under the economist's definition, waste of a resource occurs when additional consumption results in more cost to the producer than the value provided to the customer. By this definition, water is often wasted when it is offered at prices below the true cost to society of producing the resource and when the consumer buys it for low value uses. An economist would not define certain uses of water such as hosing down sidewalks or filling swimming pools as wasteful if the value to the consumer of the water used for these purposes is at least as high as the price charged for the water when that price truly reflects the real cost to society for producing this water.

The map of urban water use and price reveals the startling differences in the rates of per capita water use which occur under the various prices charged by urban water agencies in California. In part these differences in use are due to climatic conditions which vary, for example, according to whether a particular community is located along the coast, in the interior valleys, or on the desert. The spectacularly high rates of use among the communities of the Owens Valley and the succession of tall, yellow columns which can be seen marching down the spine of the Central Valley Project, however, suggest a correlation between high use and low-cost or free water. But this relationship, as the map shows, is neither direct nor wholly consistent. Within the Owens Valley, for example, per capita use is higher in Independence and Big Pine, where a flat fee is charged, than in Bishop, where water is free. And water use in Mammoth is much lower than that in Bishop even though both communities charge nothing for water deliveries. The map instead reveals a much more consistent relationship between high water use and high wealth, as in the cases of Beverly Hills, Montecito, Hillsborough, and Palm Springs.

Nevertheless, the price of water does have a direct effect upon the desire for new water supplies and the readiness of society to pay for their delivery or development. Prices are almost certain to increase dramatically in the heavily populated south coastal plain, for example. Both the State Water Project and the Colorado River Aqueduct, the principal sources of supply for the Metropolitan Water District, require large quantities of energy to effect their deliveries. Given the rapid rise in energy costs which has occurred since these projects were begun, the Metropolitan Water District is already predicting a doubling of its water prices by 1987.

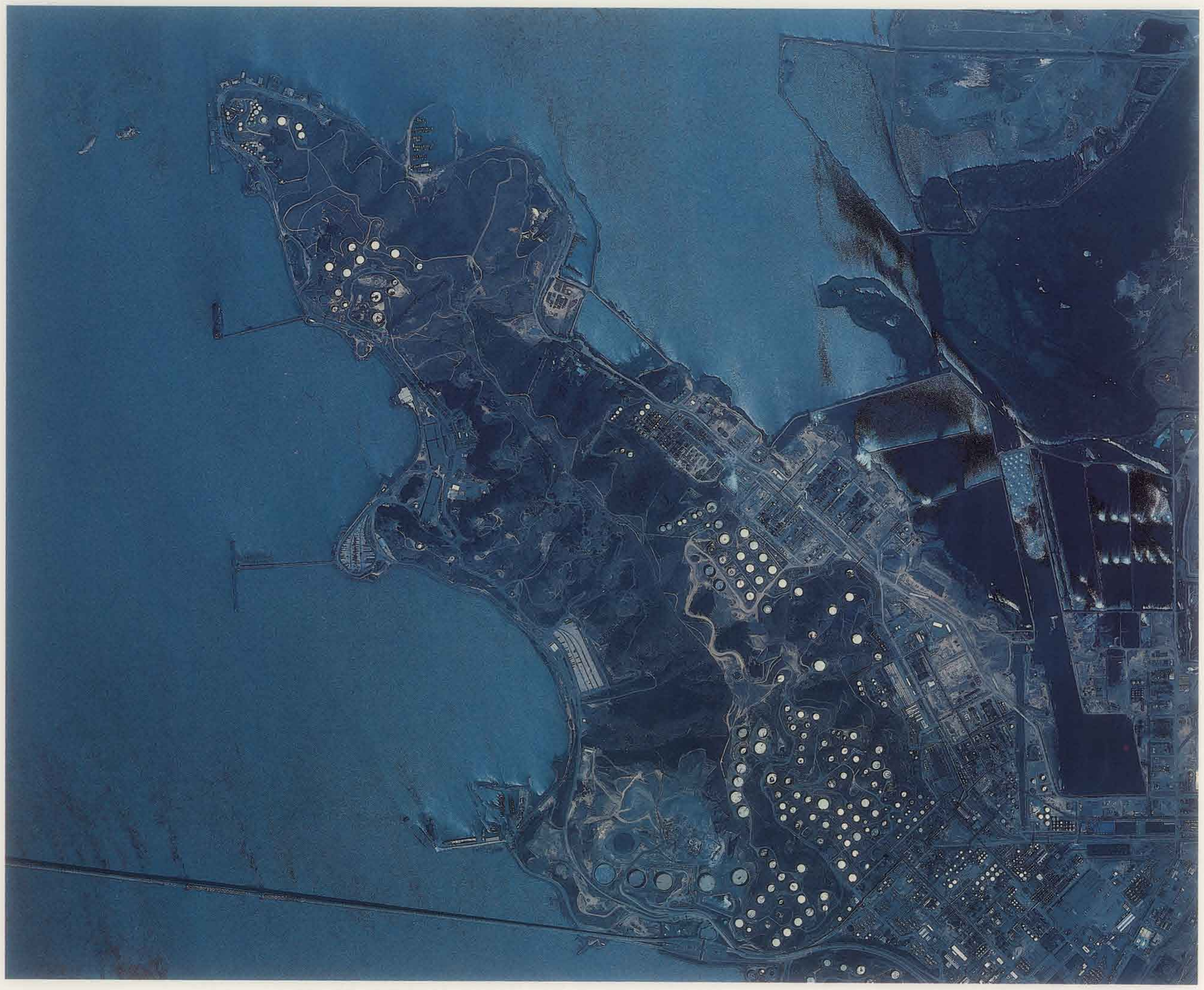
With prices rising, it would be expected that all users of water would have more incentive to conserve. The fixed cost component of water delivery is predetermined and is not affected by the actual quantity of water users demand. But the variable portion of costs, such as the charges for pumping and maintenance, can be reduced through conservation. Conservation, however, is beneficial to society only up to a point. The time may come when society values the benefit of new water supplies more highly than the costs of developing it. The high cost of fresh water, coupled with governmental requirements for wastewater treatment to effect pollution control, may mean, for example, that reclaimed water will become economic for some types of use, including greenbelts, irrigation, and groundwater replenishment to prevent salt water intrusion. To the extent that this becomes possible, there will be reduced pressure to construct new energy-intensive delivery systems unless demand grows very quickly as a result of population pressures or increased development of water-intensive enterprises such as agriculture and certain types of industry.

Theory suggests that under low price conditions, demand is higher than it would be otherwise. An appearance is thus created that we need more water supplies. Since Western water law and practice have historically permitted contractual obligations to be made to provide water at prices lower than the full cost of supply, from a practical standpoint California may very well determine that it requires new supplies. The economist's retort, however, is that no more water projects can be proved to be needed until every user pays through his water rate the full cost of supplying the water. Only then will the state and affected agencies have adequate information about the real demand for water.

The high cost of developing new water supplies and changes in the traditional concepts of what constitutes reasonable use may ultimately pose a challenge to the continued application of great quantities of water to grow rice on these fields north of Sacramento.

CHAPTER 9

Commercial and Recreational Water Use



Standard Oil Refinery on Point Richmond

INDUSTRIAL WATER USE

Gold mining constituted the first significant water-using industry in California. The early miners used pans and small sluice boxes to separate the free gold from stream sediments. As hydraulic mining developed, high pressure water hoses were used to wash gold-bearing hillsides into large-capacity sluice boxes. The lumber industry grew apace to meet the demand for lumber for the sluice boxes, flumes, and dams associated with the gold mining activities and to provide housing for the state's burgeoning population. Commercial food processing too had an early start in California. The Civil War's demand for preserved food reduced the quantity available for import into the state and the completion of the transcontinental railroad in 1869 further stimulated the continued growth of the industry as mining declined. By the late 1800s, the petroleum industry began to emerge as a significant industrial enterprise requiring large quantities of water. With the advent of the automobile and the tremendous growth in population and supporting industrial development during the twentieth century, petroleum refining has continued to increase production to meet demand.

In California today, industrial use accounts for approximately 20 percent of the five million acre-feet of fresh water applied annually to urban-related purposes. By far the largest quantities of water among industrial groups is used for food processing in the state which today produces nearly one-third of the nation's canned food. Paper and pulp mills, petroleum refineries, chemical plants, and lumber mills are the next largest industrial water users. Lesser but still significant quantities of water are used by transportation equipment producers and metal fabricators, principally to provide air conditioning and sanitation facilities for the large numbers of their employees.

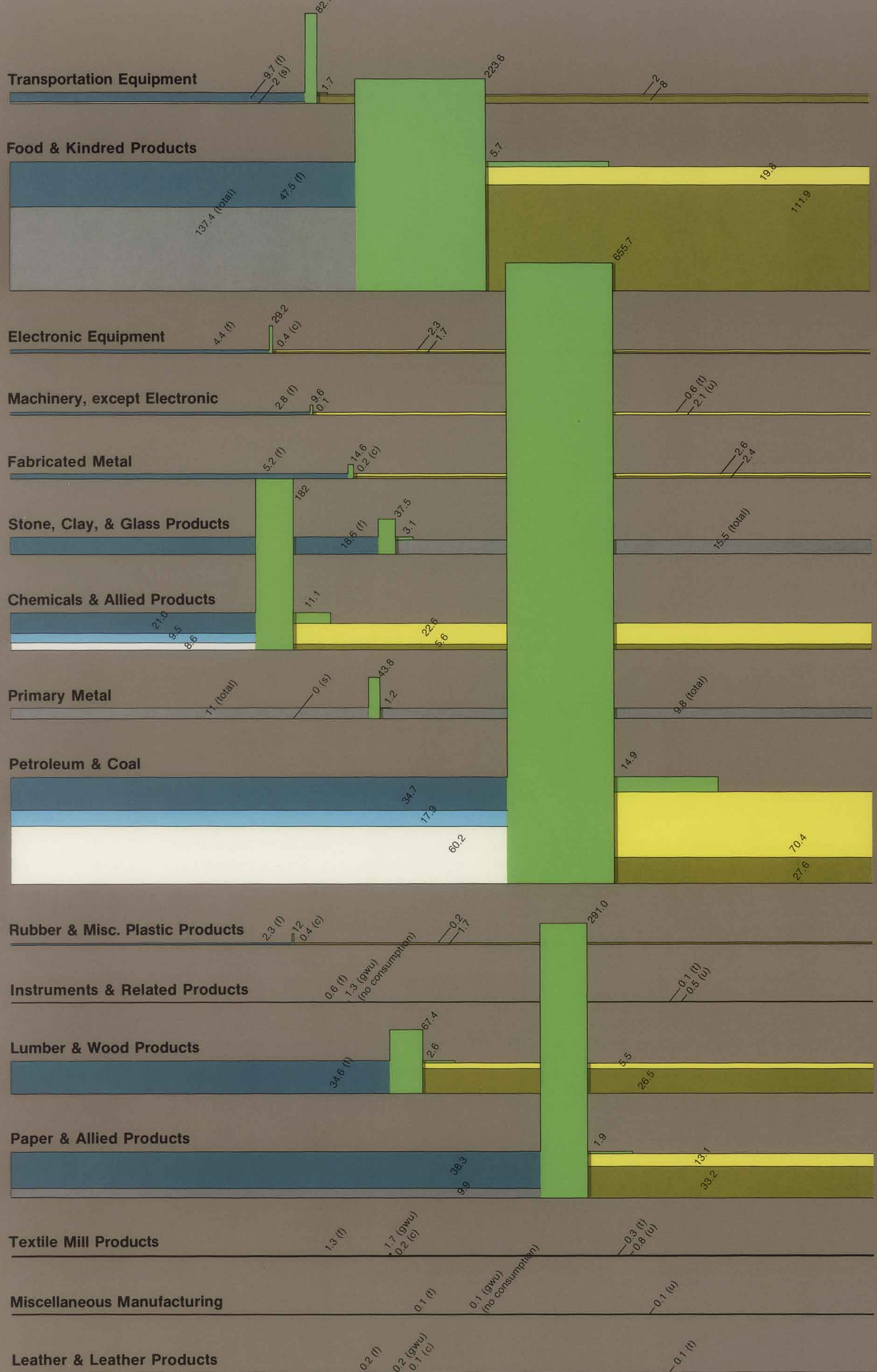
The availability of adequate water supplies has consequently become as important a factor in the location of industries as the availability of raw materials and a sufficient labor supply. The relative importance of these three factors, however, varies according to the kind of industry. Lumber, pulp, and paper mills, for example, are principally found in or near the forest areas of Northern California. Most of the food processing plants are located in the Central Valley, where about 75 percent of the state's cropland is located, although these plants can be found wherever significant amounts of agricultural production occur. In some instances, such as in the San Francisco Bay Area, food processing plants have remained in operation in locations where the surrounding croplands which originally supported them have long since been converted to urban settlement.

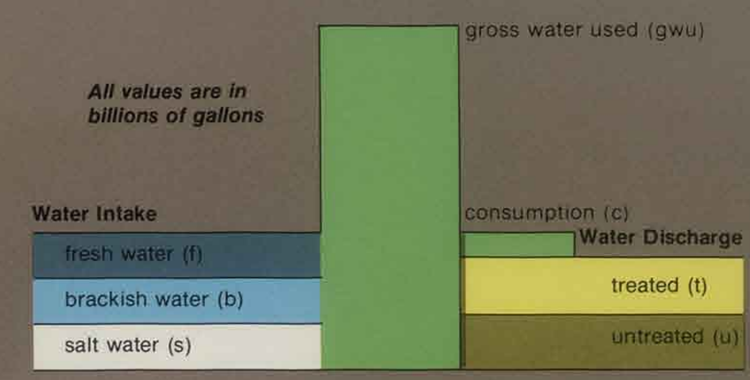
In the case of petroleum refineries, proximity to transportation facilities and a supply of crude oil are the principal considerations in locating plants. Most refineries are located in the oil-producing areas of Los Angeles County and the southern San Joaquin Valley and in those places where crude oil can be discharged from ocean-going vessels to onshore facilities along the Southern California coast and the shores of San Francisco Bay. Transportation manufacturing and metal fabricating industries, on the other hand, tend to locate in any major metropolitan area where labor is readily available.

Because the uses of water in industry are so different, the quality of water required can vary accordingly. The food processing industry, for example, requires large volumes of clean water which meets potable standards because raw foods must be clean and wholesome for human consumption and food processing plants must be sanitary at all times. Fruits and vegetables are blanched with steam or hot water, and sometimes are peeled by use of steam or high-pressure jets. Cereals are steam-exploded to produce the many forms of breakfast food or are wet-milled and separated into fractions in water suspension, as in the production of cornstarch. Some meats are injected with, or pickled in, water solutions of salts. Beverages are malted, boiled, cooled, and fermented by means of water and steam. Sugar is decolorized in, and crystallized from, water solution. Hot water or steam is applied to sterilize food stuffs and flume systems are often used to transport produce through the various plant operations. Where possible, water used for one process is often reused for another purpose for which water quality requirements are less demanding.

Paper and pulp mills also reuse significant quantities of water in order to prevent waste of chemicals and pulp. California now has more than 40 pulp and paper plants producing kraft paper and board, corrugating medium, box board, newsprint, fine paper, tissues, molded pulp, roofing felts, and many specialty products. Wood is fed to digesters where water, steam, and chemicals act to separate the individual wood fibers. The fibers are blown into pits where they are washed and then flushed onto screens where knots and larger pieces of wood are removed. Next, the material is bleached in a solution of hypoclorite, chlorine dioxide, or peroxide, washed, and passed to beaters where more water is added. From here it is blended, treated in mills to further separate the individual fibers, and, with the addition of water to obtain the desired consistency, passed to the paper machine. The pulp is distributed uniformly onto a continuous wire screen through which the water drains. Steam is then employed to raise the temperatures of reacting mixtures and to dry the final product.

Water Use by Industry



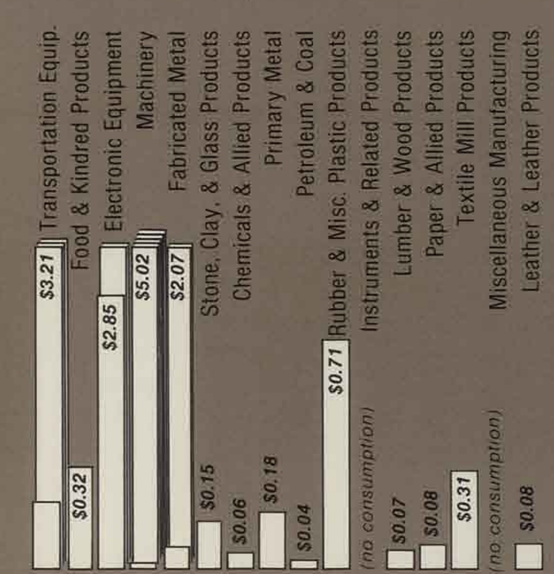


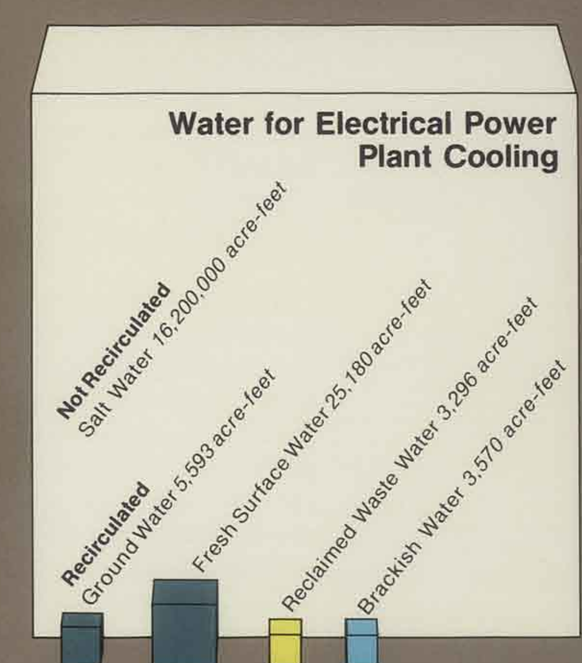
The diagrams at left illustrate water intake, use, and discharge by California's major industries in 1972. Water is taken in at the left of each diagram and discharged to the right. **Consumption** is the difference between water intake and water discharge, regardless of its eventual disposition. **Gross water used** is the amount necessary for the industry; because most industries recirculate some water internally, this figure is usually greater than intake and only some of it will be consumed. When the volume of water in a given category is too small to be shown by its designated color, the abbreviation for that category follows the number. The industrial groups have been ranked according to the number of their employees.

Data deleted to protect the anonymity of specific companies.

Value Added / Water Consumed

Value added expresses the gain in value when raw materials are converted to finished products. This graph compares the average amount of value added for each gallon of water consumed by various industrial groups. Value added does not measure relative water efficiency, but the comparison does reveal that those industries most dependent upon an abundant water supply obtain less value added for the water they consume.





The cubes compare the kinds and quantities of cooling water used by steam plants for electrical power generation in 1977. Coastal power plants use sea water only once before discharging it back into the ocean. Inland power plants continuously recirculate their more limited water supplies, replacing only the amounts lost through evaporation.

The Sacramento Municipal Utility District maintains its own reservoir to replace the water that is evaporated from the cooling towers of the Rancho Seco nuclear power plant.

The ever-increasing demand for petroleum products has made petroleum refining the third largest industrial water user in California. Petroleum refining is a distillation process. The crude oil is heated to boiling and each product is separated in accordance to its boiling temperature in a fractionating tower where vapor is condensed and cooled by water. Many of these petroleum fractions must be specially treated by cracking or reforming molecules, then redistilled to make products which will meet the required specifications. All of this takes considerable heat, followed by quick cooling with water. Fresh water is needed for steam generation, to replace evaporation and blow-down from cooling towers, and for washing the gases and liquids in the process streams. Steam is used for a number of purposes in a refinery, in the generation of electrical power for operation of the plant, in chemical reactions, and in providing heat in certain chemical processes. A recent survey by the Department of Water Resources shows a substantial increase in the rate of recirculation and reuse of the initial intake supply by refineries before the deterioration of water quality requires its discharge. Without this high rate of reuse, the water requirements of the petroleum industry would surpass that of any other industry in California.

The separation and purification of substances with the use of water are also fundamental operations in the chemical industry. Large volumes of water are often required to extract heat from products or to use the water as a reactant which is chemically or physically combined with other substances. For example, water reacts with calcium carbide to form acetylene, the basic material for a large organic chemicals industry. Another type of reaction is the hydrolysis of animal fats to produce glycerine and fatty acids for soap manufacture. Miscellaneous uses of water include the disintegration or milling of clays, the quenching of molten products such as caustic soda, and the emergency drowning of reactions out of control, such as might occur in the manufacture of trinitrotoluene (TNT). These are but a few of an endless list of water use functions in chemical or chemical-related industries.

Cooling and process water also play prominent roles in the steel industry. The reduction of iron from its ore, the compounding of this iron into pig iron, wrought iron, carbon steel, and alloy steels, and, finally, the forging of these products into usable shapes, are all done at very high temperatures. Water is used for cooling parts of the furnaces, the rollers, and skid rails. Hot billets are descaled by means of high-pressure water jets which provide a combination of thermal shock and mechanical action. Steel is pickled in a strong acid solution to remove mill scale and then rinsed with water. When the metal is to be tinned, galvanized, or chemically coated for corrosion protection, it is passed through successive tanks containing alkaline detergent solutions and rinsed in water.

As impressive as the many uses of water in industrial processes may be, however, on a statewide basis, the greatest use of water by industry is for cooling, not processing. Industrial use of water for cooling in 1970 was larger by one-third than the use for all other industrial purposes combined. And, the use of cooling water for electrical energy production that same year was more than four times greater than the total use for industrial cooling.

POWER GENERATION

Electrical energy production requires the use of large quantities of water for two very different kinds of generating plants. Hydroelectric plants use falling water to turn turbines which generate electrical energy. Because hydroelectric plants can begin generating power almost as soon as water is diverted to them, they are used today to respond quickly to fluctuations in peak power demand. In this way, they operate in partnership with steam plants, fired by fossil or nuclear fuels, which handle the base load of daily power supply. Although both types of plants depend upon the availability of water, electrical energy production is not itself a major consumptive use of water. Once through the turbines, the water used by a hydroelectric plant usually flows downstream for subsequent use in cities and irrigated agriculture. The water in the boilers of steam plants, on the other hand, is condensed and reused repeatedly. While steam plants also employ large amounts of water for cooling, that water too is either continuously recirculated by inland plants or used in the form of salt water passed through the power generating systems of plants on the coast. Part of the cooling water used by inland plants, however, is evaporated in cooling towers and must be replaced.

The use of water for energy grew apace with the astonishingly rapid expansion of electrical services in America. The first electrical street lighting system in the United States was erected in Cleveland in 1877; San Francisco and New York installed their own systems only three years later. By 1892, when the San Antonio Light and Power Company put the first commercially successful hydroelectric plant in California into operation, there were 235 municipally owned electric systems in America. On September 7, 1893, the Redlands Electric Light and Power Company (since acquired by the Southern California Edison Company) was the first to use polyphase transmission now in universal use. In 1895, the same year Niagara Falls began generating electrical power, a 10,000-volt transmission line was installed at Folsom for service to Sacramento. And by the end of 1899, when the Colgate Plant on the Yuba River began long distance transmission to Oakland 142 miles away, it is estimated that California's hydroelectric resources had reached 21,500 kilowatts.

Early hydropower developments in California were almost exclusively constructed by investor-owned utilities to meet the expanding demand for a cheaper energy supply. These developments usually operated for the single purpose of power generation, and any downstream flow improvements in late summer from reservoir operations were regarded as incidental. Similarly, nineteenth century developers of water supplies for urban and agricultural use treated the hydroelectric generating potential of their projects as only a happy but definitely subsidiary byproduct of their efforts. It was not until 1906, for example, that Congress in the Town Sites and Power Act specifically provided for the lease of surplus power from a reclamation project and even then the lease was forbidden to interfere in any way with the efficiency of irrigation.

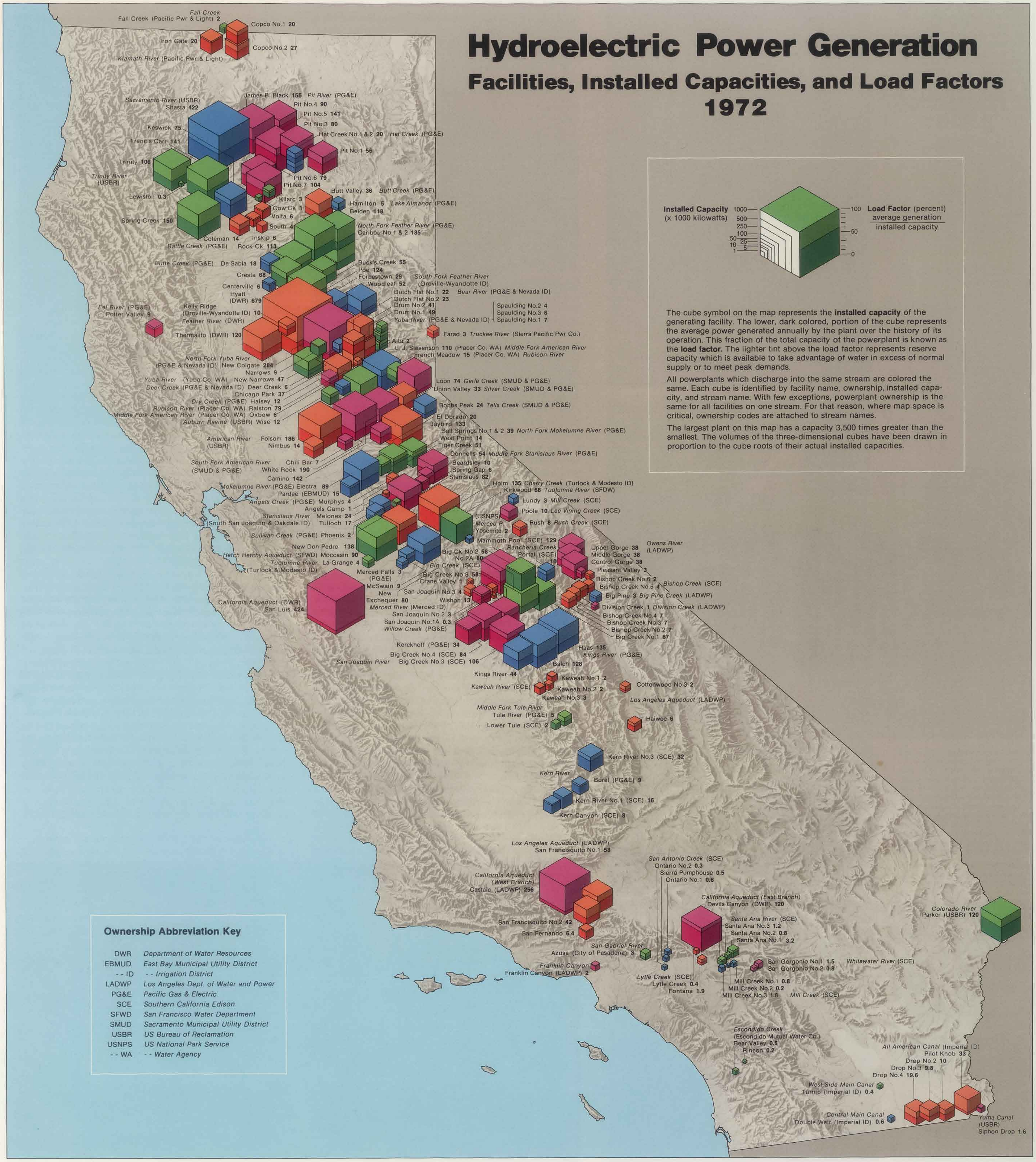
The Los Angeles and San Francisco water projects of the early twentieth century, however, made energy production and sales a central feature of both the design and financing of their systems. Soon, water planners in Theodore Roosevelt's administration at the federal level recognized that hydroelectric power sales could provide the means of financing multi-purpose public water projects throughout the nation. "It seems clear," President Roosevelt wrote in 1902, "that justice to the taxpayers of the country demands that when the Government is or may be called upon to improve a stream, the improvement should be made to pay for itself, so far as practicable."

The establishment of this linkage between public water projects and power sales touched off a controversy which eventually emerged as one of the principal obstacles to water development in California. Private power companies did not object to water development *per se* but they fought mightily to prevent public agencies from entering the business of distributing power from these public projects. Private companies successfully resisted municipalization of the local power system in San Francisco but lost in Los Angeles. When the Boulder Canyon Project was proposed, private power companies throughout the Southwest rallied in opposition out of a general concern that increased power supplies from the project would lower prices and out of a more specific fear that, by increasing the supply to Los Angeles' municipally owned electric system, the project would aid the cause of what the power companies called "socialism." The battle over public versus private power, however, reached its peak in the controversy surrounding construction of the Central Valley Project, a process described in an earlier section of this volume.

Private utilities today produce and distribute approximately 72 percent of the electrical energy consumed in California each year. Residential use constituted 30 percent of consumption in 1975, commercial use 29 percent, and industrial use 28 percent. Although agriculture only consumes approximately two percent of all the electrical energy used each year, its dependence upon electrical supplies for groundwater pumping illustrates an important aspect of the relationship between water and power in California today. In contrast to the early days of water development—when electrical power generation was regarded as a profitable byproduct of a water delivery system—modern water planners in an era of dwindling energy reserves have had to take increasing cognizance of the considerable quantities of energy that are consumed simply in moving water around the state. Electrically powered

Hydroelectric Power Generation

Facilities, Installed Capacities, and Load Factors 1972



Installed Capacity (x 1000 kilowatts): 1000, 500, 250, 100, 50, 25, 10, 5, 1

Load Factor (percent) = average generation / installed capacity: 100, 50, 0

The cube symbol on the map represents the **installed capacity** of the generating facility. The lower, dark colored, portion of the cube represents the average power generated annually by the plant over the history of its operation. This fraction of the total capacity of the powerplant is known as the **load factor.** The lighter tint above the load factor represents reserve capacity which is available to take advantage of water in excess of normal supply or to meet peak demands.

All powerplants which discharge into the same stream are colored the same. Each cube is identified by facility name, ownership, installed capacity, and stream name. With few exceptions, powerplant ownership is the same for all facilities on one stream. For that reason, where map space is critical, ownership codes are attached to stream names.

The largest plant on this map has a capacity 3,500 times greater than the smallest. The volumes of the three-dimensional cubes have been drawn in proportion to the cube roots of their actual installed capacities.

Ownership Abbreviation Key

DWR	Department of Water Resources
EBMUD	East Bay Municipal Utility District
- - ID	- - Irrigation District
LADWP	Los Angeles Dept. of Water and Power
PG&E	Pacific Gas & Electric
SCE	Southern California Edison
SFWD	San Francisco Water Department
SMUD	Sacramento Municipal Utility District
USBR	US Bureau of Reclamation
USNPS	US National Park Service
- - WA	- - Water Agency

The streets of Los Angeles were illuminated by electricity for the first time on New Year's Eve, 1882. The arc light in the upper photograph at right was one of seven installed on 150-foot poles at Main Street near Commercial and at First and Hill Streets. California today is experimenting with a new source of power from water through the development of geothermal power plants like the one shown below.

Sacramento was once the hub of a great network of inland ports. The arrival of the railroads, which can be seen near the center of the painting at right, brought an end to the prosperity of the commercial navigation companies that flourished during the nineteenth century.

pumps, for example, lift an average of 15 million acre-feet of water a year from underground reservoirs to provide approximately 40 percent of the irrigation water used by California agriculture. Both the Colorado River Aqueduct and the State Water Project use more energy than they generate. Under ultimate project water deliveries, in fact, hydroelectric power plants on the State Water Project will generate only 40 percent of the estimated 12 billion kilowatt-hours per year the State Water Project will require by the year 2000; the rest will have to be obtained from other sources.

These considerations, together with other factors in the rapidly changing energy picture for California, have caused some experts to predict a renewed interest in hydroelectric power plant construction. In the first decade of the twentieth century, hydroelectric plants replaced many steam plants because hydroelectric plants offered lower operating costs at a time when fuels were expensive. Even until the early 1950s, hydroelectric plants generated more than half of the electrical energy produced in California. As the most economical hydroelectric sites were developed, however, and steam plant technology improved, nuclear and fossil fuel steam plants assumed a larger part of the burden of supplying California's demand. By 1975, 174 hydroelectric plants with a combined capacity of 8,440 megawatts generated only 30 percent of the total energy produced in California, while 63 steam plants with a combined capacity of 25,735 megawatts produced almost all the rest.

If fossil fuel costs continue to escalate, however, and resistance to nuclear power development does not diminish, hydroelectric power generation may become increasingly attractive as a power source which depends upon a non-consumptive use of a renewable resource. Although few new dams are being constructed in California, plans are underway for construction of power plants below several existing dams that were built without power plants due to unfavorable economic conditions at the time. These tentative plans include the addition of power plants at such sites as the Thermalito Diversion and Warm Springs dams. Further development of hydroelectric power in California, however, will be restricted by the limited number of suitable sites that have not already been developed.

INLAND NAVIGATION

California's rivers were the original routes of commerce. John Sutter operated the first large vessel on the Sacramento River between 1840 and 1848. As hordes of new immigrants began to arrive in San Francisco following the discovery of gold in 1849, dozens of steamboat companies sprang up to work the trade routes to the gold fields along the Sacramento, Feather, Yuba, and American rivers. Many of these companies consolidated in 1854 to form the California Steam Navigation Company. On the Sacramento, steamboats navigated regularly as far upstream as Colusa and Chico Landing. On the San Joaquin River, there was a twice-weekly service available between Stockton and Fresno. And on the Feather, waterfronts developed at Marysville and Oroville. The onslaught of debris from hydraulic mining, however, put an end to navigation above Sacramento and the railroads bought out the California Steam Navigation Company in 1869 as part of their increasing domination of California's transportation network. By the 1890s, when other states began to press for the expansion of their inland harbors and waterways, inland navigation in California seemed to have entered upon an irreversible decline as demands increased for other uses of the state's limited water resources for irrigation, urban development, and electrical power generation.

California's first state engineer, William Hammond Hall, envisioned in the nineteenth century a system of canals in the San Joaquin Valley which would operate not only for drainage and water supply but also for transport using long chains of electrically powered barges carrying freight and produce throughout the valley. When the Central Valley Project and State Water Project were finally built, however, navigation was no longer a central feature of their design. The principal responsibility for the development of navigation within California consequently passed to the Army Corps of Engineers. Authorized by Congress in 1852 to assist in the development of civilian works, the Corps played a major role in the development of ports at San Diego, San Francisco, and Oakland. Inland, it worked to improve river navigation through dredging and the removal of obstructions along the San Joaquin and Sacramento rivers.

The Corps' devotion to its principal mission of enhancing navigation often set it at odds with water planners at the state and federal levels near the turn of the century. As the concept of multi-purpose water development gained currency with the advent of Theodore Roosevelt's administration, for example, the Corps strenuously resisted new programs for water conservation, reclamation, and a coordinated, basin-wide approach to the development of water resources. The need, according to Corps officials, was "to differentiate instead of coordinate" and navigation should always be made the primary feature of river development with all other uses secondary to that. The Corps' major role in the development of the Sacramento Flood Control system, for example, was played out under a formal guise of improving navigation because the Corps at that time was reluctant to involve itself directly in flood control.

Although navigation is still a major part of its program, the Corps' range of activities has expanded today to include flood control, wastewater management, and beach erosion protection. California's two major inland ports, Stockton and Sacramento, operate on commercial navigation channels created by the Corps of Engineers. The deep-water port at Stockton opened in 1933 and today handles bulk and processed agricultural products primarily for export. Since its opening in 1963, the Port of Sacramento has expanded an export trade tied to the bulk handling and processing of rice, lumber, and wood chips, as well as farm products from the Sacramento Valley and many other mid-America products shipped to the Port through an extensive rail and highway system. Together the ports of Sacramento and Stockton account for about five percent of the total deep-draft shipping in California. In 1977, the Port of Sacramento handled 1.8 million tons of shipping on 121 ships while the Port of Stockton handled 2.5 million tons on 101 ships. Both ports have regularly scheduled barge service to San Francisco Bay and the Pacific and this shallow-draft traffic accounts for approximately one-fourth of the total tonnage handled by the ports.

Many experts foresee a gradual increase in inland commercial navigation although estimates of the anticipated growth rate vary widely. In California the growth of commercial navigation has been and will continue to be closely related to the expansion of agriculture and the continued development of the state's transportation system. Overall development of commercial navigation, however, depends not only upon the expansion of physical facilities such as docks, terminals, and warehouses but also upon commodity manipulations, foreign exchange rates, and technology advancement in the export markets. The most immediate planned improvements that could influence the growth of the ports of Sacramento and Stockton, given suitable world market conditions, include studies by the Corps of Engineers to deepen the San Francisco Bay approaches to inland waters at Collinsville to 45 feet and then deepen to 35-45 feet the Sacramento and Stockton ship channels. The completion of these improvements would permit larger-tonnage carriers and deeper-draft shipping to enter the Delta directly instead of transferring their cargo to barges to lighten the loads. Contrary plans, however, call for the use of small-unit cargo carriers between inland ports which would then be loaded directly onto very large container ships at centralized container terminals in San Francisco Bay. Therefore, while commercial waterborne traffic is expected to grow,the extent and location of this growth is difficult to predict.

The most rapidly expanding aspect of navigation in terms of vessel numbers and movements is occurring in recreation. The California recreational fleet has increased from 288,000 to 540,000 craft since 1962. Waters suitable for boating exist throughout the state, although in some areas, particularly the central and south coastal regions, inland lakes and reservoirs are limited in number and size with the result that a heavier burden is placed on the ocean and coastal bays. In terms of size and boat accommodations, the Pacific Ocean is virtually unlimited while the channels of the Sacramento-San Joaquin Delta and San Francisco and Suisun bays provide thousands of miles of boating waterways. The Delta waterways, by virtue of their 40,000 surface acres, offer in fact some of the most diverse recreational opportunities for boating in the United States.

RECREATIONAL BENEFITS

A major national survey of recreation conducted in the 1960s reported that 44 percent of the American people prefer water-based recreational activities over all others. Californians are especially attracted to water-based recreation. A California recreation plan also prepared in the 1960s estimated that nearly 60 percent of the state's total recreational activity occurs near streams, reservoirs, lakes, or the ocean. Typical recreation scenes, such as a Chamber of Commerce would use to illustrate a poster, might show:

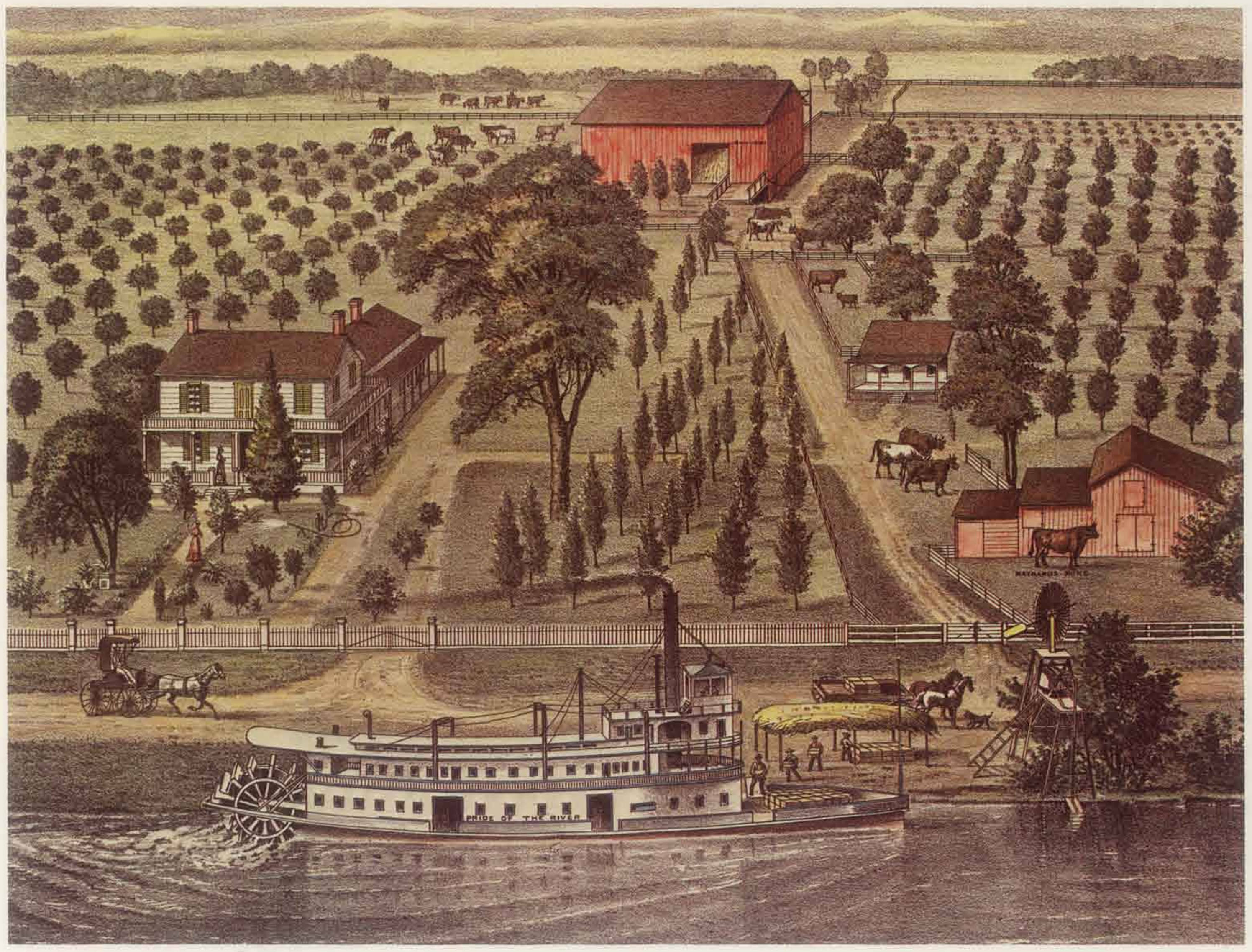
- Swimming, surfing, and sailboating on the Southern California coast;
- Steelhead fishing in streams of the North Coast;
- Trout fishing or snow skiing in the Sierra Nevada;
- Water-skiing on the foothill reservoirs of the Central Valley or Southern California; and,
- Boating on the waterways of the Sacramento-San Joaquin Delta.

Even those activities not directly dependent on water—camping, hiking, picnicking, and bird watching—are enhanced by the presence of a serene lake or quiet stream. Only in interior Southern California might it be expected that a typical recreation scene would be other than water-associated. Perhaps a desert recreation scene would be most likely, but even in such a scene there would be a good chance of a swimming pool being shown.

Most water-related recreation in California—like most other outdoor recreation—is provided by governmental agencies. Approximately half of the state is owned by the federal government, and most of the agencies managing these federal lands recognize recreational enhancement as one of their responsibilities. The National Park Service and the United States Forest Service manage some of the most magnificent resources in California—many of them of a water resources character. The two large federal water agencies—the Bureau of Reclamation and the Army Corps of Engineers—have developed numerous water projects offering major water recreation benefits. The Bureau of Land Management also controls vast amounts of land and is currently expanding its role of offering recreation opportunities. State agencies with significant water-related recreation programs include the departments of Parks and Recreation, Fish and Game, Water Resources, and Navigation and Ocean Development. And, local agencies—cities, counties, and many types of districts—provide recreation services and programs of all sorts.

The dramatic increase in the recreational use of water projects began shortly after World War Two. California's rapidly growing population found itself with more leisure time, greater disposable income, and greater mobility. As a result, many people increased their participation in outdoor recreation. As the natural lakes and streams became heavily developed and crowded, recreationists began flocking to newly completed reservoirs. Water planning and development agencies, which had formerly added recreational facilities and operations only as an afterthought to existing projects, now began to include them in their planning. In fact, water agencies were the first to recommend that recreation should be treated as a water project purpose and included with irrigation, hydroelectric power, flood control, and other traditional purposes in the planning and financing of multi-purpose projects.

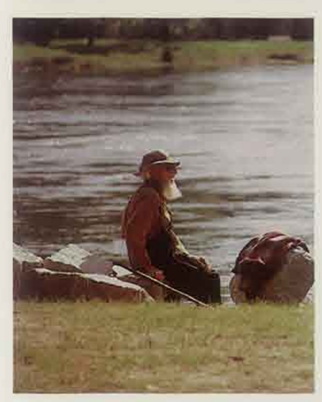
In 1961 the California Legislature enacted the Davis-Dolwig Act, setting forth a policy which declared for the first time that recreation and the enhancement of fish and wildlife resources are among the purposes of water projects constructed by the state. Comparable legislation affecting federal programs was enacted in 1965 as the Federal Project Recreation Act. Legislation has also been enacted to encourage the integration of recreation as a project purpose in water projects undertaken by local agencies. The Davis-Grunsky Act, for example, which provides financial assistance to local water projects in several ways, furnishes grants to projects that include recreation and fish and wildlife enhancement among their purposes. Since the program began in 1958, a total of $62,500,000 in grants has been approved for 33 water projects that include recreational programs as part of their operations.



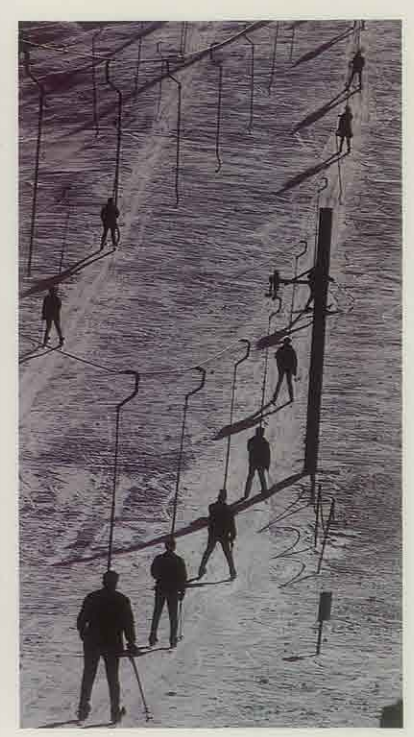
Ham Hall's original plan for a water project in the Central Valley included a water-borne transportation system to serve the needs of agricultural commerce. But when the state and federal governments built their modern systems, inland navigation was no longer a part of their plans. The painting at left shows a steamboat calling at a stock farm near Courtland.

In the State Water Project, where recreation and the enhancement of fish and wildlife have been made a part of planning and development, a number of project features are included that would not have been possible had recreation been added as an afterthought. For instance, at all State Water Project reservoirs, recreational lands have been acquired along with lands needed for other project purposes. More than 45,000 acre-feet of the project's annual capacity was built to deliver water for specific recreation needs—drinking water, water to irrigate landscaping, water to maintain live streams, and water for recreational pools.

Recreational activity and resources generally do not consume significant quantities of water. Usually, the development of recreational facilities takes place on a lake, reservoir, or stream that would have existed in any event. When a water surface is maintained solely for recreational use, however, evaporation losses from the surface and transpiration losses from vegetation at its edges do constitute consumptive uses that must be charged to recreation. Water released to streams for recreational use, as occurs on the American River, is usually recaptured downstream and used again for other purposes. Consumptive uses do occur, however, when the flow cannot be recovered, as in the case of a release to a coastal stream that reaches the ocean. The use of water for drinking and sanitation, and for irrigation of landscaped areas, is also a factor at every recreation site. Although such uses are usually moderate, a recreational facility which attracts great concentrations of people at the same time, such as a ski resort, can create problems by, for example, overloading the capacity of a local wastewater treatment facility during those periods of peak usage.



These photographs illustrate only a few of the many ways water is used in recreation for swimming, skiing, white-water kayaking as well as for quiet comtemplation. The hotel at Redondo Beach in the photograph above was one of the most popular resorts in California at the turn of the century, and it was here some say that the Hawaiian sport of surfing was first introduced to the mainland.



Public Water Recreation Facilities

Region/County	Population July 1, 1977	Total Area (acres)	Acreage of Publicly Operated Land and Water for Recreation	Surface Area of Lakes (acres)	Surface Area of Reservoirs (acres)	Vessel Registrations 1977	Boat Berthings 1977	Boat Moorings 1977	Boat Ramp Lanes 1977
Planning District 1 Del Norte; Humboldt; Lake; Mendocino	212,200	6,041,410	1,466,642	48,905	9,740	13,349	3,811	2,202	205
Planning District 2 Butte; Colusa; Glenn; Lassen; Modoc; Plumas; Shasta; Siskiyou; Tehama; Trinity	384,300	20,579,810	9,711,861	338,504	204,046	27,239	4,202	1,378	269
Planning District 3 El Dorado; Nevada; Placer; Sacramento; Sierra; Sutter; Yolo; Yuba	1,133,900	5,476,730	1,661,910	128,530	58,103	53,164	4,508	1,269	196
Planning District 4 Alameda; Contra Costa; Marin; Napa; San Francisco; San Mateo; Santa Clara; Solano; Sonoma	4,955,100	4,746,080	416,502	460	45,379	131,722	20,088	1,247	274
Planning District 5 Alpine; Amador; Calaveras; Merced; San Joaquin; Stanislaus; Tuolumne	732,500	6,158,140	1,559,313	5,859	73,985	32,288	4,610	484	137
Planning District 6 Fresno; Kern; Kings; Madera; Mariposa; Tulare	1,183,700	15,396,170	4,383,791	16,210	85,307	29,761	2,101	1,302	155
Planning District 7 Monterey; San Benito; San Luis Obispo; Santa Barbara; Santa Cruz	891,100	7,188,320	1,486,939	1,218	22,514	23,004	4,262	903	74
Planning District 8 Imperial; Los Angeles; Orange; Riverside; San Bernardino; Ventura	10,700,900	24,788,690	5,785,915	225,457	70,660	197,482	30,669	3,127	400
Planning District 9 San Diego	1,672,300	2,739,560	859,616	9	17,815	32,562	7,678	150	92
Planning District 10 Inyo; Mono	25,000	8,448,590	5,708,497	60,304	15,731	1,232	347	206	41
State Total	21,891,000	101,563,500	33,040,986	825,456	603,280	542,665	82,276	12,268	1,843

This table provides several indexes of the extent of water recreation facilities available in California. Not all publicly owned lands are open to the public and only those which are available for recreational use have been included in the totals shown here. In addition, these figures do not include the extensive recreational use made of the state's streams and rivers. Counties have been grouped according to the planning districts of the state Department of Parks and Recreation.

As a consequence of being included as a full project purpose, recreation has also been made to assume some of the burdens of water project development. In a multipurpose project, the costs of joint project facilities are allocated among the various uses for which the project has been built. In the State Water Project, for example, recreation has already paid more than $51 million in joint costs allocated to it and, when all joint costs are allocated, the Department of Water Resources estimates that recreation's share will reach $100 to $200 million. Funds for many of these specific recreation and fish and wildlife costs have come from bond issues approved by the people of the state. Proposition 20 in the General Election of 1970 provided $60 million for State Water Project recreation and fish and wildlife facilities. Proposition 2 of the 1976 General Election included an additional $26 million for this purpose.

With the expansion of recreational facilities has come an increasing sensitivity to the changes in recreational opportunities which are a necessary consequence of water development. The regulation of streamflows, for example, shifts the recreational use of a particular water resource from stream to lake fishing, from kayaking to motorboating, and from bird watching to more intensive camping. From the years following World War Two through the 1960s, most water projects which included recreational development were welcomed. Such projects were looked upon as providing large water surfaces for recreation at a time when the demand for water-related recreation greatly exceeded the supply. Opposition to these projects from those who might prefer to keep a river environment in its natural state was not often heard.

Beginning in the late 1960s, however, as the result of a popular surge of environmental concern, greater value came to be placed on natural environments than on artificial ones, and voices preferring natural and free-flowing streams to impounded water were heard with increasing effect. The impact of this movement on water-associated recreation has brought a great increase in interest and participation in very active instream recreational sports such as whitewater boating, kayaking, and rafting on flowing streams. One major effect of this new interest was the enactment by the California Legislature of the Wild and Scenic Rivers Act of 1972. This new law protects five river systems from development or use that would impair their free-flowing character and prohibits state agencies from providing any assistance to federal projects which might have these effects.

In any range of activities as broad and diverse as California's water-based recreation, there will probably never be uniform agreement on resource use priorities. Fishermen will probably always resent intrusions by water-skiers, and whitewater boaters will have different development priorities than those who enjoy the large open expanses of reservoirs. As the state's population continues to grow, the job of allocating resources among the different recreational interest groups will become more difficult. Now that recreation interests have been included in planning for resource use, however, it is essential to provide a means of expression for those with differing viewpoints in order that the great variety of water-associated recreational opportunities that exist now in California will continue to exist in the future.

CHAPTER 10

Water Quality

Although the long history of human involvement with the water environment has been focused upon efforts to rearrange the natural distribution of water supplies within California so as to enhance a wide range of human activities, the last three decades have brought an increasing appreciation of the fact that water quality can act as just as important a constraint upon use as water quantity. The term water quality should not suggest a value judgment concerning the innate good of a particular water source; for, the very constituents in a water sample which would make it unacceptable for one type of use may enhance its suitability for another use. Modern programs for the protection and enchancement of water quality therefore emphasize control rather than the eradication of all the elements in water which can affect its quality. Pure, distilled water is seldom found in nature, and, if our water supplies were this pure, most life systems in the natural environment could not survive. The goal of water quality control consequently involves the maintenance of a balance between the competing needs of all aspects of our environment for water possessing very different qualities and constituents.

NATURAL WATER QUALITY

Because the world's water supply is fixed and virtually no part of that supply has been added or lost since the formation of the planet, the water we rely upon today is the result of continuous recycling and cleaning by natural processes. Evaporation and transpiration by plants are the principal natural methods of water purification, and both of these natural processes are powered by solar energy. Once water molecules condense into water vapor in the atmosphere, however, they begin picking up additional properties almost immediately. Water vapor collects around minute particles of salt and dust and liquid water in the atmosphere tends to become saturated with gases. Carbon dioxide, although it makes up only a small part of the total volume of the atmosphere, most frequently combines with atmospheric moisture because it is very soluble. Atmospheric water can also contain other gases which are the result of volcanic eruptions; natural, bilogical, or chemical processes; or human air pollution.

The impact of a broad range of human activities that affect water quality can be seen in the sediment plumes discoloring the waters of San Pablo Bay. Moving clockwise from the Richmond-San Rafael Bridge at bottom, the bay is ringed by reclaimed agricultural lands, the Mare Island Naval Shipyard at Vallejo, and the complex of oil refineries and sewage treatment facilities near Richmond.

When gases combine with atmospheric water, weak acids are formed that aid in the breakdown of rock when the moisture falls to earth as precipitation. Rain and melting snow and ice thus work to dissolve minerals that are then washed into streams and percolate into groundwater reservoirs. The minerals dissolved in water reflect the geology of the watershed. The streams draining the granitic watersheds of the Sierra Nevada, for example, are low in dissolved solids and suspended sediment, while the streams of the North Coast have higher dissolved solids and carry large amounts of suspended sediment. Vegetation also helps to determine water quality within individual watersheds. Bicarbonate waters are usually found in areas of lush plant growth and some metals which are stored by plants may enter the water system when the plants decay. Accordingly, temperature, rainfall, geology, vegetation, and the seasonality of runoff all work to produce variations in natural water quality which can change with the season, month, or day.

Human activities have had a profound influence upon these natural processes. Rainfall has been chemically altered by concentrated air pollutants in some areas, producing acid rains which destroy vegetation, accelerate the weathering of rocks, and harm fish. Dams modify the natural transport of sediment and organic material in streams and rivers. Municipal sewage plants, irrigation, and industrial growth have introduced a wide range of nutrients, chemicals, and pollutants to natural water bodies. The construction of highways and housing, logging, and some agricultural activities have enhanced surface runoff and erosion. And water temperature has been changed by the discharge of cooling water used in certain industrial processes and in the generation of electrical energy. The growing recognition of the detrimental effects of these human influences upon the water environment prompted the development over the last three decades of an increasingly sophisticated range of water quality control programs. With the development of these programs has come, in turn, a greater understanding of the specific constraints which the various elements of water quality impose upon water use.

The great quantities of sediment carried by the Eel River appear here as a vivid blue extending into the ocean beyond the river's mouth. Eureka, Arcata, and the wood processing plants on Humboldt Bay are at left.

QUALITY AS A CONSTRAINT UPON USE

In general, the elements of water quality which are most directly related to human use have been divided into three broad categories of impurities, pollutants, and contaminants. Impurities are physical, chemical, or biological substances found in water and include: dissolved gases such as carbon dioxide; dissolved solids such as decomposing plant and animal matter; dissolved minerals such as calcium, magnesium, chlorides, sulfates, and bicarbonates; and suspended and settleable solids such as the colloidal material that causes coloring and turbidity. Pollutants are substances in water that impair the usefulness of water or make it offensive to the senses. Sediments, and floating matter such as grease, oil, or organic matter are all pollutants. Pathogenic organisms or toxic substances that make water unfit for human or animal consumption or domestic use are called contaminants and include bacteria, viruses, protozoa, flukes (worms), heavy metals, toxic organic compounds, and radioactive substances.

The study of the full range of chemical, physical, biological, and bacteriological properties of water involves measurements of minute quantities of material. Quantities of dissolved chemicals in water are often expressed in nearly equivalent terms as parts per million or milligrams per liter. The range of concentration levels which are acceptable for certain uses can be similarly small. A concentration of 13 parts per million of dissolved oxygen, for example, is considered quite high, while a concentration of four parts per million is low. Boron, a minor constituent of most water, is an essential element for plant growth but is fatal in excess for most vegetation. Sugar beets, lettuce, and asparagus, for example, can tolerate boron concentrations as high as four milligrams per liter, but trees in citrus orchards may be damaged if their water supply contains more than one milligram per liter.

The concentration of dissolved oxygen is one of the most widely used indicators of the biochemical condition of water because it indicates how much "free" oxygen (that not chemically bound with other elements) is available for respiration by plants and aquatic organisms and for organic and inorganic chemical reactions. Unlike most other parameters of water quality, a high level of dissolved oxygen concentration is considered desirable. Because oxygen is needed by bacteria to break down plant and animal wastes, a low level of dissolved oxygen would suggest the presence of large concentrations of these wastes. Water bodies display fluctuations in the level of dissolved oxygen both in the long and short run. Temperature affects the amount of dissolved oxygen water can hold; the higher the temperature the less oxygen water can dissolve. Organic material, the magnitude of flow, and the gradient of the stream also affect dissolved oxygen levels. All other things being equal, dissolved oxygen levels would be higher in a steep mountain stream than in a slowly moving river on a flood plain.

The amount of waste in a stream can also be measured in terms of the amount of oxygen required for chemical reactions. These relationships are expressed as biochemical oxygen demand or chemical oxygen demand. If there is not enough oxygen to meet the demand for these reactions then anaerobic reactions can begin, producing noxious and sometimes explosive gases.

California has several areas where low levels of dissolved oxygen have been a problem, most notably in the San Francisco Bay. In the 1960s, for example, the inflow of municipal and industrial wastes created low levels of dissolved oxygen in the South Bay and in many of the streams tributary to the northern portions of the Bay. Improved sewage treatment techniques in recent years, however, have achieved some progress in correcting these problems.

High levels of suspended sediments in a stream may be due to natural conditions within a drainage basin, or they may be caused by road building, logging, overgrazing of pasture lands, fire, agriculture, or urban development. Erosion rates can be increased four to nine times by some types and methods of agricultural development and by as much as ten times by construction activities. The presence of dams on a stream can substantially alter the natural concentrations of sediment. The high dams on the Colorado River, for example, have reduced the large quantities of sediment this river once carried and these sediments have accumulated in the reservoirs behind the dams. On the Trinity River below Clair Engle Reservoir, however, controlled releases of water have so reduced the natural flow of the river that the mainstream cannot dispose of the silt delivered by its tributaries. As a result, the stream bed is suffering from siltation.

If a stream or river does not flow at a rate sufficient to carry its sediment load, numerous problems can result. Deposited material can blanket fish spawning gravels, smother aquatic organisms that dwell on the bottom of stream beds, and interfere with the respiration of fish eggs. Turbid waters, by reducing light penetration, can also reduce the population of photosynthesizing microorganisms which are a primary food source in the aquatic food chain. In addition, high loads of sediment increase the costs of water treatment and can interfere with irrigation by leaving a hard layer of sediment on the topsoil which seedlings may have difficulty breaking through.

The total dissolved solids in water indicates the concentration of inorganic salts and other dissolved materials. Although the concentration of total dissolved solids can be measured in parts per million, this determination requires the filtration and drying of a water sample. A more practical method measures the specific conductivity of water. Two electrodes are placed in the water and the resistance of the water to the flow of an electrical current is measured. The higher the conductance, the higher the concentration of dissolved solids. The advantage of this method is that it is quick and can be done in the field. The result is commonly expressed in micromhos.

Excess dissolved solids are objectionable in drinking water because they affect the taste of the water, induce possible physiological effects, and usually

What appear to be waves in this aerial view of Clear Lake in Northern California are in fact non-point source pollutants which the wind has whipped to froth.

EXAMPLES OF WATER QUALITY PROBLEMS

Modern water quality control programs must deal with a wide range of problems which originate in different ways and require correspondingly diverse responses. The problems of water quality on the Santa Ana and Trinity rivers and at Lake Tahoe suggest the breadth of this diversity.

The demands placed upon the Santa Ana River for industry, recreation, and urban development greatly exceeded the capacity of this small Southern California stream. Flows at some times declined to only one or two cubic feet per second, resulting in excessive concentrations of nutrients, salts, bacteria, and virus. Beginning in 1971, a plan was formulated to augment the flows of the river with wastewater effluents from a series of three new regional treatment plants which would replace the eight plants already located on the river. Industrial discharges high in boron and salts were limited within the basin, and some saline effluents are now piped to Orange County for discharge into the ocean.

Completion of the Trinity Dam in 1962 drastically altered the regimen of the lower Trinity River. The Trinity watershed has a naturally high sediment yield which has been increased by logging and construction activities within the basin. With the diversion of a million acre-feet of water to the Central Valley Project, streamflows on the lower stretches of the river declined to the point that the spawning beds of anadromous fish silted in and willows and other vegetation began to encroach upon the stream bed, thereby further slowing the river's flow and complicating the problems of sedimentation. A task force composed of federal, state, and local representatives is now at work developing a 20-year program for the rehabilitation of the river through the removal of barriers, the construction of sediment catchments and riffles, and the stocking of anadromous fish.

At Lake Tahoe, the problem of protecting the clarity of this largest of North American alpine lakes involves the control of non-point sources of sediment and nutrientw. Sewage at Lake Tahoe is pumped out of the basin and construction practices have been controlled for the last 15 years. The rate of new development along the shoreline, however, and the effects of airborne pollutants have resulted in siltation and the growth of algae near the shore and especially in the areas around the mouths of tributary streams. The 208 plan for Lake Tahoe was rejected by California's Water Resources Control Board and is currently being revised. Meanwhile, negotiations between California and Nevada are proceeding over the means of developing an effective program for regulating the rate of new growth and development within the basin.

create a need to use large amounts of detergent for washing. Many industries set specific limits on the concentration of dissolved solids acceptable for their use. If the quantity of dissolved solids in irrigation water is high enough, agriculture can also be affected because the salts will accumulate in the root zone, thereby reducing the crop yield and creating a need for larger volumes of irrigation water to flush the salts from the soil.

High concentrations of calcium, magnesium, and certain metals decrease the effectiveness of soap. This quality, called hardness, causes scale on radiators, boilers, water heaters, pipes, and other water fixtures; toughens cooked vegetables; and increases wear on clothes. Limestone deposits are a natural source of hardness, although inorganic chemical processing plants and some mining activities can also contribute to hardness.

Heavy metals in water, such as cadmium, iron, lead, mercury, and arsenic, usually occur in trace amounts which require extremely sensitive equipment to be measured. These substances, however, do not break down organically and hence they become concentrated in plant and animal tissues along the food chain. Runoff from urban areas and drainage from operating and abandoned mines in the Sierra and Klamath mining areas are common sources of heavy metals in California waters. Water degradation from mine drainage can be controlled by regrading or sealing the mine, diverting its drainage, or by the use of chemical and biological inhibitors to reduce acid formation. Arsenic pollution can result from residual concentrations of certain types of pesticides which are no longer in use today.

Many pesticides are extremely poisonous. Only a few parts per billion, or even parts per trillion in the case of some compounds, can be extremely toxic to fish and other aquatic life. In 1976 an estimated 252 to 290 million pounds of pesticides were used in California to control weeds and insects. Next to air, water is the most common method for the transportation of pesticides within the environment. These toxic organic chemicals enter the water supply directly through some industrial processes, agricultural discharge, spillage, and illegal dumping. They can also enter water systems indirectly, however, by drifting away from areas where pesticides are being sprayed, through surface runoff from treated fields, and by leaching or return flows from irrigation. Like heavy metals, pesticides concentrate in plant and animal tissues and many of these compounds are considered to be carcinogenic to humans. Although many pesticides are designed to deteriorate rapidly when exposed to sunlight and air, they may persist for months or even years in water.

Agricultural activities can also cause excessive concentrations of nitrogen, which is an important constituent of many fertilizers. Nitrogen in its various forms is an important nutrient for plants. But when it occurs in sufficient concentration in drinking water, it can be hazardous to infant children. Excessive concentrations of nitrogen also accelerate the natural process of eutrophication in lakes and reservoirs by which the water becomes so rich in nutrients that algal blooms form and the resulting abundance of aquatic organisms eventually depletes the oxygen content of the water. Small amounts of nitrogen are found in rocks and much higher concentrations are found in most soils and organic matter. Some nitrogen, generally in the form of nitrates, is found in rainwater. When used by plants, nitrogen usually returns to the soil upon the death of the plants, where some of it is carried away by subsurface percolation and surface runoff. Other sources of nitrogen pollution include municipal and industrial effluent, feed lots, and septic tanks.

The acidity or alkalinity of water is measured by the pH factor. The pH scale ranges from 1 to 14, with 1 to 7 being acid, 7 to 14 being alkaline, and 7 being neutral. A change of one point on this scale represents a ten-fold increase in acidity or alkalinity. The pH of water is measured for public water supplies to determine what treatment process to employ. Acidic waters may be corrosive to pipes and treatment facilities. In addition, certain water treatment and sewage treatment processes work most effectively within certain pH ranges. Water acidity is also an important consideration in the management of fisheries. Ranges of 6.5 to 9.0 are considered harmless to fish. Outside this range, however, fish begin suffering physiologically. The pH range itself is not a problem for fish and aquatic animals and plants, but certain chemical reactions become lethal for fish at pH levels outside this range. For example, ammonia, which is a major component of sewage discharges, can be completely safe at pH 7.0 and extremely toxic to fish at pH 8.5 for the same total ammonia concentration.

Although the various elements described so far are important in determining water quality, temperature is a factor which can affect nearly all of the chemical, physical, and biological properties of water. Temperature is an important agent in any chemical reaction and heat can consequently affect the sanitary and aesthetic condition of any water body. Higher temperatures accelerate the biodegradation of organic material. This accelerated "cleaning," however, also means that more dissolved oxygen will be demanded, even though the ability of water to hold dissolved oxygen decreases as temperature increases. Temperature also determines the kinds of plants and animals that will flourish within water bodies. Different species live and, more importantly, reproduce at different temperatures. Anadromous fish migrate in response to temperature changes and their eggs require water that is around 50 degrees Fahrenheit. Temperature also directly affects human uses of water. Industrial uses for processing and cooling require water of a certain temperature and temperature also influences the effectiveness of water and sewage treatment processes. Coliform bacteria for example, tend to die more quickly in warmer waters. Warmer water is also desired for certain agricultural products such as rice because warmth accelerates growth.

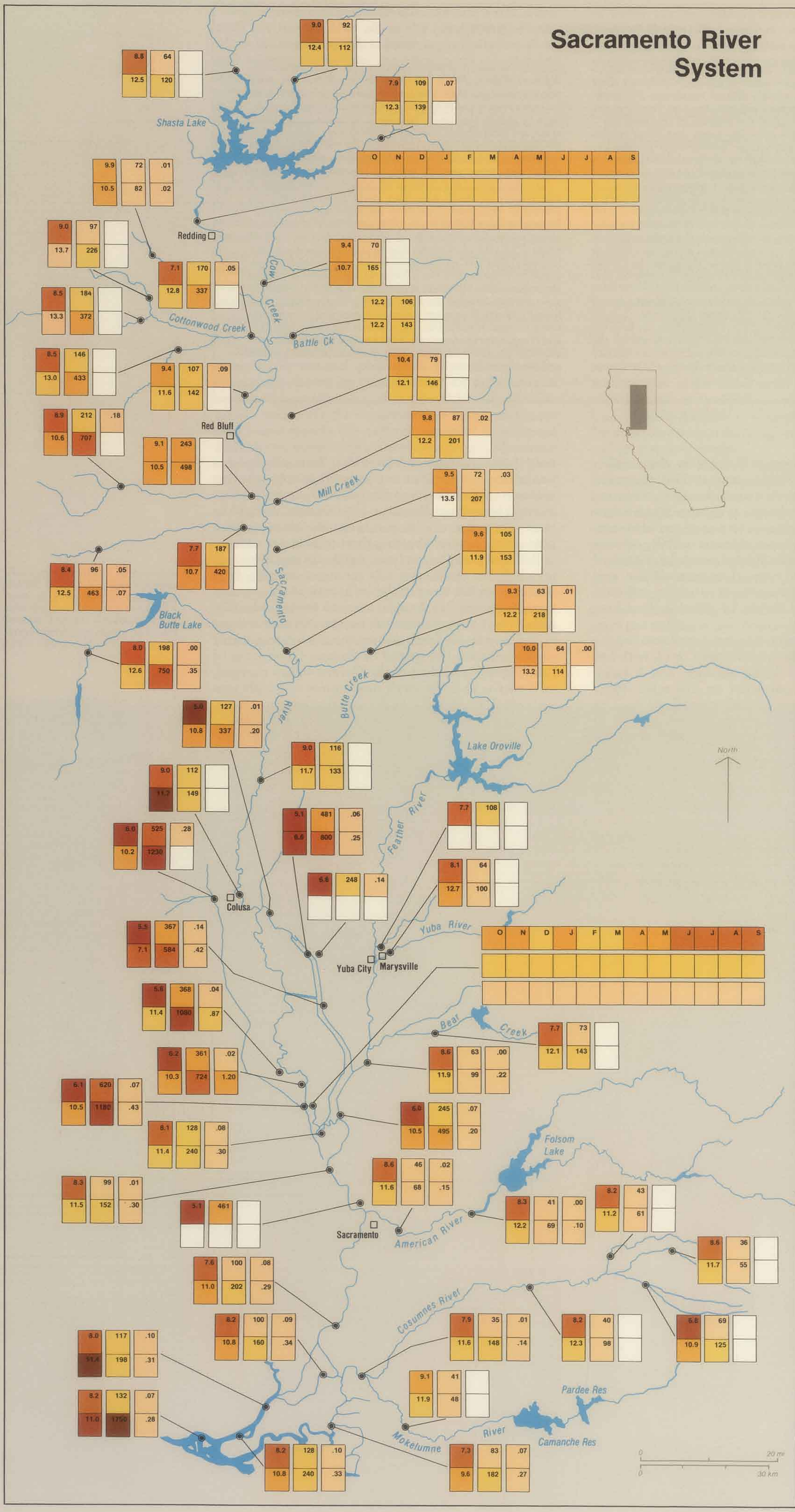
WATER QUALITY CONTROL PROGRAMS

Although water quality control has become a central part of all water planning in the United States only in the years since World War Two, people have probably been concerned about water quality management since the earliest days of water development. The ancient Romans, for example, learned to their regret that dumping refuse indiscriminately on land overlying and abutting their local water sources would foul them beyond use, and it was this discovery which drove the Romans to construct aqueducts to distant supplies beyond the influence of their pollution. In California, the resistance to the introduction of systematic irrigation in the nineteenth century was fueled in part by fears that so much standing water would enhance the spread of disease. Opponents of Los Angeles' aqueduct to the Owens Valley charged, incorrectly, that the city's new source of supply was polluted by alkali and cow droppings from agricultural operations around Bishop. And one of the many things that agitated the early settlers of the Imperial and Coachella valleys to campaign so vigorously for construction of the All-American Canal was the fact that corpses from revolutionary Mexico sometimes floated into their irrigation systems.

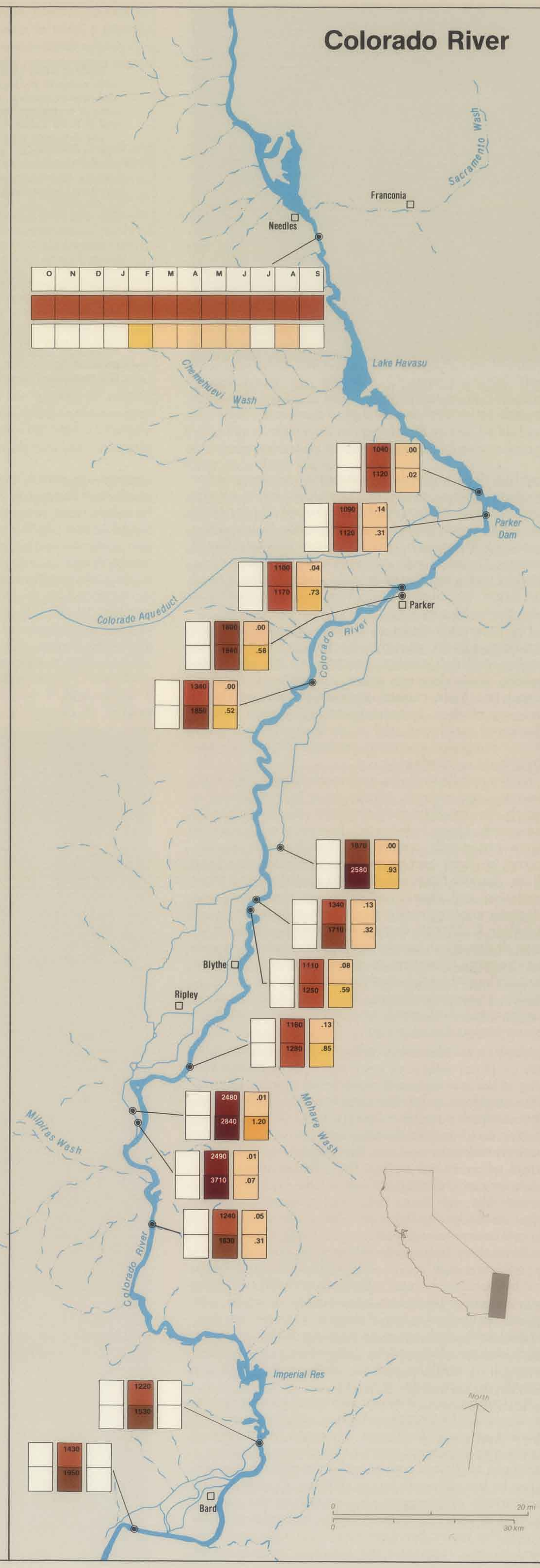
Although domestic water supplies have existed in the United States since the Water Works Company of Boston began service to Conduit Street in 1632, the formation of water quality control agencies was delayed until 1869, when the Massachusetts State Board of Health was formed in response to findings by European bacteriologists that epidemic diseases were passed through drinking water contaminated by untreated wastes. For the most part, dangers to public health in domestic water supplies arise from the presence of contaminants in the water. Pathogenic organisms are those that cause disease or death in people and animals. Viruses are organisms that attach to the cell walls of the host, inject their own structure into the cell, and cause the cell to acquire the characteristics of the virus. Although viruses are very difficult to detect and remove from public drinking water supplies, they are responsible for such diseases as aseptic meningitis, infectious hepatitis, and polio.

Probably no other creature has played so central a role in mankind's rearrangement of the natural waterscape as the mosquito, seen below in its larval stage. Many of the most densely populated areas of California today were once uninhabitable malarial bogs, and it was the fear of the diseases mosquitoes spread which lent support for the reclamation programs of the nineteenth century. The opposition to the introduction of systematic irrigation at the turn of the century was founded in part upon the same fear that large fields of standing water would provide a breeding ground for mosquitoes. As a result, the spread of irrigation districts was attended by the rise of another kind of special district for mosquito abatement. Recent studies suggest that the area of California's mosquito populations has extended to correspond almost exactly with the acreage of irrigated agriculture. Those species which carry encephalitis and malaria are found near rice fields and other areas that stay wet for long periods. The most common pest species of mosquito (*Aedes nigromaculis*) thrives where crops are periodically flooded, as in irrigated pastures.

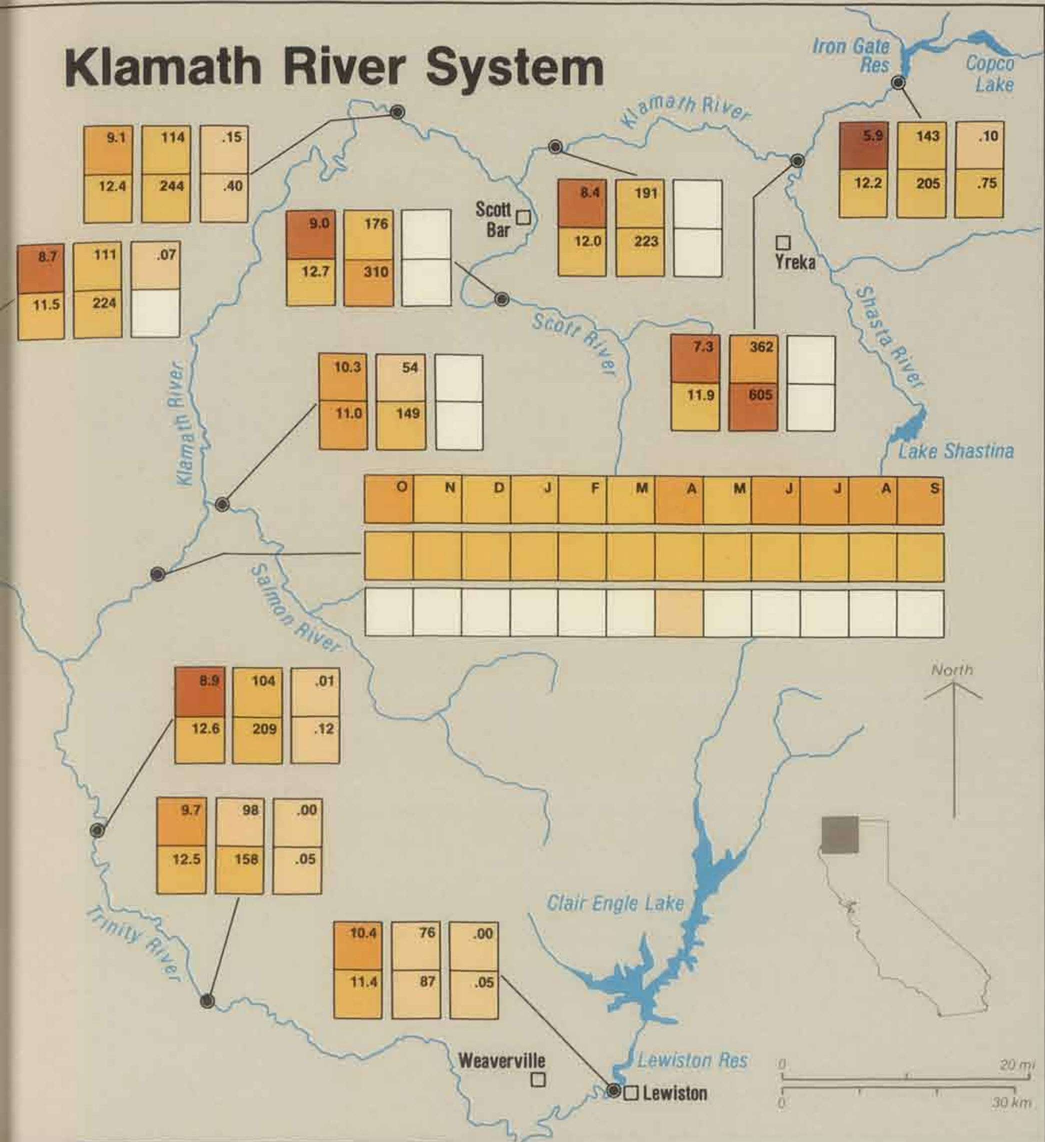
Sacramento River System



Colorado River



Klamath River System



Surface Water Quality Water Year 1975

These maps compare the concentration of three principal constituents of water quality in four stream systems during water year 1975. **Dissolved Oxygen (DO)** and **Nitrates (NO_3)** are represented in milligrams per liter (mg/L) and **Total Dissolved Solids (TDS)** is shown in terms of the electrical conductivity of the water measured in micromhos (mmhos). Generally, higher levels of **TDS** and **NO_3** indicate degradation of water quality, while higher levels of **DO** are beneficial to most uses of water.

Minimum and maximum observed concentrations of the three constituents are shown at specific locations. Seven stations have been selected for a more detailed presentation of month to month variations in concentration. The concentrations of these constituents vary from year to year as well, depending upon flow levels and other changing conditions within individual watersheds.

The tables below present the minimum and maximum concentrations of these constituents which are commonly regarded as acceptable for various uses.

DO mg/L	EC micromhos	NO_3 mg/L
13.1 and above	100 and below	.50 and below
11.1-13.0	101-250	.51-1.00
9.1-11.0	251-500	1.01-1.50
7.1-9.0	501-1000	1.51-2.00
5.1-7.0	1001-1500	2.01-2.50
3.1-5.0	1501-2000	2.51 and above
3.0 and below	2001-2500	
	2501 and above	

A colorless square represents **no data.**

Minimum/Maximum Concentrations (Water Year)

	DO	EC	NO_3
Minimum	7.3	83	.07
Maximum	9.6	132	.27

Monthly Concentrations*

DO	O	N	A	S
EC	O	N	A	S
NO_3	O	N	A	S

* The graphs represent monthly concentrations from October 1974 through September 1975.

Total Dissolved Solids (TDS): A measure of salts in solution. TDS can be measured either in milligrams per liter or specific conductance (EC). An EC measurement of 1500 micromhos is approximately equal to 1000 mg/L TDS.

Recommended limits	micromhos
Domestic water supply	750
Irrigation water-salinity	
No detrimental effects	750
Detrimental to sensitive crops	750-1500
Can have detrimental effects on many crops	1500-3000
Water for tolerant crops permeable soils	3000-5000
Livestock and Poultry excellent for all	1500
Industrial Uses	
Canning	825
Fine Paper	300
Petroleum refining	5250
Electrical utility	45000
Propagation of fish	3000
Good mixed fish population (fish can grow accustomed to very high levels of dissolved solids)	600

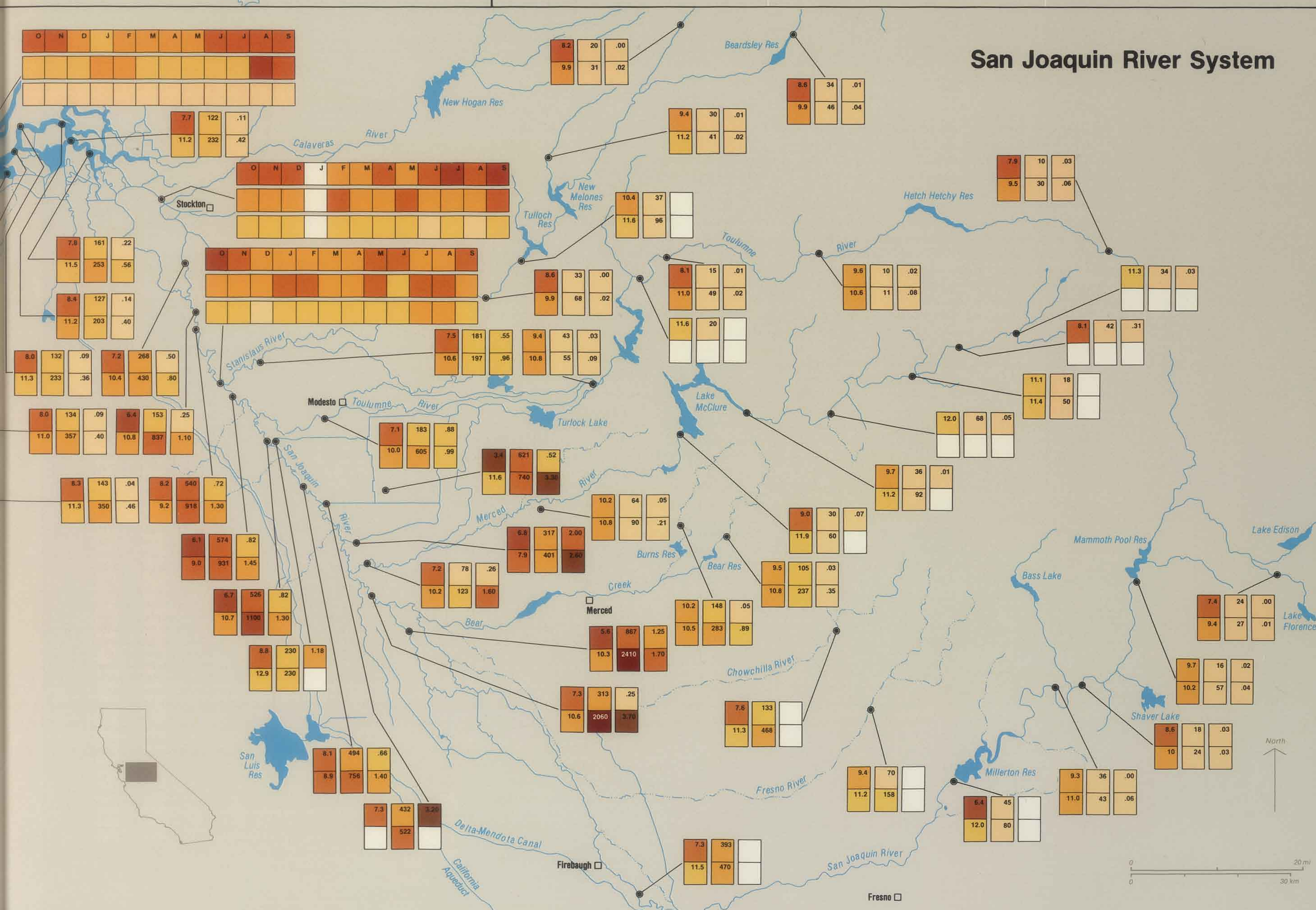
Dissolved Oxygen (DO): High levels of dissolved oxygen indicate that excessive quantities of oxygen demanding wastes probably are not present.

Domestic water supply	not significant
Industrial water supply	not significant
Irrigation	not significant
Livestock and Poultry	not significant
The following are recommended minimum levels	
Fish embryos and larvae	5 mg/L
Salmonoid spawning	9 mg/L
Salmonoid migration	7 mg/L
Warm water fish	5 mg/L
Highest number and variety of fish exist when DO is greater than	9 mg/L
To prevent generation of sulfide	2 mg/L
The following are recommended maximum levels	
Low pressure boiler feed water (industrial)	2.5 mg/L
Electrical utilites	.007 mg/L
Optimum range for minumum damage to pipes	1-4 mg/L

Nitrate (NO_3): A major nutrient for vegetation and a measure of the amount of inorganic nitrogen in water. Sources of nitrate include municipal and industrial wastes, irrigation return flows from fertilized soils, and septic tank outfalls.

Industrial	
Petroleum refining	8 mg/L
Food canning industry	45 mg/L
Canned, dried, frozen fruits	10 mg/L
Agricultural	
Livestock and Poultry	
recommended limit	100 mg/L
tolerance	300 mg/L
Irrigation water for sugar beets, grapes, apricots, citrus, avocado, and tomatoes	
no problem-less than	5 mg/L
increasing problem	5-30 mg/L
severe problem-greater than	30 mg/L
An algae bloom requires greater than (plus greater than .01 mg/L phosphorus)	.30 mg/L
Warm water fish	90 mg/L
Chinook salmon-96 hour tolerance	1310 mg/L

San Joaquin River System



Although early water quality control programs emphasized the installation of sophisticated central sewage treatment systems, resistance to the construction of such expensive facilities is growing in remote areas like the Bolinas Lagoon, where simpler alternative technologies may be more appropriate. The conflict, however, has created serious hazards for the public health in the communities of Bolinas and Stinson Beach, which can be seen at the left and right sides respectively of this photograph.

Bacteria are single-cell organisms found both in nature and in human wastes. Of major interest to sanitary engineers is the coliform group of bacteria, whose presence in very small amounts is a reliable indication of the extent of bacteriological treatment of waste water. Other bacteria are responsible for a variety of ailments, such as cholera, typhoid, paratyphoid, and dysentery. Protozoa are single-cell organisms ranging from 10 to 100 microns in diameter. The only known pathogen is the Endamoeba histolytica, which causes amoebic dysentery in tropical climates. Flukes that live in the bloodstream may, however, be passed into the water by contact with human feces and thus spread shistosomiasis, a disease afflicting the intestine, liver, and spleen.

The earliest emphasis in American water quality control programs was placed upon the protection of public health through the treatment of domestic water supplies. Congress created the Public Health Service in 1901 to protect the public from waterborne diseases, and in 1912 the authority of this new agency was extended to include the control of pollution in navigable streams. Enforcement of water quality standards, however, from 1912 to 1948, was left largely to the individual states. California responded in 1915 by creating its own Bureau of Sanitary Engineering and requiring all suppliers of domestic drinking water to obtain permits from the bureau. The Legislature failed, however, to grant this new agency any enforcement power. Although the State Department of Fish and Game did establish a regulatory program to prohibit discharges that might be harmful to fish, the principal responsibility for the protection of water quality was left in large part to local initiative.

As a result, California's major metropolitan areas pursued their own independent courses with respect to the development of sewage treatment facilities. Although sewer systems were common, communities such as San Diego and San Francisco continued to discharge untreated or minimally treated wastes into local bays and the ocean as late as the 1940s. Inland, the situation was even more chaotic. Upstream communities which shared a common stream had little incentive to undertake the costs of constructing sophisticated water treatment facilities because the effects of pollution were seldom experienced locally but instead troubled only the users downstream. The communities downstream in turn objected strenuously to having to build treatment systems to control the wastes of their neighbors.

As California's urban population swelled in the 1940s, a series of incidents dramatically demonstrated the consequences of this haphazard approach to water quality control. Shellfishing in San Francisco Bay was quarantined because of contamination of the fishery by municipal and industrial sewage. Fourteen miles of the beach near El Segundo were also closed as a result of grease building up along the shore. And in Montebello, the illegal dumping of industrial chemicals polluted the wells of three water companies and contaminated the principal groundwater recharge area for the region of Los Angeles.

These and similar incidents prompted the Legislature to establish the modern system of regional water quality control boards. The Dickey Act of 1949 created nine regional boards with the authority to establish and enforce water quality standards within entire watersheds under the direction of a central state board. The Porter-Cologne Act of 1969 expanded the supervisory and appelate powers of these boards and required the formulation of specific water quality objectives and plans for their achievement for each of the regions they serve.

From the 1950s forward, the basic framework for a coordinated approach to the state's water quality problems began to be set in place. The state government began offering grants to local agencies to subsidize the construction of new and improved sewage treatment facilities. A quarantine which the state Health Department imposed on San Diego Bay brought about a major renovation of that city's sewage treatment system. In Orange County, a county-wide sanitation district was formed in 1947 to bring an end to the dumping of raw municipal sewage into the ocean by numerous small towns and cities. In the San Francisco Bay Area, San Leandro, Oakland, Hayward, Ora Loma, and Castro Valley all installed primary treatment facilities by 1950. San Francisco stopped discharging all of its raw sewage into the Bay with the construction of the Sunset-Richmond primary treatment plant, although the fact that San Francisco's sewage and storm runoff systems are linked results in the continued discharge of untreated municipal sewage whenever heavy rains occur.

Although California's approach to water quality control has in many respects provided models for similar efforts in other parts of the country, the principal authority over water quality programs has been increasingly assumed by the federal government. The Water Pollution Control Act of 1948 authorized federal assistance to states in the development of comprehensive programs to reduce pollution, and subsequent amendments to that act have greatly enhanced the availability of federal technical assistance, funding, and research. The creation of the federal Environmental Protection Agency in 1970 and the adoption of a national water quality program in 1972 established a systematic program for the control and reduction of water pollution backed up by unprecedented amounts of financing for the construction of pollution control works. And the Safe Drinking Water Act of 1974 gave the EPA the authority to establish and enforce guidelines for the achievement of minimum national water quality standards for every public water supply system serving 25 people or more.

METHODS OF CONTROL

Most municipal water supplies are treated to provide safe, pleasant-tasting drinking water. The level of treatment required by federal standards, however, may not be sufficient to meet the criteria for certain industrial and other uses. Process water and water to be used in boilers, for example, often require further treatment of municipal supplies by industrial users.

An important factor in water treatment processes is the source of water. Different sources have varying water quality characteristics which require different treatment operations. These characteristics can change seasonally or even daily. Well water, for example, may be hard because it has a higher concentration of dissolved minerals than surface supplies. River water may have many constituents that require treatment or removal, depending on the characteristics of the drainage basin and the amount of pollution added upstream by municipalities, industries, and agriculture. Although the quality of streamflow fluctuates according to the quantity of runoff available at any given point in the water year, lake and reservoir sources are also subject to seasonal quality changes due to temperature stratification. Usually the highest quality water comes from the middle depths of such a storage facility. Efforts to control the quality of water in a storage reservoir by adding chemicals to inhibit algal growth can, however, interfere with later treatment processes and harm the aquatic resources of the reservoir itself.

The initial purpose of water treatment is to remove suspended material and kill possibly pathogenic organisms. The water is filtered either through sand

THE 208 NON-POINT SOURCE CONTROL PROGRAM

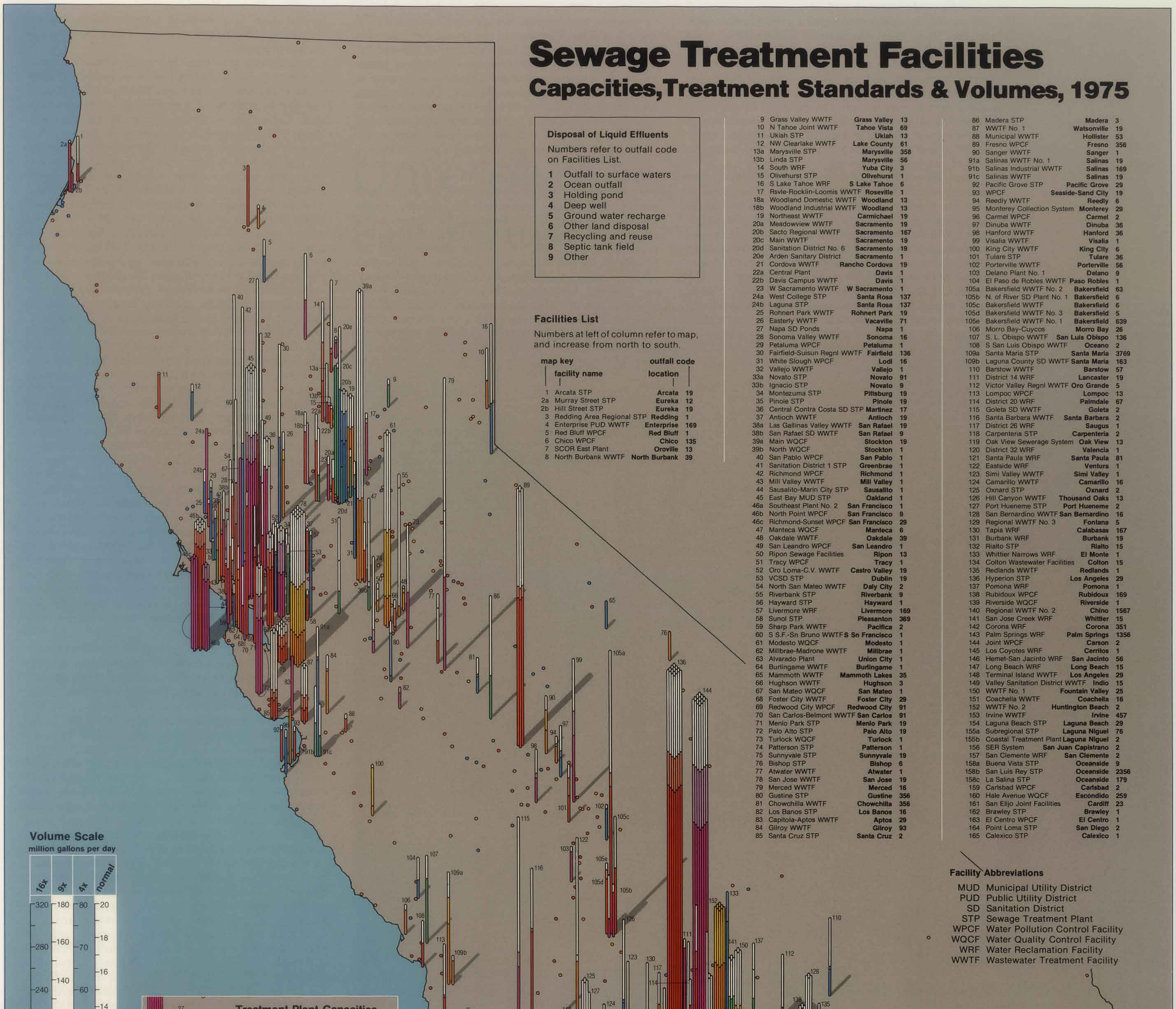
Under the Water Pollution Control Act Amendments of 1972, the federal government has provided extensive subsidies for the construction of sewage treatment facilities to combat the effects of point source pollution. Section 208 of the Act also included a systematic program for dealing with non-point source degradation of water quality. Non-point sources of water pollution include drainage and runoff from some agricultural activities, erosion from logging practices, mine drainage, saltwater intrusion, the effects of hydrologic modifications such as reduced streamflow due to dams and diversion facilities, and the effects of water runoff from urban centers which include constituents resulting from the fertilization of home gardens, landfills, and the grease, oil, and asbestos which accumulate on streets and highways.

Section 208 requires each state to develop a plan to control non-point source pollution in order to achieve mandated clean water levels by 1983. Each state plan will identify the so-called Best Management Practices for various types of land use which will cause the least degradation to water quality. Regulatory and planning agencies at the federal, state, and local levels are responsible for developing and implementing these plans, and once the plans have been approved by the United States Environmental Protection Agency, the regulatory agencies will in turn be responsible for their enforcement.

The success of the 208 non-source point program depends upon cooperation among the many public and private interests that would be involved in the adoption and implementation of the plans. Data on the full extent of the cause and effect of non-point source pollution, however, have been lacking, and some advocates of 208 planning complain that the federal government has failed to provide sufficient guidance or funding for the development and implementation of the plans required by the Act. Nevertheless, increasing recognition of the importance of non-point source pollution seems to assure that similar cooperative approaches to the problems of enforcement will become an important part of water quality control programs in the future.

Sewage Treatment Facilities

Capacities, Treatment Standards & Volumes, 1975



Disposal of Liquid Effluents

Numbers refer to outfall code on Facilities List.

1. Outfall to surface waters
2. Ocean outfall
3. Holding pond
4. Deep well
5. Ground water recharge
6. Other land disposal
7. Recycling and reuse
8. Septic tank field
9. Other

Facilities List

Numbers at left of column refer to map, and increase from north to south.

map key	facility name	location	outfall code
1	Arcata STP	Arcata	19
2a	Murray Street STP	Eureka	12
2b	Hill Street STP	Eureka	19
3	Redding Area Regional STP	Redding	1
4	Enterprise PUD WWTF	Enterprise	169
5	Red Bluff WPCF	Red Bluff	1
6	Chico WPCF	Chico	135
7	SCOR East Plant	Oroville	13
8	North Burbank WWTF	North Burbank	39
9	Grass Valley WWTF	Grass Valley	13
10	N Tahoe Joint WWTF	Tahoe Vista	69
11	Ukiah STP	Ukiah	13
12	NW Clearlake WWTF	Lake County	61
13a	Marysville STP	Marysville	358
13b	Linda STP	Marysville	56
14	South WRF	Yuba City	3
15	Olivehurst STP	Olivehurst	1
16	S Lake Tahoe WRF	S Lake Tahoe	6
17	Rsvle-Rocklin-Loomis WWTF	Roseville	1
18a	Woodland Domestic WWTF	Woodland	13
18b	Woodland Industrial WWTF	Woodland	13
19	Northeast WWTF	Carmichael	19
20a	Meadowview WWTF	Sacramento	19
20b	Sacto Regional WWTF	Sacramento	167
20c	Main WWTF	Sacramento	19
20d	Sanitation District No. 6	Sacramento	19
20e	Arden Sanitary District	Sacramento	1
21	Cordova WWTF	Rancho Cordova	19
22a	Central Plant	Davis	1
22b	Davis Campus WWTF	Davis	1
23	W Sacramento WWTF	W Sacramento	1
24a	West College STP	Santa Rosa	137
24b	Laguna STP	Santa Rosa	137
25	Rohnert Park WWTF	Rohnert Park	19
26	Easterly WWTF	Vacaville	71
27	Napa SD Ponds	Napa	1
28	Sonoma Valley WWTF	Sonoma	16
29	Petaluma WPCF	Petaluma	1
30	Fairfield-Suisun Regnl WWTF	Fairfield	136
31	White Slough WPCF	Lodi	16
32	Vallejo WWTF	Vallejo	1
33a	Novato STP	Novato	91
33b	Ignacio STP	Novato	9
34	Montezuma STP	Pittsburg	19
35	Pinole STP	Pinole	19
36	Central Contra Costa SD STP	Martinez	17
37	Antioch WWTF	Antioch	19
38a	Las Gallinas Valley WWTF	San Rafael	19
38b	San Rafael SD WWTF	San Rafael	9
39a	Main WQCF	Stockton	19
39b	North WQCF	Stockton	1
40	San Pablo WPCF	San Pablo	1
41	Sanitation District 1 STP	Greenbrae	1
42	Richmond WPCF	Richmond	1
43	Mill Valley WWTF	Mill Valley	1
44	Sausalito-Marin City STP	Sausalito	1
45	East Bay MUD STP	Oakland	1
46a	Southeast Plant No. 2	San Francisco	1
46b	North Point WPCF	San Francisco	9
46c	Richmond-Sunset WPCF	San Francisco	29
47	Manteca WQCF	Manteca	6
48	Oakdale WWTF	Oakdale	39
49	San Leandro WPCF	San Leandro	1
50	Ripon Sewage Facilities	Ripon	13
51	Tracy WPCF	Tracy	1
52	Oro Loma-C.V. WWTF	Castro Valley	19
53	VCSD STP	Dublin	19
54	North San Mateo WWTF	Daly City	2
55	Riverbank STP	Riverbank	9
56	Hayward STP	Hayward	1
57	Livermore WRF	Livermore	169
58	Sunol STP	Pleasanton	369
59	Sharp Park WWTF	Pacifica	2
60	S S.F.-Sn Bruno WWTF	S Sn Francisco	1
61	Modesto WQCF	Modesto	1
62	Millbrae-Madrone WWTF	Millbrae	1
63	Alvarado Plant	Union City	1
64	Burlingame WWTF	Burlingame	1
65	Mammoth WWTF	Mammoth Lakes	35
66	Hughson WWTF	Hughson	3
67	San Mateo WQCF	San Mateo	1
68	Foster City WWTF	Foster City	29
69	Redwood City WPCF	Redwood City	91
70	San Carlos-Belmont WWTF	San Carlos	91
71	Menlo Park STP	Menlo Park	19
72	Palo Alto STP	Palo Alto	19
73	Turlock WQCF	Turlock	1
74	Patterson STP	Patterson	1
75	Sunnyvale STP	Sunnyvale	19
76	Bishop STP	Bishop	6
77	Atwater WWTF	Atwater	1
78	San Jose WWTF	San Jose	19
79	Merced WWTF	Merced	16
80	Gustine STP	Gustine	356
81	Chowchilla WWTF	Chowchilla	356
82	Los Banos STP	Los Banos	16
83	Capitola-Aptos WWTF	Aptos	29
84	Gilroy WWTF	Gilroy	93
85	Santa Cruz STP	Santa Cruz	2
86	Madera STP	Madera	3
87	WWTF No. 1	Watsonville	19
88	Municipal WWTF	Hollister	53
89	Fresno WPCF	Fresno	356
90	Sanger WWTF	Sanger	1
91a	Salinas WWTF No. 1	Salinas	19
91b	Salinas Industrial WWTF	Salinas	169
91c	Salinas WWTF	Salinas	19
92	Pacific Grove STP	Pacific Grove	29
93	WPCF	Seaside-Sand City	19
94	Reedly WWTF	Reedly	6
95	Monterey Collection System	Monterey	29
96	Carmel WPCF	Carmel	2
97	Dinuba WWTF	Dinuba	36
98	Hanford WWTF	Hanford	36
99	Visalia WWTF	Visalia	1
100	King City WWTF	King City	6
101	Tulare STP	Tulare	36
102	Porterville WWTF	Porterville	56
103	Delano Plant No. 1	Delano	9
104	El Paso de Robles WWTF	Paso Robles	1
105a	Bakersfield WWTF No. 2	Bakersfield	63
105b	N. of River SD Plant No. 1	Bakersfield	6
105c	Bakersfield WWTF	Bakersfield	6
105d	Bakersfield WWTF No. 3	Bakersfield	5
105e	Bakersfield WWTF No. 1	Bakersfield	639
106	Morro Bay-Cuycos	Morro Bay	26
107	S. L. Obispo WWTF	San Luis Obispo	136
108	S San Luis Obispo WWTF	Oceano	2
109a	Santa Maria STP	Santa Maria	3769
109b	Laguna County SD WWTF	Santa Maria	163
110	Barstow WWTF	Barstow	57
111	District 14 WRF	Lancaster	19
112	Victor Valley Regnl WWTF	Oro Grande	5
113	Lompoc WPCF	Lompoc	13
114	District 20 WRF	Palmdale	67
115	Goleta SD WWTF	Goleta	2
116	Santa Barbara WWTF	Santa Barbara	2
117	District 26 WRF	Saugus	1
118	Carpenteria STP	Carpenteria	2
119	Oak View Sewerage System	Oak View	13
120	District 32 WRF	Valencia	1
121	Santa Paula WRF	Santa Paula	81
122	Eastside WRF	Ventura	1
123	Simi Valley WWTF	Simi Valley	1
124	Camarillo WWTF	Camarillo	16
125	Oxnard STP	Oxnard	2
126	Hill Canyon WWTF	Thousand Oaks	13
127	Port Hueneme STP	Port Hueneme	2
128	San Bernardino WWTF	San Bernardino	16
129	Regional WWTF No. 3	Fontana	5
130	Tapia WRF	Calabasas	167
131	Burbank WRF	Burbank	19
132	Rialto STP	Rialto	15
133	Whittier Narrows WRF	El Monte	1
134	Colton Wastewater Facilities	Colton	15
135	Redlands WWTF	Redlands	1
136	Hyperion STP	Los Angeles	29
137	Pomona WRF	Pomona	1
138	Rubidoux WPCF	Rubidoux	169
139	Riverside WQCF	Riverside	1
140	Regional WWTF No. 2	Chino	1567
141	San Jose Creek WRF	Whittier	15
142	Corona WRF	Corona	351
143	Palm Springs WRF	Palm Springs	1356
144	Joint WPCF	Carson	2
145	Los Coyotes WRF	Cerritos	1
146	Hemet-San Jacinto WRF	San Jacinto	56
147	Long Beach WRF	Long Beach	15
148	Terminal Island WWTF	Los Angeles	29
149	Valley Sanitation District WWTF	Indio	15
150	WWTF No. 1	Fountain Valley	25
151	Coachella WWTF	Coachella	16
152	WWTF No. 2	Huntington Beach	2
153	Irvine WWTF	Irvine	457
154	Laguna Beach STP	Laguna Beach	29
155a	Subregional STP	Laguna Niguel	76
155b	Coastal Treatment Plant	Laguna Niguel	2
156	SER System	San Juan Capistrano	2
157	San Clemente WRF	San Clemente	2
158a	Buena Vista STP	Oceanside	9
158b	San Luis Rey STP	Oceanside	2356
158c	La Salina STP	Oceanside	179
159	Carlsbad WPCF	Carlsbad	2
160	Hale Avenue WQCF	Escondido	259
161	San Elijo Joint Facilities	Cardiff	23
162	Brawley STP	Brawley	1
163	El Centro WPCF	El Centro	1
164	Point Loma STP	San Diego	2
165	Calexico STP	Calexico	1

Facility Abbreviations

MUD	Municipal Utility District
PUD	Public Utility District
SD	Sanitation District
STP	Sewage Treatment Plant
WPCF	Water Pollution Control Facility
WQCF	Water Quality Control Facility
WRF	Water Reclamation Facility
WWTF	Wastewater Treatment Facility

The great quantities of sediment occurring as effluents into the ocean from the urban and industrial centers of the South Coast have been chromatically enhanced in the satellite image below.

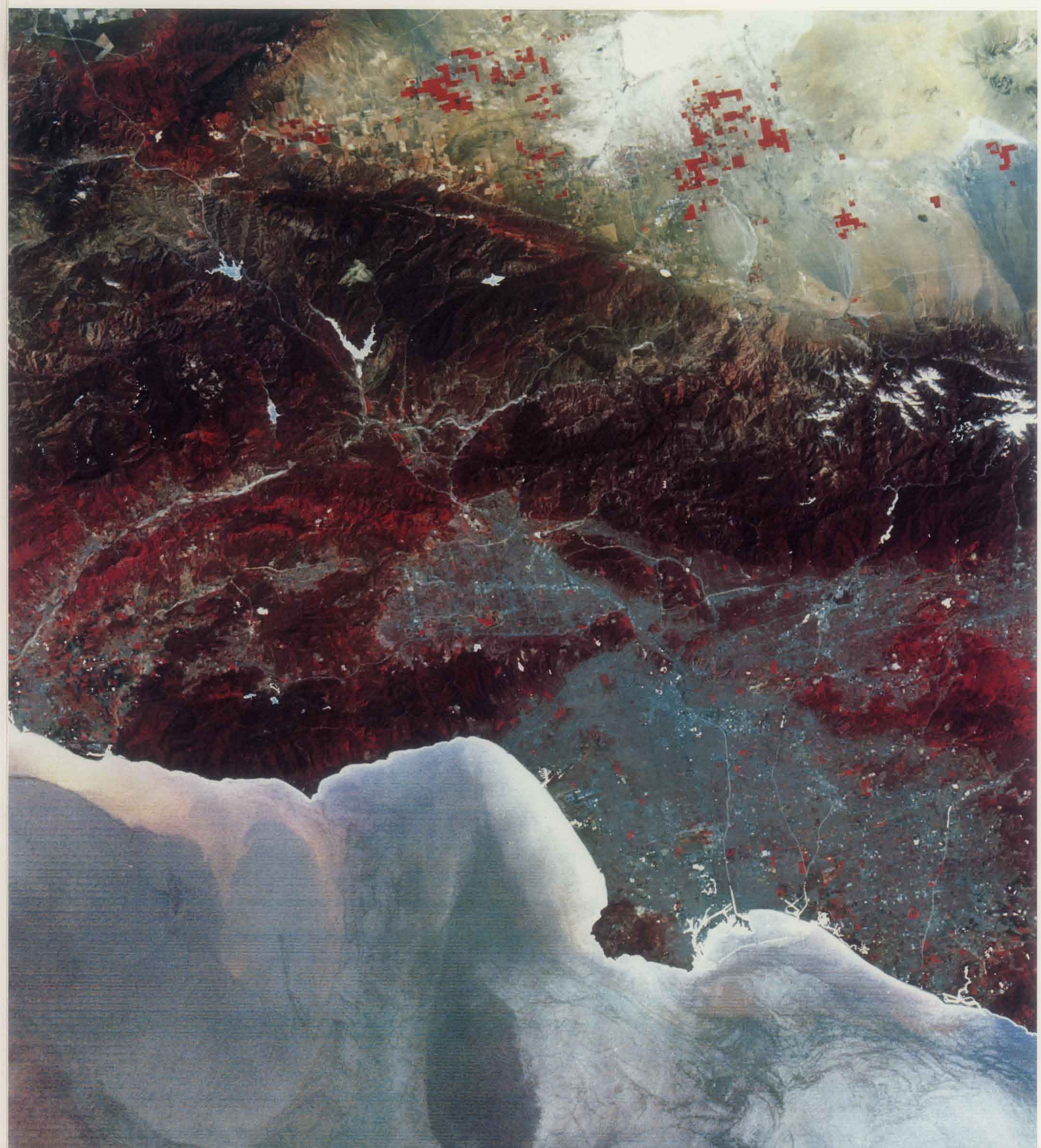
or activated charcoal and, if necessary, treated chemically to remove unwanted constituents such as iron. It is then sterilized by chlorination or by exposing it to ultraviolet lights. While the goal of water treatment is to change the characteristics of water to meet certain use requirements, the purpose of sewage treatment is to remove organic and other material that may deplete the quantity of dissolved oxygen and thereby bring on septic conditions in receiving waters. Like water treatment, sewage treatment methodology is dependent upon the composition of the sewage received.

Sewage treatment is classified into three levels: primary, secondary, and tertiary. Primary treatment removes trash, oils, and other solids. The sewage is first screened to remove sticks, rags, and other large items. The fluid is then passed into basins where suspended solids are settled out. At this point the sewage leaves the primary treatment phase. Although many plants discharge disinfected primary effluents, this practice is changing under the Federal Water Pollution Control Act. If further treatment is required, the effluent is usually pumped to another portion of the plant for secondary treatment.

Secondary treatment removes many of the remaining biological and chemical impurities. Treatment begins by aerating the sewage to increase the amount of oxygen and hasten the natural breakdown of organic wastes. This part of the treatment process is biochemical in nature; microorganisms do most of the work. The sewage is then placed in basins or ponds where the decomposed organic materials—known as sludge—are allowed to settle out. The remaining water is given chlorine or ozone treatment to eliminate bacteria before it is discharged. The remaining sludge is converted into methane gas, water, and a heavy humus-like material through a process known as sludge digestion. Sludge may also be burned or used for landfill or compost.

Primary and secondary treatments are generalized processes. Tertiary treatment, in contrast, varies according to the specific constituents that are to be removed. Tertiary treatment most often involves the removal of nutrients. Nutrients provide food for aquatic plants and algae and aid in the eutrophication of water bodies. Several methods of nutrient removal are available. One process begins with nitrification. Water is aerated to convert ammonia to nitrites and then to nitrates. In the next step in the process, called denitrification, methyl alcohol is added to the solution which helps bacteria to convert nitrates into nitrogen gases. Phosphorus can be precipitated out of solution by adding lime to the effluent. Viruses are removed by filtration. The resulting water is disinfected and then either discharged to water bodies or reused for certain purposes.

Wastewater treatment is a more efficient method of protecting downstream uses than additional treatment at the next point of use. Wastewater treatment can also be considered a method of water conservation. California, however, currently reclaims only about 190,000 acre-feet of water each year through formal reclamation projects. The amount of incidental reclamation—where water is used, treated, and then returned to a water course for reuse downstream—is unknown but believed to be substantial. The inertia against development of this resource stems from the lack of a clear concept of who will utilize reclaimed water, restrictions based on the assumed "staying power" of certain pollutants such as heavy metals, water rights laws, a preoccupation with the fact that agricultural needs exceed the amount of water that could be reclaimed, the tendency to persist in accustomed habits, and the lower cost of fresh water as opposed to the economies of reclamation. The Office of Water Recycling, established by Governor Edmund G. Brown Jr. in 1977, is currently attempting to overcome these obstacles in order to reclaim an additional 400,000 acre-feet per year by 1982.



The science of water quality treatment is changing rapidly and technological advances have introduced new approaches to treatment and revealed new areas of concern. The most virulent waterborne diseases have been all but eradicated in California, for example, while concern for the largely unknown, long-term effects of pesticides on human health is growing. The emphasis in California's programs was originally placed upon the control of effluents from specific sources and the removal of specific contaminants. As these approaches have progressed, nonpoint sources of pollution and the control of trace elements such as heavy metals are receiving greater attention. These new areas of activity, in turn, have required the development of new methods which are not so dependent upon structural solutions to the problem of pollution.

The trend now is toward source control and nonstructural solutions which seek to get at the source of a problem by changing the practices which cause it rather than simply treating the waste product. Water pollution from some agricultural practices can be reduced, for example, by altering irrigation and tillage techniques and by controlling the amount of pesticides and nitrogen fertilizers applied. Similarly, erosion and sedimentation from logging operations can be restricted by not harvesting timber adjacent to streams. The implementation of these new approaches, moreover, depends upon cooperation between individual industries, state, and local agencies instead of the traditional methods of regulation and enforcement.

In addition, governmental agencies today are exploring alternative methods for the treatment of domestic waste through wastewater reclamation, sprinkler irrigation, and the use of septic tanks. An estimated 12 percent of the housing units in California are currently served by septic tanks or other home-site waste management systems. Although governmental water quality control programs have traditionally emphasized the construction of centralized sewer systems, there is growing support today for further experimentation with these so-called on-site waste management techniques as a less expensive alternative to sewer construction in rural areas.

A field of expertise that is developing as rapidly as water quality control depends ultimately upon the continuous monitoring of the constituents of water quality. Although a relatively expensive activity, continuous monitoring provides the means of identifying developing trends and changes in water quality so that necessary corrective measures can be taken in advance. Through monitoring, for example, scientists have learned that some of the chemical compounds formed in early water treatment processes may themselves be carcinogens. Similarly, monitoring has revealed that airborne pollutants can be an important factor in the protection of natural water bodies such as Lake Tahoe and that air and water quality control programs should consequently be linked. Monitoring has thus become an essential part of water planning in California and increasing attention to the relationships between land and water resource planning helps to assure that fewer remedial measures will need to be adopted in the future.

CHAPTER 11

Unresolved Questions for the Future

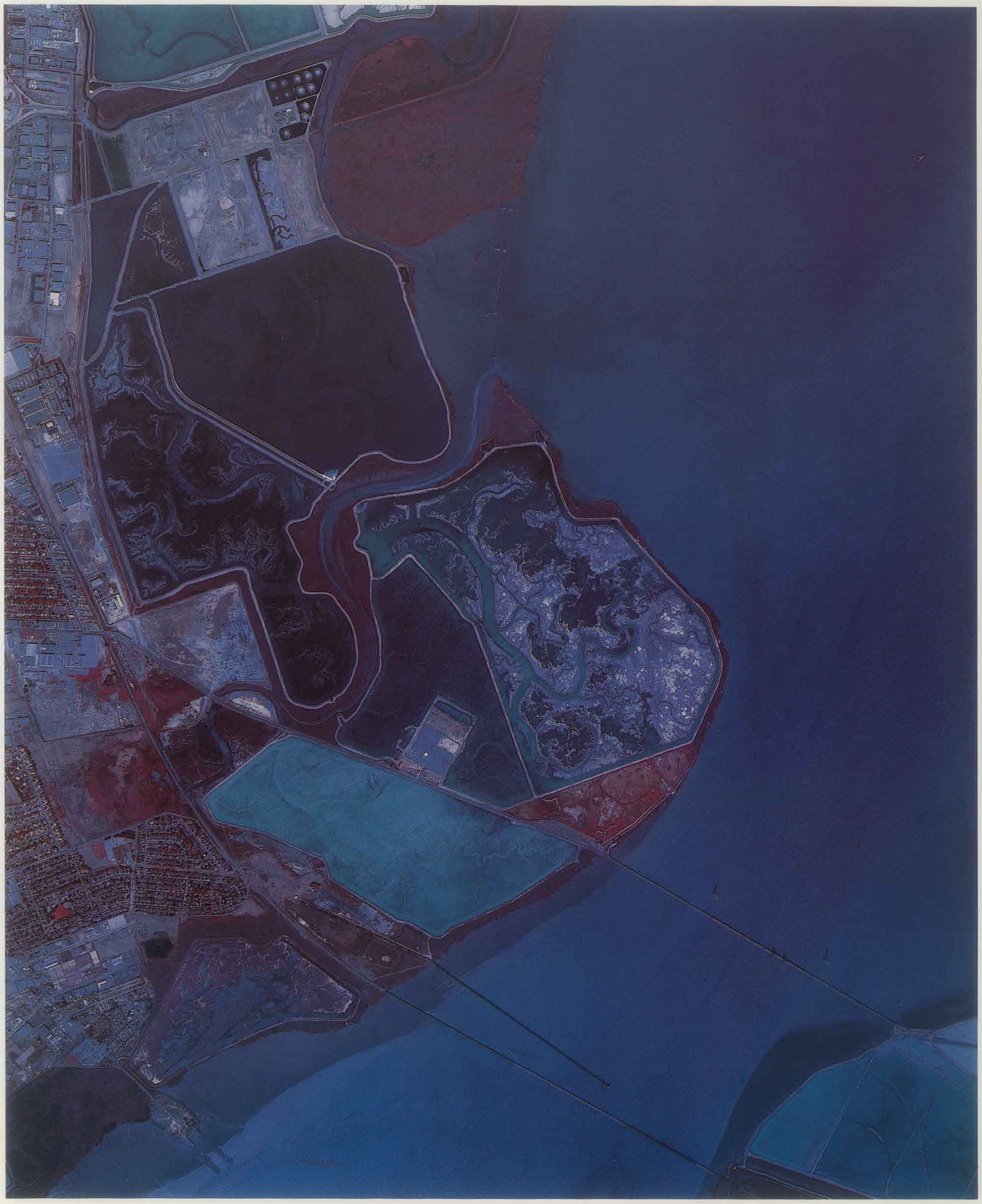
The preceding sections of this volume have each identified problems for the future which rise to significance in relation to the individual topics treated and the expertise of the authors involved. This section will not seek to separate from this multitude of issues those that seem really important in the view of this author; nor will it attempt to prognosticate the future of water development in California. The intent of this section is to identify instead those questions related to water which seem to loom largest for the state as a whole, at least in 1978. The risk of such an undertaking is great. It is doubtful, for example, that any but the most far-sighted water developers in 1880 would have predicted that the problems of urban water supply would have assumed the urgency they obtained by 1900. Similarly, few people in 1950 foresaw the influence that the costs of energy supply have come to exercise over the economics of water delivery in the 1970s. The risk, therefore, is that this piece too may become simply an historical curiosity 20 years from now, of interest principally for the things it left out or the problems it failed to foresee.

On the other hand, many of the great water systems we have built in California and the institutional arrangements we have erected to manage the business of water today were designed, for the most part, to resolve problems that had already been identified in the nineteenth century. Inflation, a greater awareness of environmental considerations, and a host of other factors, however, are changing the rules by which water development proceeded in the past. As a result, many of the problems that concern us most today have simply not been raised before now. The development of water quality protection programs since the 1950s provides the most prominent example of a new range of concerns that have been addressed by later additions to the water supply and delivery systems we have built. The questions for the future of our relationship with the water environment are consequently legion, and only time, hard work, and the involvement of an informed public will tell what answers we will find.

ELEMENTS OF DEMAND

One thing that has not changed is the expectation that our demand for additional water supplies will continue to increase. California's population is projected to increase to a level of approximately 29 million by the year 2000. In addition, the increasing complexity of the social, economic, and technological aspects of our culture can be expected to intensify demands for water use.

Southern California in particular has experienced a phenomenal rate of population and economic growth in the last 50 years, despite the fact that water supplies in this entire area from local streams and groundwater sources are not nearly adequate to support so great a demand for water. These needs were met by massive importations of water, first from the Owens Valley, then from the Colorado River, and today through deliveries from the State Water Project. The United States Supreme Court decree in *Arizona v. California* reduced California's apportionment of Colorado River water by approximately one million acre-feet. This reduction will not take full effect, however, until the completion of the Central Arizona Project by the United States Bureau of Reclamation sometime after



Salt marshes and mudflats off Palo Alto

Irrigation Methods and Crop Acreage, 1972

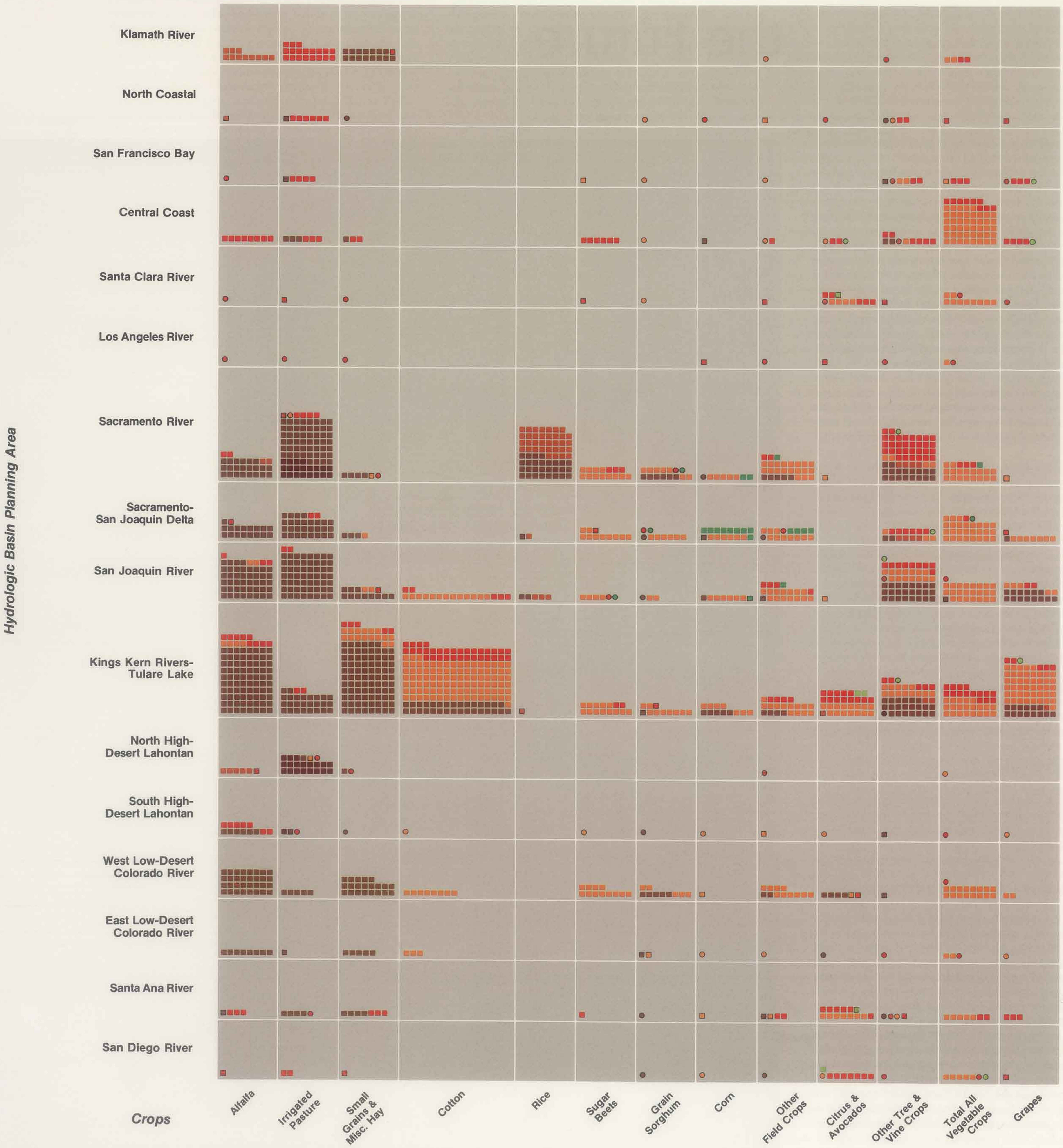
Acreage

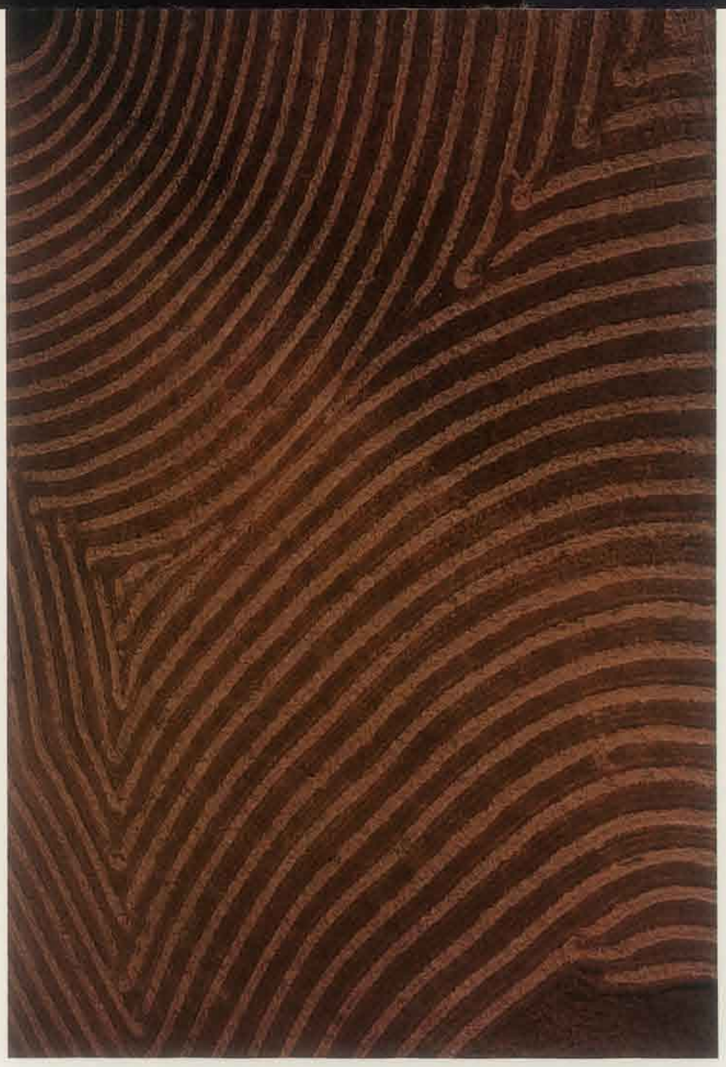
- ■ 5,000 acres employing the same irrigation method
- □ 2,000 - 4,999 acres employing the same irrigation method
- ○ Less than 2,000 acres employing the same irrigation method

In areas where only one symbol is present, the total irrigated acreage is under 5,000, and only the dominant irrigation method has been shown.

Methods of Irrigation

- Surface Irrigation, Wild Flood
- Surface Irrigation, Border
- Surface Irrigation, Basin
- Surface Irrigation, Furrow
- Sprinkler Irrigation, Solid Set, Hand Move, or Mechanical Move
- Drip Irrigation
- Sub Irrigation





The grain fields in the photograph at top are an example of dry farming in the Montezuma Hills. In the lower photograph, irrigation water enters the furrows of a field south of Dixon.

IRRIGATION METHODS

The selection of the various irrigation methods used in different areas in California is determined in large part by the cost, availability, and quality of the water used; drainage, ground slope, and the quality, texture, and depth of the soil; and the type of crop being grown. Border check irrigation, whereby water is directed across a field by parallel earth dikes, is the most prevalent method and has developed in areas where the topography is flat and water is available cheaply and in abundance. Although a less efficient method of irrigation in terms of water use, this type flood irrigation is usually the least expensive method where water is readily available at costs of ten dollars per acre-foot or less. Rice is usually irrigated by contour checks and border check irrigation is used in some parts of California for almost all types of crops including orchards and vineyards.

Furrow irrigation is a variation of flood irrigation in which the water is confined to narrow furrows rather than wide border checks. Furrow irrigation is used for row crops, orchards, and vineyards where the ground slopes less than two percent, the soils are fine textured, and the crops themselves would be drowned if flooded.

Sprinkler irrigation systems are generally used under conditions in which flood or furrow irrigation cannot be applied efficiently, as in areas where the soil is sandy, the ground slopes more than three percent, and water is expensive and available only in limited quantities. Sprinklers are also required, however, to deal with specialized problems such as frost control, leaching, or where crops are being planted on ungraded land. Sprinkler irrigation methods usually require less water and less labor than border check or furrow irrigation, but the initial investment for installation is higher.

Drip irrigation is the most efficient in terms of water use because the system delivers small quantities of water continuously and directly to the root zones of the plants being grown. In some instances, water can be reduced by one-third or more with drip irrigation, lower quality water can be used, and crop yields are increased. The installation and maintenance costs of drip irrigation systems, however, are high and this method is used on orchard, vineyard, and truck crops but not field crops.

1985. Contracts for the delivery of two million acre-feet from the State Water Project will more than make up for this reduction.

Although the most immediate problems of water supply for Southern California and the protection of water quality in the Colorado seem to have been met, numerous questions remain for the years ahead. The State Water Project has contractual commitments to provide water service in the future that exceed its present supply by a considerable margin. Additional development will therefore be needed to firm up these commitments. On the Colorado, although the upper basin states have not as yet used all of their compact rights to the river, accelerated development of the extensive oil shale and coal deposits in this area could create water quality problems all the way down to the mouth of the river unless existing laws are enforced. A question of even greater potential effect is posed by the claims of various Indian tribes to portions of the flow of the Colorado, a concern which applies equally to virtually all the rivers on which California depends.

Even though 85 percent of California's people live in cities, about 85 percent of the state's total water supply is used for agriculture. California has been the nation's leading agricultural state for each of the past 25 years. Today California has more irrigated acreage and produces a wider variety of commercial crops than any other state. Agriculture in California currently pours out a cornucopia of wealth worth some $9 billion a year. When these commodities are processed, stored, transported, and marketed, another $18 to $20 billion is added to California's economy. Irrigated agriculture provides a uniformity of quantity and quality of output and, thus, a degree of economic stability, that cannot be matched by the rain-fed agriculture of the Mid-Western and Eastern United States. Irrigation allows the production of a wider variety of crops with the result that California's agricultural industry can respond more readily to changes in market demands. Irrigation also permits an intensity of land use that surpasses that of any rain-fed producing region.

Agriculture is like water in that both are annually renewable resources so long as they are managed properly. Otherwise, deterioration follows. In recent years, however, hundreds of thousands of acres of prime farm land have been forever lost to the expansion of large and small cities in the south coastal area of Southern California, San Jose, Sacramento, Fresno, Modesto, and Davis. It is currently estimated that 20,000 acres of irrigated land are converted to urban uses every year in California.

The problem is one of significance to consumers throughout the United States, especially to the extent that urban expansion affects those agricultural regions which produce two-thirds or more of the total national supply of a given crop. These crops in which California has virtually a monopoly position in the national market include lettuce, broccoli, garlic, artichokes, Brussels sprouts, grapes, plums, lemons, almonds, walnuts, olives, avocados, apricots, figs, dates, and ladino clover seed. Most of these crops require special climatic and soil conditions, and urban expansion in such areas could consequently reduce production and increase costs for the consumer. In addition, with millions of people living in concentrated areas, air quality in some of the agricultural regions located adjacent to large urban centers has deteriorated to the point that the productivity and quality of some crops have been reduced. If this situation continues to worsen in the future, the market may be forced to accept the substitution of crops which are more tolerant of air pollution. State policy is lacking, however, with respect to these specialized crop situations and future action on these questions or the lack thereof will affect all consumers of these commodities throughout the country.

A second threat to agricultural productivity, which is also growing worse each year, is posed by the deterioration of soil quality due to waterlogging and soil salinity. The continued application of fertilizers and irrigation water, which usually contains some mineral salts, results in a buildup of salts in the soil and an accumulation of saline groundwater near the soil surface. These conditions reduce the quantity and quality of crop production. The remedy is drainage, whereby the salts can be leached out and carried away and the water table lowered. Irrigated croplands that slope usually drain adequately, but lands located in flat areas, especially lands lying in the trough or lowest parts of a valley, may have little or no natural drainage. These areas will eventually go out of production if drainage is not provided.

The state's most endangered area in this regard is the San Joaquin Valley, where upwards of 400,000 acres could be lost by the end of this century. Salts and salty water threaten the productivity of the soils, endanger the valley's groundwater basins, and degrade surface water supplies in the San Joaquin River. At the level of development predicted to occur by 1990, about three million tons of new salts will be added to the valley floor each year, mostly on irrigated lands. Approximately 1.1 million acres, or nearly 25 percent of the irrigated land in the valley, possess the potential of developing saline drainage problems.

Although a master drain has been proposed to carry salts out of the valley through a canal extending along the length of the valley trough from a point west of Bakersfield to a final point of discharge in the tidal waters contiguous to San Francisco Bay, the financial and institutional obstacles to development of this project have thus far proven insurmountable. To avoid degrading usable water supplies with saline water or adversely affecting fish and wildlife resources, the point of discharge for such a drain would have to be carefully chosen. Although the ocean, with its vast assimilative capacity to absorb poor quality water, seems the most logical physical solution, the cost of transporting saline waters from inland valleys directly to the ocean is enormous. Short of that, any other receiving waters such as the Delta, would probably be adversely affected unless the draining waters were treated first to a quality equal to that of the water already in the Delta. Thus, while the implementation of a valley-wide salt management system with the master drain as its central feature has been delayed by financial, institutional, and political problems, the need for drainage continues to increase.

GROUNDWATER MANAGEMENT

The future productivity of the San Joaquin Valley is further threatened by the problem of overdraft of its groundwater supply, which could eventually remove large amounts of the valley's land from crop production if some kind of rescue action is not taken. Although there are numerous instances of groundwater overdraft occurring throughout the state, the situation is most serious in the San Joaquin Valley, where the extent of overdraft has reached 1.5 million acre-feet in years of normal precipitation.

The problems of groundwater management are complicated by a lack of clarity in the legal principles governing groundwater extractions and the competition among pumpers. Questions about groundwater apply both to the nature of the groundwater right and to the possible limitations upon this right which might be imposed in order to develop effective management of the total groundwater resource. The decision of the California Supreme Court in 1975 in *City of Los Angeles v. City of San Fernando* largely destroyed the utility of the "mutual prescription" doctrine under which the rights of groundwater pumpers in overdrafted groundwater basins had been decided on the basis of historical usage by the pumpers. In principle it remains possible to return to concepts developed by the court at the beginning of the twentieth century, according to which pumpers overlying a groundwater basin and using water on land they owned would have the first preference and others would be treated as appropriators of groundwater bound by the principle of "first in time, first in right."

These concepts are easy to state, but in basins with heavy groundwater pumping at a wide range of locations and for a diversity of purposes, these concepts may be difficult if not impossible to apply in practice. Another approach, suggested indirectly by the court's opinion in the San Fernando case, is to allocate groundwater pumping rights on the basis of the doctrine of "equitable apportionment." This doctrine, frequently used by the United States Supreme Court in resolving conflicts between states, provides a flexible means for courts to take into account a broad range of factors in order to reach a just result in particular controversies.

Whatever doctrine is used to allocate groundwater pumping rights after the San Fernando decision, it remains clear that the judiciary could premise any adjudication of groundwater rights upon the notion of "safe yield." In overdrafted basins the aggregate of pumping would have to be reduced in order to return that basin to some balance between extractions and average annual replenishment. It also appears to be clear that under the established precedents, such cutbacks would not entitle present or potential pumpers to compensation for their losses.

Safe yield adjudication provides one means for achieving effective groundwater management. In several Southern California adjudications of this type, the parties engaged in elaborate negotiations to reach settlements based upon stipulated judgments. These judgments establish relatively sophisticated management programs for the particular groundwater basins in question. These programs, however, have been made possible by the fact that the basins involved are relatively isolated, and in every instance supplemental surface waters have been available to replace waters no longer available from under the ground. The focus of these negotiations consequently has been upon means for paying for the more expensive supplemental surface water, not upon deciding who should receive less water.

In considering means for bringing effective groundwater management to other areas of California, adjudication may be of limited utility. Particularly with regard to the badly overdrafted areas in the southern half of the San Joaquin Valley, it has been recognized that the basins are related to each other, that supplemental surface water is not readily available, and that the number of groundwater pumpers may make groundwater rights adjudication entirely impractical. An important question in this context is whether proposed projects for importing water to the San Joaquin Valley can be made to correct such overdrafts before bringing new lands under irrigation. If, on the other hand, the cost of providing new water supplies continues to increase at its current rate, agriculture by the end of the century may be unable economically to compete for these additional supplies, and even some urban areas may find them too expensive, with the result that a portion of agriculture's existing supplies could be transferred to urban uses.

A report by the Governor's Commission to Review California Water Rights Law in 1978 recommended that emphasis be placed upon development of nonadjudicatory means for the effective management of the groundwater resource through the development of a statewide groundwater policy. The commission recommended a process by which local governments would develop groundwater management programs within the context of state groundwater policy. The commission suggested that such a process would be useful in protecting the local and statewide interests in proper groundwater management, both in deficit basins plagued by problems of overdraft, water quality degradation and subsidence, and in nondeficit basins where groundwater surpluses may exist and may serve to meet deficits elsewhere in the state.

THE DELTA

The Sacramento-San Joaquin Delta lies at the center of almost all discussions of California's future water supply. What is so important about it? Why should 700,000 acres—less than one percent of the total area of California—have such a major influence on our future?

The Delta lies in that area where the Sacramento and San Joaquin rivers meet to discharge over 40 percent of the state's natural runoff into the eastern part of San Francisco Bay. As a result, whatever affects the Delta in one way or another tends to influence much of our total water resource. And the reverse is also true, for whatever affects water elsewhere in the state sooner or later is felt in the Delta. This was never more apparent than in 1977 when California was short on water and long on perplexing water issues. Probably one of the biggest stumbling blocks to resolution of the tangle of Delta problems is the enormous complexity of the issues involved and the manner in which each ties in tightly with another. This is the case whether it is a matter of preserving the fishery, maintaining a usable supply of water for Delta farms and industries, or making certain that enough good quality water is available to meet delivery commitments to contracting water agencies elsewhere in California. Solving one problem depends on solving some others. And there is a multiplicity of interests and overlapping jurisdictions—federal, state, county, regional, local, and private—which have a stake in the well-being of the Delta.

The Delta has had problems ever since the 1860s, when Delta farmers began to suffer from the vast amounts of debris that were being swept down the rivers from the upstream hydraulic mining sites. Once a vast marshland, much of the Delta today has been reclaimed for rich agricultural lands, producing crops worth over $300 million a year. This land, some of it as much as 20 feet below sea level, consists of almost 60 islands protected by aging levees from over 700 miles of meandering waterways. When the flow of fresh water through the Delta is substantially decreased by upstream diversions or by natural conditions, it is replaced by salt water from San Francisco Bay. This saline intrusion adversely affects the farmers and other Delta industries which take their water directly from the waterways.

Saline intrusion in the Delta does not only affect human enterprise, for in addition to agriculture, the Delta provides a major habitat for many kinds of wildlife. The Suisun Marsh, located in the western part of the Delta and the largest area not under agricultural production, is the winter home for millions of waterfowl of the Pacific Flyway. Because of upstream water diversions, the diking of natural waterways, the uncertainties of nature during periods of low Delta outflow, and poor management techniques, the marsh during some years has become dependent on releases of water from upstream storage to sustain the plants on which the wildfowl feed. In addition, over half of California's anadromous fish, such as striped bass and salmon which live in the ocean but travel to fresh water to spawn, are dependent on the waters of the Delta. They need positive downstream water flows and a salinity gradient where they can make a gradual change from salt water to fresh water and back in order to migrate successfully. And, because of the abundant fish and wildlife, and the scenic lands and waterways, the Delta is an important recreation area for hunters, fishermen, bird watchers, and boaters from throughout the state.

Approximately 20 major storage projects, each with a capacity of 200,000 acre-feet or more, have been constructed in the Central Valley for supplying local uses and for export to the San Francisco Bay region, the San Joaquin Valley, and Southern California. Each of these projects affects the quantity and quality of inflows to the Delta. Both the State Water Project and the Central Valley Project pump water through the Delta for export. In addition to upstream and local Delta uses, one-fourth of the land area and two-thirds of the population of the state are served (at least partially) by water exported from the Delta. Under the presently authorized contracts of these two agencies, the amount of water exported will increase substantially during the balance of this century.

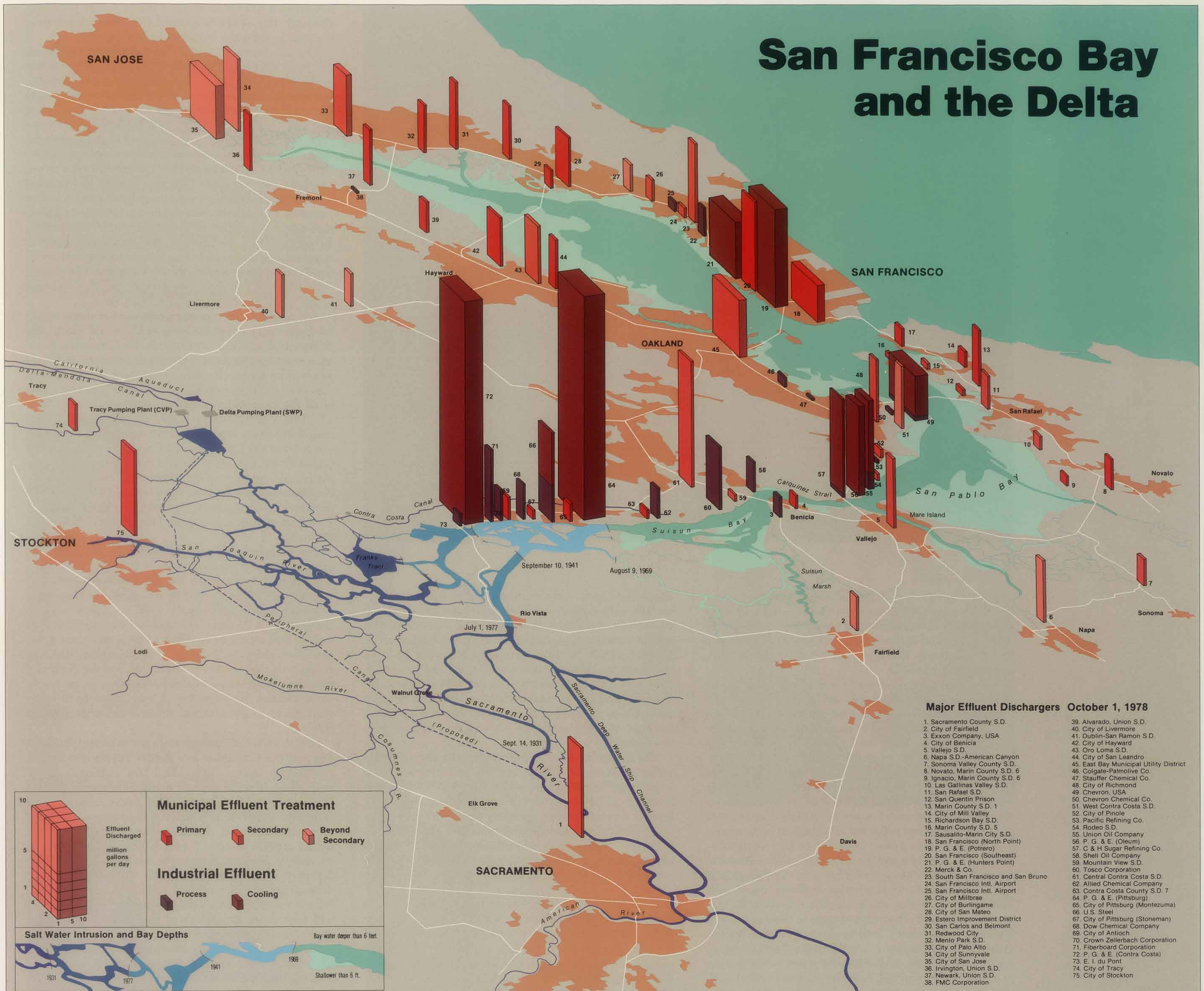
While some of these projects provide valuable flood control for the Delta and the release of stored water during the dry summer months improves water quality and the general environment of the Delta, the lessening of naturally high winter and spring flows through capture and storage and the pumping of water through the natural waterways of the Delta cause damage to the environment. As exports increase, these problems will become more severe.

Pumping water from the Delta has resulted in numerous conflicts among the water agencies involved. The Bureau of Reclamation, for example, has not conformed with water quality standards adopted by the state and the United States Environmental Protection Agency, although the 1978 decision by the United States Supreme Court concerning the operation of the New Melones Dam may result in some modification of the Bureau's policies. In addition, although the State Water Project and Central Valley Project have the right to pump water from the Delta, the operators of these systems have failed to establish a permanent operating agreement which specifies their respective responsibilities in meeting both Delta needs and project needs. Moreover, there are no contracts between the major Delta water agencies, the state Department of Water Resources, and the federal government concerning water supply and quality. The present yield of both projects, moreover, is insufficient to cover existing export water supply contracts while still meeting Delta quality and quantity needs.

In sum, all of these human activities have combined with nature's functions to produce severe problems of supply for both local and distant water users, and problems of quality which will affect fish and wildlife because of the reduced flows available to flush out the Delta and San Francisco Bay and resist the ebb and flow of the ocean tides. The welter of issues surrounding the Delta involve questions of efficiency, monetary gains

The rich agricultural productivity of the Delta farmlands, indicated in the photograph at right by red colors, contrasts dramatically with the unirrigated land on the opposite bank of the Sacramento River. Rio Vista can be seen in the upper right quarter of the photograph and the San Joaquin River enters from the lower right corner.

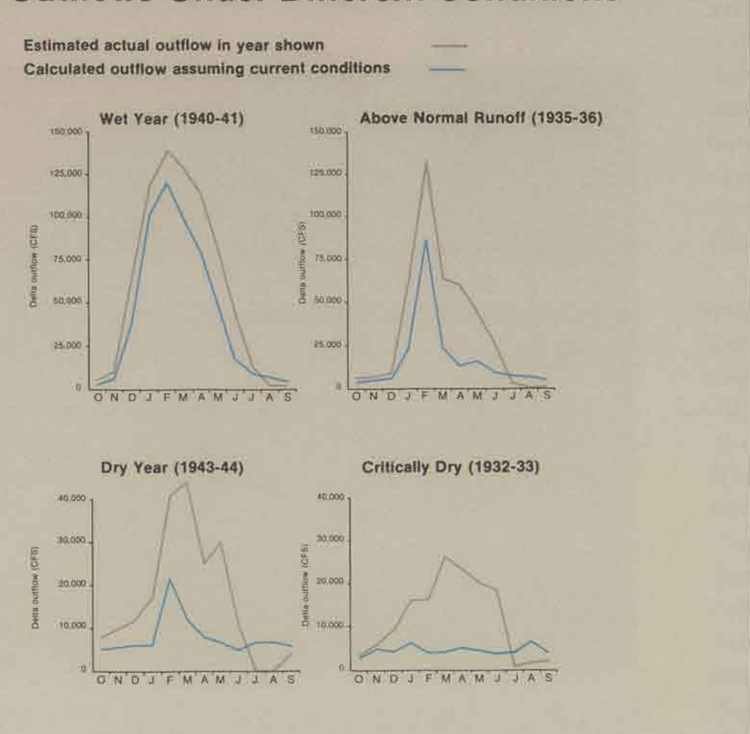
San Francisco Bay and the Delta



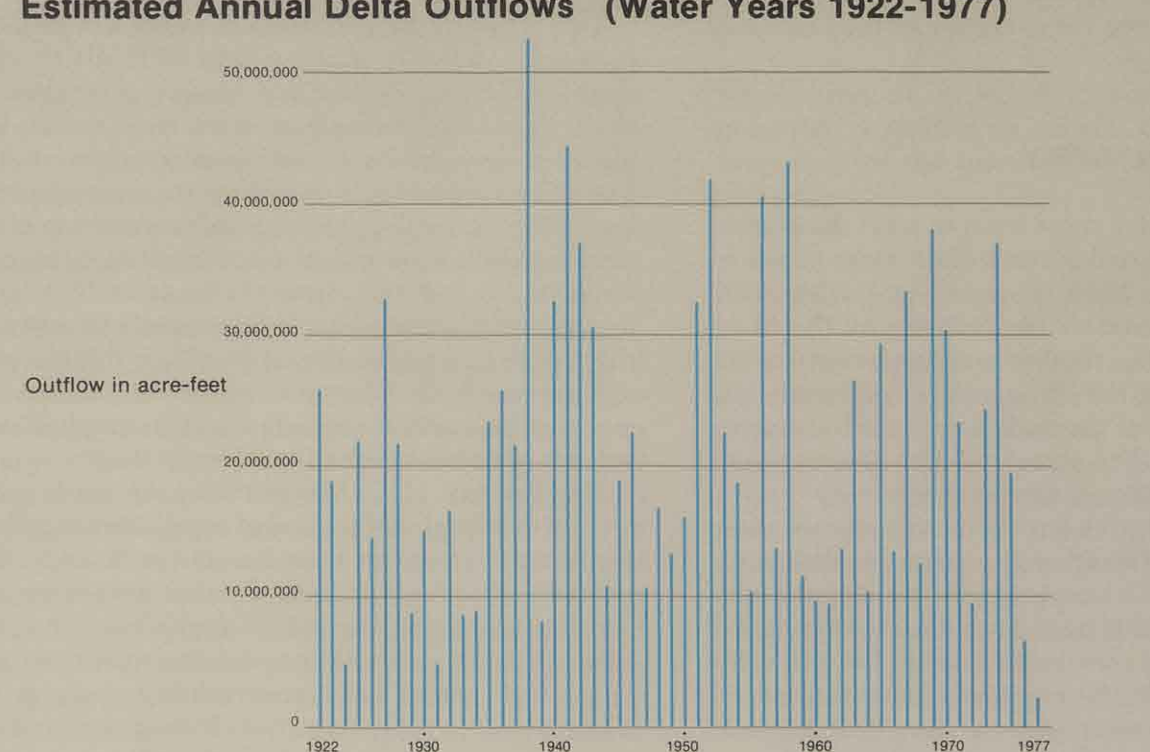
Major Effluent Dischargers October 1, 1978

1. Sacramento County S.D.
2. City of Fairfield
3. Exxon Company, USA
4. City of Benicia
5. Vallejo S.D.
6. Napa S.D.-American Canyon
7. Sonoma Valley County S.D.
8. Novato, Marin County S.D. 6
9. Ignacio, Marin County S.D. 6
10. Las Gallinas Valley S.D.
11. San Rafael S.D.
12. San Quentin Prison
13. Marin County S.D. 1
14. City of Mill Valley
15. Richardson Bay S.D.
16. Marin County S.D. 5
17. Sausalito-Marin City S.D.
18. San Francisco (North Point)
19. P. G. & E. (Potrero)
20. San Francisco (Southeast)
21. P. G. & E. (Hunters Point)
22. Merck & Co.
23. South San Francisco and San Bruno
24. San Francisco Intl. Airport
25. San Francisco Intl. Airport
26. City of Millbrae
27. City of Burlingame
28. City of San Mateo
29. Estero Improvement District
30. San Carlos and Belmont
31. Redwood City
32. Menlo Park S.D.
33. City of Palo Alto
34. City of Sunnyvale
35. City of San Jose
36. Irvington, Union S.D.
37. Newark, Union S.D.
38. FMC Corporation
39. Alvarado, Union S.D.
40. City of Livermore
41. Dublin-San Ramon S.D.
42. City of Hayward
43. Oro Loma S.D.
44. City of San Leandro
45. East Bay Municipal Utility District
46. Colgate-Palmolive Co.
47. Stauffer Chemical Co.
48. City of Richmond
49. Chevron, USA
50. Chevron Chemical Co.
51. West Contra Costa S.D.
52. City of Pinole
53. Pacific Refining Co.
54. Rodeo S.D.
55. Union Oil Company
56. P. G. & E. (Oleum)
57. C & H Sugar Refining Co.
58. Shell Oil Company
59. Mountain View S.D.
60. Tosco Corporation
61. Central Contra Costa S.D.
62. Allied Chemical Company
63. Contra Costa County S.D. 7
64. P. G. & E. (Pittsburg)
65. City of Pittsburg (Montezuma)
66. U.S. Steel
67. City of Pittsburg (Stoneman)
68. Dow Chemical Company
69. City of Antioch
70. Crown Zellerbach Corporation
71. Fiberboard Corporation
72. P. G. & E. (Contra Costa)
73. E. I. du Pont
74. City of Tracy
75. City of Stockton

Delta Outflows Under Different Conditions



Estimated Annual Delta Outflows (Water Years 1922-1977)



Water quality in San Francisco Bay and the Delta is the product of a complex and only incompletely understood interaction of natural and human influences. The columns on this map identify the major sources of man-made wastes that are introduced into the waters of this dynamic system, either as industrial effluents in the form of processing or cooling water, or as municipal sewage which is characterized by various levels of treatment as defined by the Environmental Protection Agency.

Salinity levels in the Delta are determined by the interaction of tides, freshwater inflows, and agricultural return flows. The histogram of estimated annual Delta outflows reveals wide variations in historic freshwater flows. These flow variations are linked to expanding and contracting areas of salinity intrusion in the Delta, as shown by the lines marking the maximum intrusion of water containing 1,000 parts per million of chloride. Differences between the limits of salinity intrusion during the dry years of 1931 and 1977, and between the wet years of 1941 and 1969 are primarily the result of water management programs upstream. The four graphs at left show monthly Delta outflows under various conditions and the outflows that would have occurred in these years if current levels of water export and development had existed.

Tidal action plays a central role in the dynamics of San Francisco Bay and the Delta. Tidal features and the variations in water depth are given special prominence in this view of the southern end of the bay at low tide.

and losses, equity, and the environment. And, the problems grow more acute with each passing year, as the amounts of water pumped out of the Delta increase while urban and agricultural development continues to expand upstream, thereby further reducing the quantities of water available.

Numerous solutions have been proffered: a peripheral canal, first formally proposed in the mid-1960s to convey water for export across the Delta more efficiently; the construction of more water projects upstream to add water to the Delta; increased use of the groundwater resources of the Central Valley conjunctively with surface water supplies; and, higher water prices for some water agencies which use water originating in the Central Valley in order to bring about the more efficient use of water. In 1977 the Department of Water Resources proposed an amalgam of programs and multi-billion dollar facilities to be jointly constructed by the state and the federal government which, among other things, would include the Peripheral Canal, Suisun Marsh protection facilities, on-stream and off-stream storage in the Sacramento Valley, groundwater and off-stream storage in the San Joaquin Valley, a Mid-Valley Canal in the San Joaquin Valley, groundwater storage in Southern California, wastewater reclamation, and enhanced water conservation practices. Each proposal, however, seems to meet with vigorous opposition from one or another of the many interests involved. As a result, that compromise which is essential for resolving the problems of the Delta has yet to be found.

CONSTRAINTS ON SUPPLY

Where will the water come from to meet the domestic needs of an estimated seven million more people in California by the year 2000, protect water quality in the Delta, fulfill the contracts for delivery by the State Water Project and the implied commitments for increased service from the Central Valley Project, and mitigate the effects of groundwater overdraft in the San Joaquin Valley? The answer to this question does not lie simply in additional development.

The last ten years have seen the introduction of some very sobering constraints upon project development, the full effects of which have probably not yet been fully realized. Inflation in this period has doubled the capital costs of water project construction, while interest rates have increased by about one-third. Thus, the annual financing costs of a major water project over a typical 30-year repayment period have increased by nearly two and one-half times. In addition, federal and state environmental laws and the requirement for more seismically safe structures have increased construction costs while at the same time restricting the areas within which construction might occur. Considering all of these factors, overall costs are estimated to have increased nearly three times within the last ten years. And even this comparison does not take into account the fact that the annual yield of water that is made available per acre-foot of project storage is declining because the best storage sites have already been developed.

The increased costs of project construction affect all water agencies, of course, but the problems are most acute for federal agencies, which have had the longtime habit or political custom of annually appropriating limited sums of money to many projects. When inflation was minimal and interest rates low, this "shotgun approach" perhaps was tolerable. In view of the serious capital funding problems that exist today, however, this tradition is causing havoc to both financing and repayment.

If a project is to be built, it would seem the only way to combat the insidious effects of inflation is either to scale down the size of the project or to obtain a lump sum of money necessary to complete the project as soon as possible rather than depending upon uncertain, sequential appropriations. This so-called lump sum method of financing is commonly used by the state and by local agencies for their construction projects.

The panoply of constraints upon development, however, make it increasingly difficult to obtain approval for any kind of new project, no matter what the method of financing may be. As a result, water planners now and in the future must confront at least five principal questions regarding any new project they may propose. Is the project feasible in terms of engineering? Is it economically justified? Is it financially feasible? Is it environmentally sound? And, is it institutionally operable? If the answer to any one of these tests is negative, then it is unlikely that the project will ever be built. Moreover, these tests become even more critical when imported water supplies are involved, whether interbasin or interstate.

The history of California's water development reveals that local surface and groundwater supplies are developed first and, as these become inadequate, then a widening parameter of source possibilities is explored. Statutes protecting the areas in which water supplies originate from exploitation and the rigidity of water rights laws retard the transferability of water from lower to higher beneficial uses of water. As a result, entities have had to reach out farther for new supplies even though cheaper sources may be nearer by. These conditions have encouraged many water planners through the years to extend their search for new supplies beyond the borders of California.

The development of the Colorado River represents the most successful interstate project California has undertaken. California is, however, involved in another interstate compact. The California-Nevada Interstate Compact of 1968 allocates the waters of Lake Tahoe and the Truckee, Carson, and Walker river basins between the two states. In contrast to the Colorado, California in this case is in the position of being an upper basin state. Unfortunately, the compact has not as yet received the necessary ratification by the federal government, but the two states have continued to honor its terms in the meanwhile. Difficulties lie ahead, especially with respect to the limited water supply in the Truckee River, because of the absence of federal approval, the claims of Indian tribes to a larger share of the Truckee River waters, the lowering level of Pyramid Lake which is the river's terminous, and the vigorous urban growth occurring in the Reno area.

Although plans have been proposed to draw water for California from as far away as Idaho and Alaska, the prospects for importation from the Columbia River have received the most widespread attention in recent years. The Columbia has more than ten times the runoff of the Colorado River and more than twice that of all the streams in California combined. In the 1950s and 1960s some federal water planners and several consulting firms began feasibility studies of importing water from the Columbia or its principal tributary, the Snake River, to California and the Southwest. These plans ran into opposition, however, from the Pacific Northwest states, and the Congress in 1968 declared a moratorium on any such planning by a federal agency. This moratorium was extended for another ten years in 1978.

The prospects for importations from the Columbia are consequently quiescent for the time being, although the day may come when the situation of supply and demand in California will be so acute that this huge, external source of supply will be given serious consideration. Given the enormous quantities of energy that would be required to lift water some 4,500 feet into California, the environmental and institutional constraints that need to be overcome, and the likelihood that the resulting cost of Columbia River water would be prohibitive for irrigation, it may prove to be more economical to go without, or to seek other sources closer by.

For its part, California's state government does not suggest the Columbia as a future supply possibility, contending instead that there are sufficient water resources within the state, if managed properly, to meet the needs of California. The great collection of programs and projects which the state proposed in 1977 in connection with the controversy over the Delta would provide about 2.7 million acre-feet of water to meet designated needs up to the end of the century. The diversity of interests competing for water and the dependence of this proposal upon extensive state and federal financial participation, however, suggest that it will take years to implement this plan or something approximately equivalent to it.

Increased storage might also be achieved by enlarging the Shasta and Monticello dams as well as expanding existing canal capacities. The New Don Pedro and New Melones dams are both the result of efforts to enlarge

The importation of water from the Columbia River would require the construction of pumping plants on an even greater scale than this facility of the State Water Project.

PIPE DREAMS

The approval of the State Water Project by California's voters in 1960 and the United States Supreme Court's decision in 1963 restricting California's access to the Colorado River inspired a flurry of plans and proposals in the mid-1960s for even larger and more technologically sophisticated waterworks to serve California and the American Southwest. All of the plans described here achieved a measure of notoriety among water planners, engineers, and some governmental agencies in this period. But this list of proposed projects is far from complete and none has actually been approved for construction.

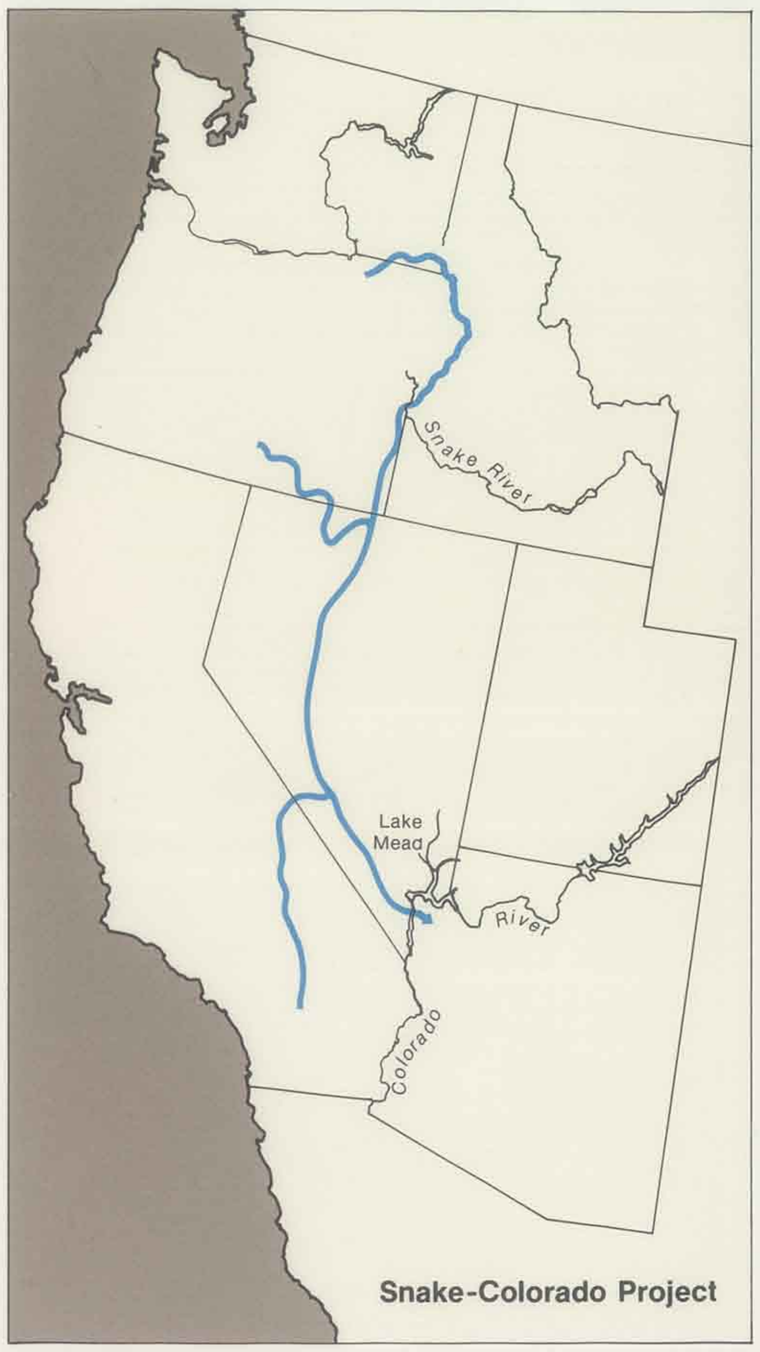
Within three months of the Supreme Court's decision in *Arizona v. California*, Secretary of the Interior Stewart Udall proposed a panoply of water conservation and development projects in the Pacific Southwest Water Plan which would have substantially rearranged the water supplies of California, Arizona, Nevada, Utah, and New Mexico. Within California the plan, among other things, called for damming the Trinity, Eel, Mad, and Van Duzen rivers on the North Coast and diverting a portion of their flows to Arizona. The Los Angeles Department of Water and Power responded to Udall's proposal by recommending consideration of a plan proposed by a private engineer, William G. Dunn, to bypass the North Coast and transfer instead 2.4 million acre-feet from the Snake River in Idaho to supplement the flows of the lower Colorado.

In contrast to the estimated $2.4 billion cost of the Pacific Southwest Water Plan, Dunn's proposal carried an estimated price tag of $1.4 billion. Another consulting engineer in Los Angeles pointed out in 1964, however, that for another $1.2 billion, the plan could be expanded to tap the Yellowstone River in Montana, thereby increasing the yield of the project to 3.4 million acre-feet. In 1965, Dunn did modify his original plan, but he eschewed the Yellowstone, determining instead to bring five million acre-feet from the Snake south through eastern Oregon at a cost then estimated at $3.2 billion.

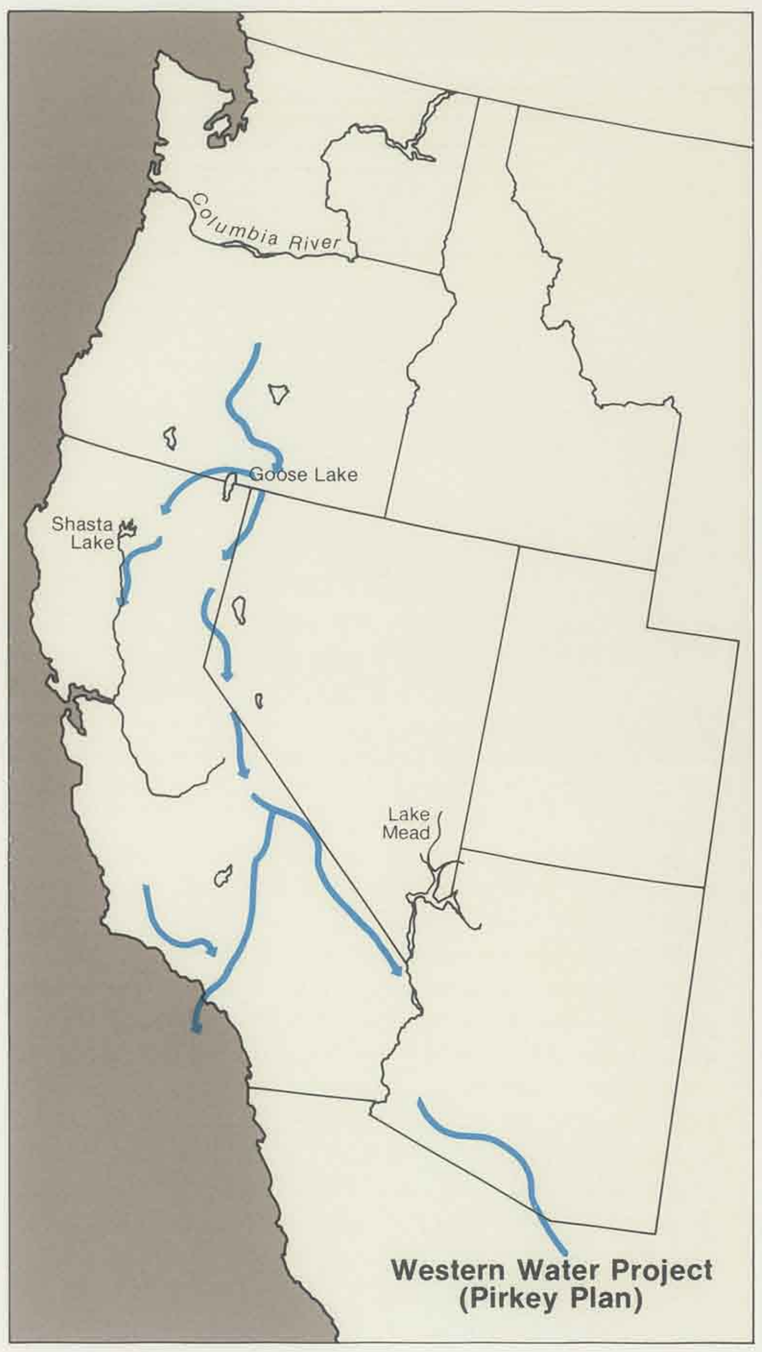
Other water planners meanwhile turned their eyes toward the Columbia River. In 1964, Frank Z. Pirkey, a private consulting engineer retired from the Army Corps of Engineers and the Department of Water Resources, proposed pumping 15 million acre-feet of water from the Columbia 4,900 feet over the mountains to Goose and Shasta lakes, whence it would flow south to Lake Mead. Pirkey estimated his project would cost $11 billion, but other engineers offered somewhat less expensive alternatives that would have bypassed Goose and Shasta lakes, relying instead upon a system of new reservoirs.

As expensive as tapping the Columbia for California may be, a Pasadena engineering firm in 1965 proposed a novel method for achieving interbasin transfers within California through a pipeline under the ocean which the Bureau of Reclamation estimated would cost $20 billion. The so-called NESCO Plan called for anchoring a fiberglass pipe along California's continental shelf to carry four million acre-feet of water from the rivers of the North Coast to serve the municipal and industrial water needs of Monterey, Santa Maria, and the South Coast.

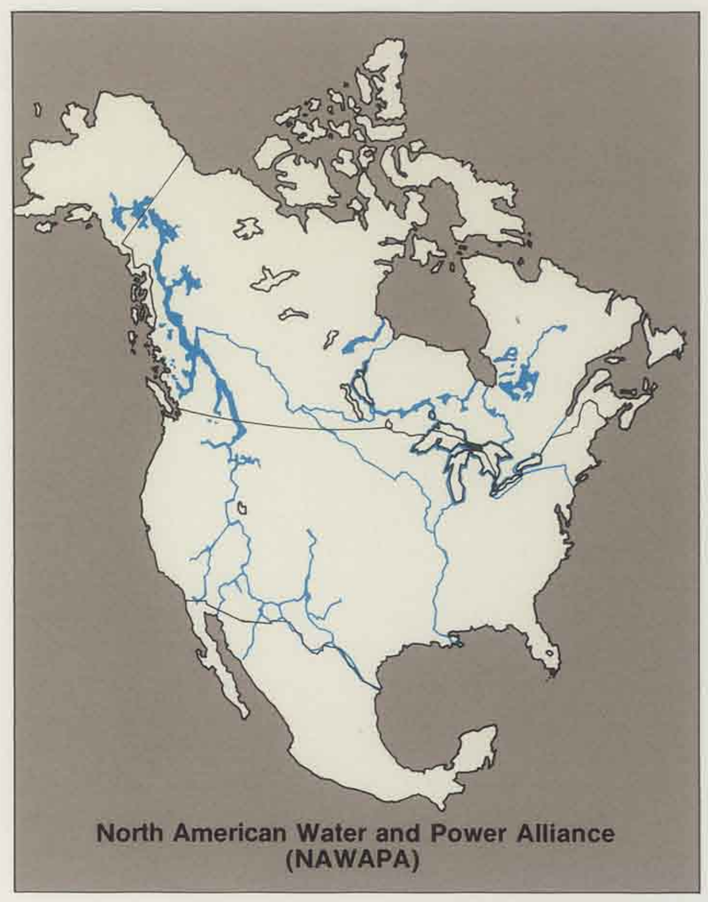
The most elaborate project of all also originated in Pasadena with the Ralph M. Parsons Company in 1964. This plan, the North American Water and Power Alliance, proposed tapping the rivers of the Yukon to augment water supplies in Canada, Mexico, and the United States from the Great Lakes to California. Although several, less expensive modifications to the Parsons plan have since been suggested by other engineers, the proponents of NAWAPA estimated that this massive system, drawing from watersheds with a total area nine times the size of California, would cost an estimated $200 billion and require over 30 years to construct.



Snake-Colorado Project



Western Water Project (Pirkey Plan)


North American Water and Power Alliance (NAWAPA)

existing dam and reservoir projects. This approach has the advantage that the incremental costs of added storage normally would be less than the cost of an alternative supply, while the environmental impacts and social dislocation effects are also reduced. In addition, a number of projects are currently being implemented for the storage of water in groundwater basins during wet years and the conjunctive use of groundwater and surface supplies in times of need. Difficult financial and institutional problems and political resistance, however, have so far precluded widespread adoption of such programs in the largest groundwater basins, which are in the Sacramento and San Joaquin valleys.

State planning and policy for the future are currently focused on the Sacramento Valley where it is possible to develop more supplies more economically by means of both on-stream and off-stream storage and through the use of groundwater basins. Nevertheless, as economic and therefore political pressures increase for additional water supplies in the Sacramento and San Joaquin valleys and in Southern California, there is expected to be increasing pressure to release at least a portion of the large undeveloped water supplies of the verdant North Coast for export. Here lie the state's last great untamed and free-flowing rivers, the Smith, Klamath, Van Dusen, and Eel, containing 21 million acre-feet of water or about one-third of the state's total supply.

Since 1972 these rivers have been under the protection of California's Wild and Scenic Rivers Act. Some North Coast waters are already exported out of the region. The Trinity River, which flows into the Klamath, has had large quantities of water diverted to the upper Sacramento Valley for the Central Valley Project since the early 1960s. And a utility has been diverting water from a branch of the upper Eel River to the Russian River for the last 50 years. The federal government is not precluded from constructing facilities in the North Coast, although the Wild and Scenic Rivers Act does prohibit state agencies from lending any assistance to such an effort. The statute does, however, provide for state reports after 1984 as to the need for flood control and water conservation facilities on the Eel River and the appearance of these reports can be expected to encourage demands by potential recipients of North Coast exports for a reopening of the question of wild and scenic rivers protection.

PROBLEMS OF MANAGEMENT

As the opportunities for new, large-scale water development projects have diminished, greater attention has been directed to problems of water management. These involve, in turn, questions of equity, economics, efficiency, administrative practice, and the prospects for new legal and technological innovations which will help California conserve the water supplies it already has.

Cities and water districts individually and collectively, and the state and federal governments have constructed an amazing grid of water storage and distribution systems that convey water through mountains and across and down valleys from one water basin to another. Probably there is no other area in the

Although the law currently permits almost any reasonable use of water, choices may have to be made among competing uses if the demand for a limited water supply continues to intensify in the future. This prospect has assumed particular currency in the case of Mono Lake, shown at top right, where diversions to the City of Los Angeles have substantially lowered the lake level in recent years. Should the needs of an urban populace supercede the use of water to preserve a remote saline lake or support desert vegetation like that of the Antelope Valley shown at the lower left? Some water planners are already suggesting that the constitutional mandate to apply water to beneficial purposes may invalidate state statutes designed to protect the environment as well as the local water supplies of areas such as the North Coast shown at bottom.

world where such intensive and extensive water development has occurred. This grid of water distribution systems became even more useful during the unprecedented drought of 1976-77 when numerous arrangements were made between local, state, and federal water agencies to exchange water or aid areas facing critical shortages. These major engineering accomplishments can thus be compared to a huge insurance policy which is capable of providing protection to the people and their activities from nearly all vicissitudes of the weather or even natural disaster.

Inasmuch as the best water development sites have been developed and water agencies have had to reach out ever farther for additional water supplies, the magnitude of the legal and financial problems associated with large projects has increased so as to preclude nearly all but the largest agencies from water development planning. As a consequence, most of the proposed projects today are being planned by the state Department of Water Resources, the Army Corps of Engineers, and the federal Bureau of Reclamation. In view of the fact, however, that there are more than a thousand districts and municipalities and numerous state and federal agencies engaged in various aspects of California's water business, many arenas for conflict exist between consumptive users of water, between consumptive and nonconsumptive uses, and between different levels of government. Recognizing this multiplicity of diverse interests, the state for at least the past quarter century has been emphasizing that it is the only agency vested with a statewide interest and responsibility and that it, therefore, is in the best position to know where, when, and how water development should occur.

The federal water agencies, though influenced by state policy and actions, do not necessarily believe themselves to be bound by such direction. As a result, opportunities for the development of comprehensive water management strategies have all too often been frustrated by a controversy between state and federal agencies that has existed for the past 25 years and that may even intensify in the future.

This continuing rivalry between state and federal authority reached its most recent peak in the controversy over efforts by the State Water Resources Control Board to impose restraints upon the operation of the New Melones Dam by the Bureau of Reclamation. Although the United States Supreme Court ruled in favor of the state on this question in 1978, indicating that the state may impose conditions so long as they are not contrary to a clear Congressional directive, it remained unsettled which, if any, of the particular conditions the board has imposed are contrary to a clear Congressional directive. Similar questions exist for the conditions contained in other permits issued to the Bureau of Reclamation.

Another broad front of continuing controversy over water management involves the pricing practices of the Bureau's Central Valley Project. The price of water plays an important role in water usage. As a general rule, when water is cheap, there is little or minimal incentive to conserve. Low-priced water in California usually occurs where there is pumping from groundwater, riparian and appropriative rights to streamflows, or subsidized prices. In such situations, crops with high water needs are grown, such as rice, alfalfa, and pasture. These, together with other crops grown for livestock use, such as corn, milo, and grain, account for 40 to 45 percent of the state's total irrigated acreage. These crops, however, generally do not have a high enough value to pay the cost of the water they require. Inasmuch as the outlook is for a tightening of water supplies in relation to increasing demand, questions are beginning to be raised as to whether applying nearly half of the water used by agriculture to crops consumed by livestock truly enhances the commonweal.

In California, the biggest subsidizer of irrigation water is the federal government, principally the Bureau of Reclamation. The Central Valley Project currently has contracts to deliver approximately 3.5 million acre-feet of irrigation water at prices which are several hundred percent below costs. The resulting subsidies amount to more than $1,100 per acre. This federal policy no doubt had merit during the first half of this century as a means of speeding up settlement of the arid West. Many believe this policy has today become anachronistic and have called for more rigorous pricing policies to put at least some of this highly subsidized water to higher beneficial uses, especially where the cost of developing new supplies exceeds $100 an acre-foot. In response, the Bureau is moving in the direction of adopting somewhat more rigorous repayment policies, although these will not become fully effective until the 1990s.

Water rights laws also play an important role in water conservation, often adversely, by protecting the longtime uses of water regardless of changing priorities and needs. The role of the law in bringing increased efficiency, however, remains uncertain. Of central importance is the provision in the California Constitution which limits all water rights to "reasonable beneficial use." While this provision serves to direct all water users to engage in water conservation in times of shortage, the courts have not established many guidelines for the determination of reasonableness. Nor has the Legislature deemed it appropriate to develop detailed statements of what would constitute reasonable beneficial use in particular situations.

Many resource economists suggest that more exchanges or transfers of water and water rights would be beneficial to improving the efficiency of water use and that the law acts currently to prevent such transactions. It has been recognized, however, that such transferability should be coupled with appropriate protection for areas of origin and that only modest exchanges and transfers should consequently be anticipated. It appears that in addition to specific constraints in the law, broad institutional factors involving the way in which water districts are established, the objectives they are designed to serve, and the means open to them for disposal of their revenues, play a large part in inhibiting water rights transfers and exchanges from taking place.

Although groundwater, discussed in an earlier part of this section, appears to be the most pressing management question for California's future, another important area of concern involves the protection of in-stream uses of water for such purposes as fishery preservation and enhancement, recreation, and scenic and aesthetic enjoyment. Although the state has

Supply and Demand 1972

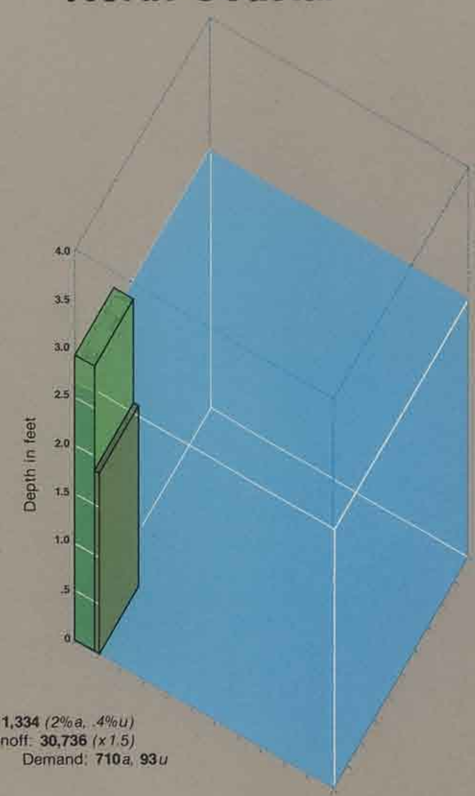
The isometric diagrams compare the natural surface water supply and actual demand within each of the eleven hydrologic basins for water year 1972.

The base of each diagram represents the total area of the basin, divided into 100,000-acre units. The total supply within the basin from precipitation is projected above this base, and is distributed to an equal depth of water, in feet, over the entire basin. This is shown as the dashed blue line. The shaded blue block represents the net supply which occurs as runoff. The difference between precipitation and runoff is a measure of the natural moisture demand within the basin.

Actual demand is shown by the orange and green columns representing the gross amount of water applied within each basin for irrigated agricultural and urban use. The area of the base of each column depicts the amount of land within that basin which is classified as urban (orange) or agricultural (green). The height of the column represents the depth in feet of water applied to that area of use within the basin.

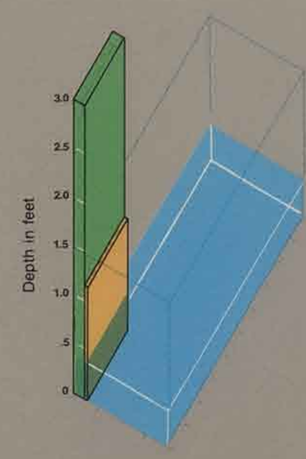
Beside each graphic is a numerical breakdown of the basin **Area** in acres (all figures are given in thousands), followed by the percentages of the basin area devoted to irrigated agriculture *(a)* and urban use *(u)*. Available supply is shown as **Runoff** in acre-feet, together with a multiplier that will give total precipitation for that basin. Finally, total agricultural and urban **Demand** is stated in acre-feet.

North Coastal



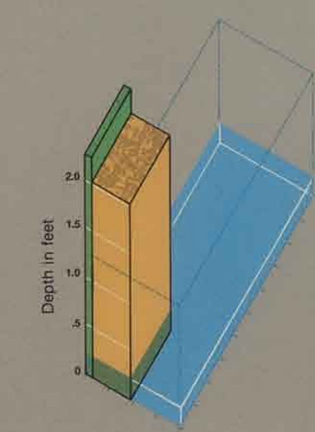
Area: **11,334** *(2% a, .4% u)*
Runoff: **30,736** *(x 1.5)*
Demand: **710** *a*, **93** *u*

North Lahontan



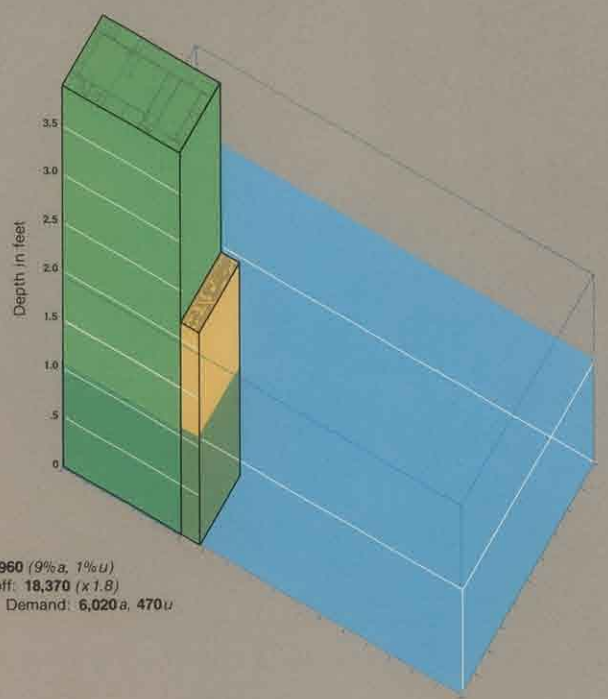
Area: **3,891** *(3.5% a, .5% u)*
Runoff: **1,420** *(x 4.0)*
Demand: **420** *a*, **23** *u*

San Francisco Bay



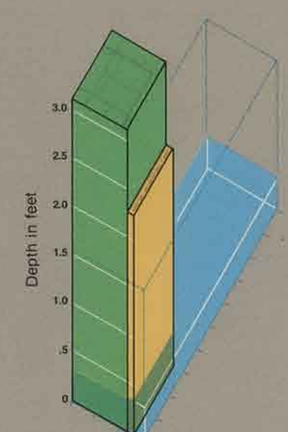
Area: **3,910** *(3% a, 12% u)*
Runoff: **1,110** *(x 4.4)*
Demand: **250** *a*, **990** *u*

Sacramento Basin



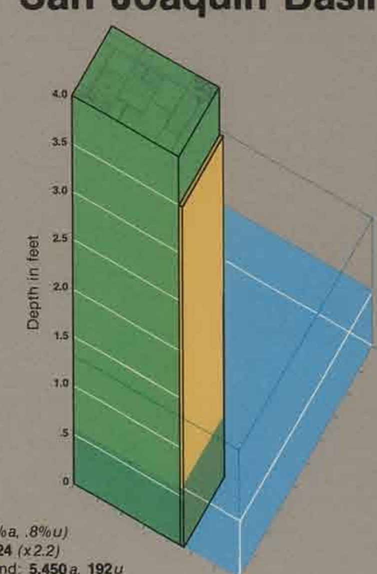
Area: **16,960** *(9% a, 1% u)*
Runoff: **18,370** *(x 1.8)*
Demand: **6,020** *a*, **470** *u*

Delta-Central Sierra



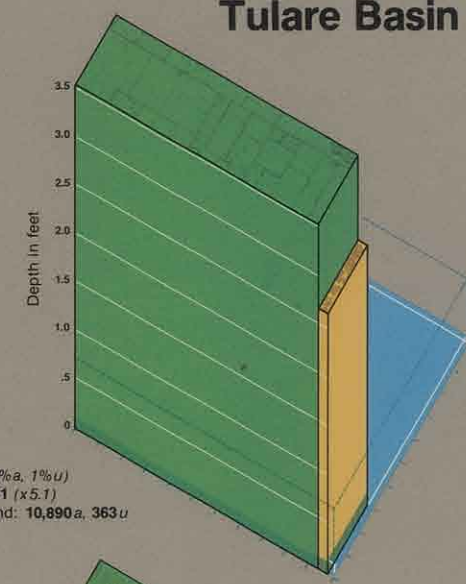
Area: **3,168** *(25% a, 2% u)*
Runoff: **940** *(x 5.0)*
Demand: **2,470** *a*, **173** *u*

San Joaquin Basin



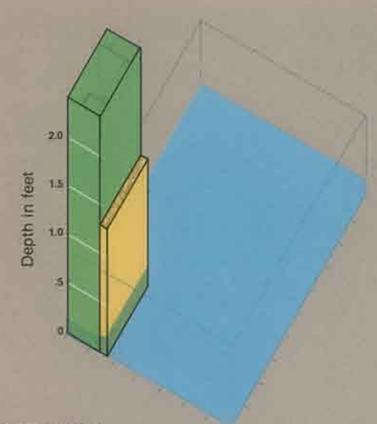
Area: **7,078** *(20% a, .8% u)*
Runoff: **4,224** *(x 2.2)*
Demand: **5,450** *a*, **192** *u*

Tulare Basin



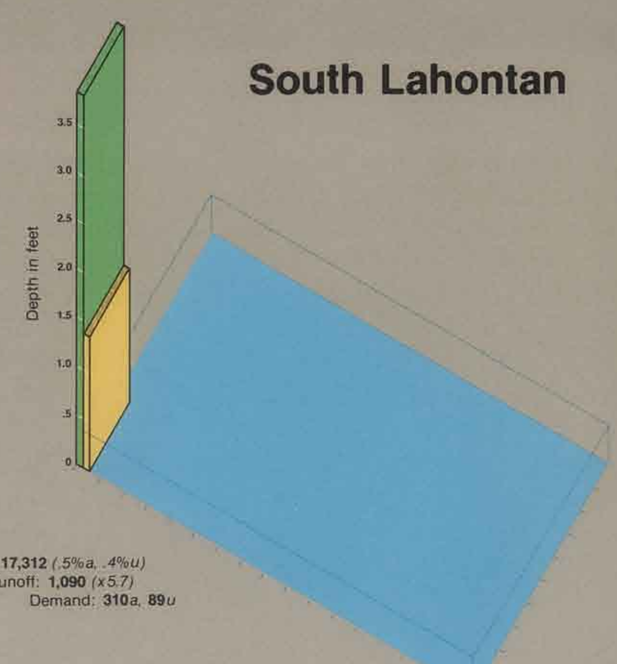
Area: **11,129** *(28% a, 1% u)*
Runoff: **1,551** *(x 5.1)*
Demand: **10,890** *a*, **363** *u*

Central Coastal



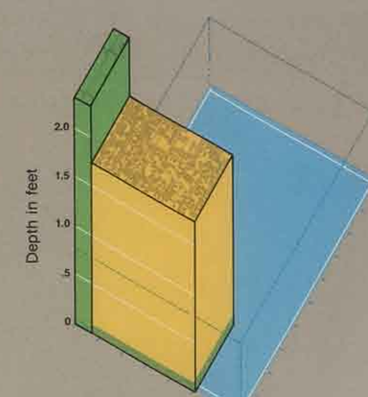
Area: **7,328** *(5% a, 2% u)*
Runoff: **730** *(x 8.2)*
Demand: **1030** *a*, **181** *u*

South Lahontan



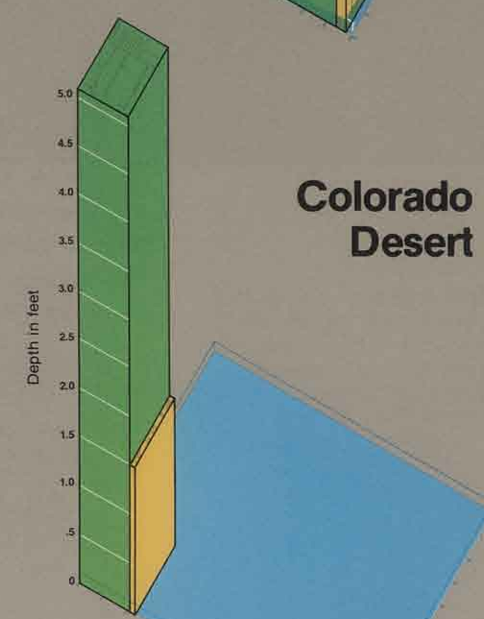
Area: **17,312** *(.5% a, .4% u)*
Runoff: **1,090** *(x 5.7)*
Demand: **310** *a*, **89** *u*

South Coastal

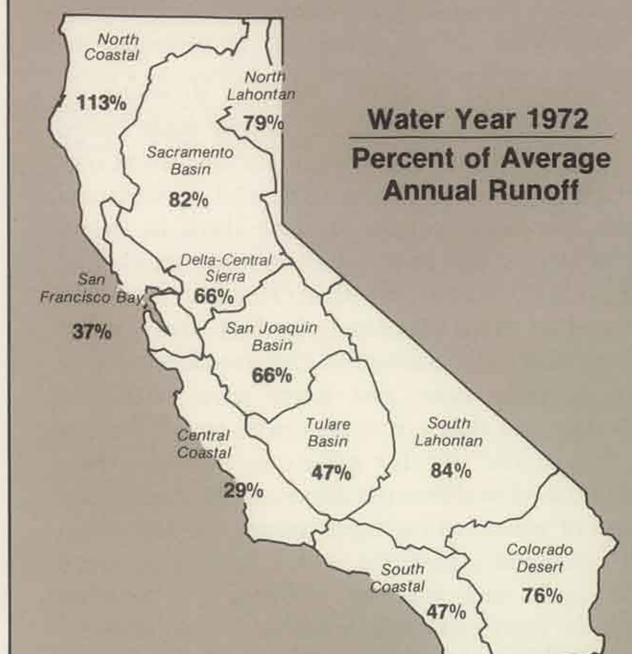


Area: **7,027** *(5% a, 20% u)*
Runoff: **560** *(x 9.6)*
Demand: **920** *a*, **2,370** *u*

Colorado Desert



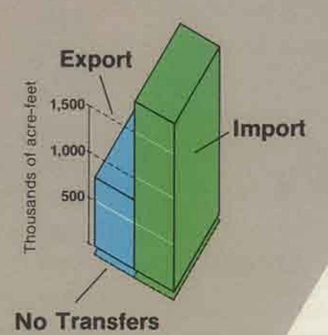
Area: **12,422** *(5% a, .5% u)*
Runoff: **150** *(x 7.6)*
Demand: **3,220** *a*, **99** *u*

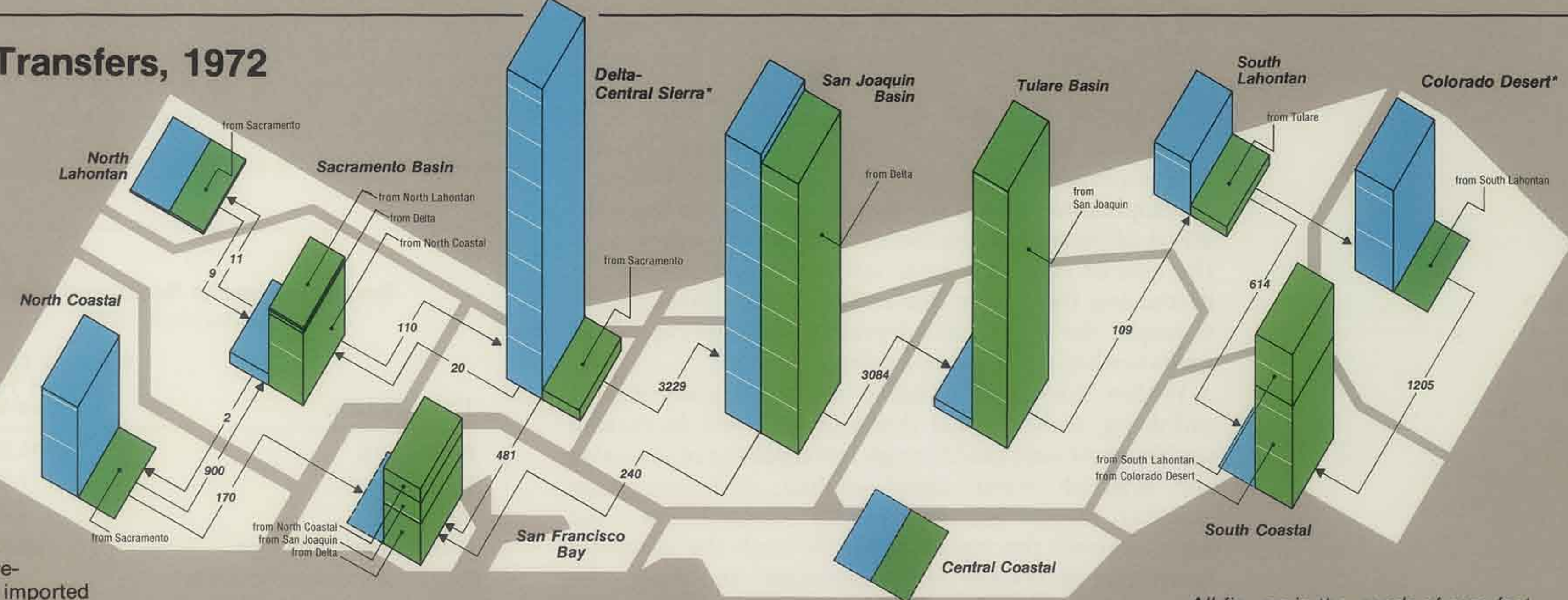


Water Year 1972

Percent of Average Annual Runoff

Interregional Transfers, 1972



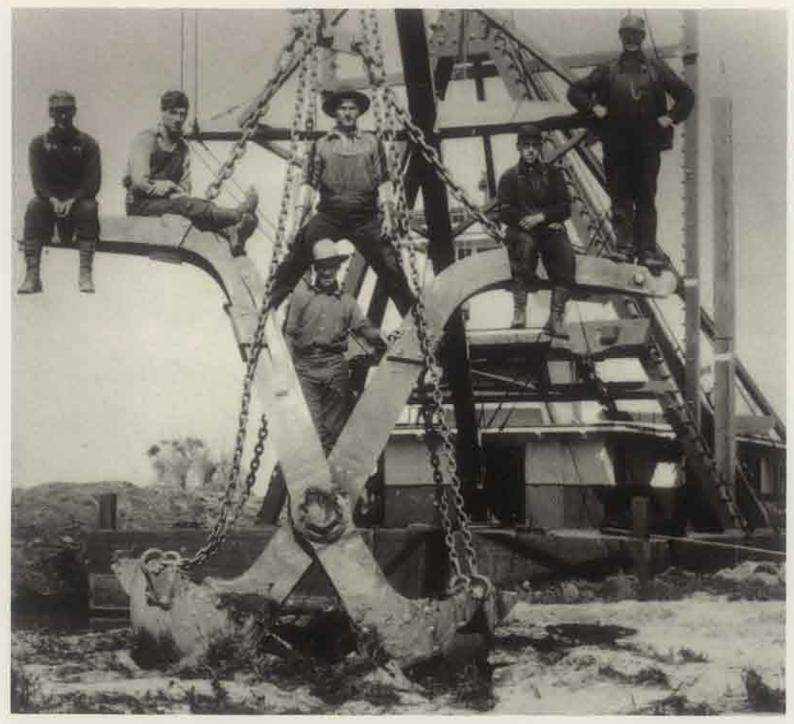


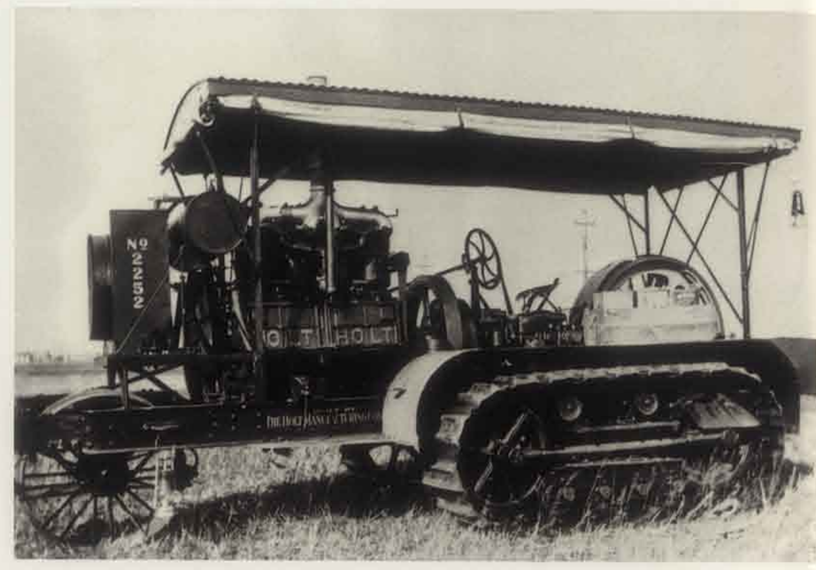
This graphic illustrates the quantity of water, in acre-feet, that was exported and imported by each hydrologic basin during 1972. Groundwater pumping alleviates deficits in some basins.

All figures in thousands of acre-feet

**Exported water does not orginate in basin.*

The photographs on this page provide several examples of the importance of technology to the creation of the modern water system. The introduction of the clamshell dredge on the left revolutionized reclamation methods and made possible the construction of hundreds of miles of dikes to protect Delta agriculture. Because horses and conventional wheeled vehicles soon bogged down in the porous, peaty soils of the Delta, track-laying vehicles like the Holt tractor at right were invented and these later served as the basis for the modern tank. Each technology, however, has locational advantages and disadvantages. When Los Angeles imported the track-laying vehicles developed for use in the Delta to haul pipe during the construction of the aqueduct to the Owens Valley, the machines quickly broke down in the desert, forcing the city to replace them by assembling huge teams of mules.





repeatedly articulated a policy favoring in-stream protection, the means for implementing this policy remain unsatisfactory. At one extreme, for many years it has been possible for those concerned about in-stream protection to protest applications filed by those seeking to appropriate water for beneficial uses away from the stream. Thus, in many instances, prospective appropriators seeking water for irrigation, municipal water supply, or other off-stream purposes have been required to negotiate protests filed by the state Department of Fish and Game. Although this process has provided some in-stream protection, it has offered at best a fragmentary, reactive, and unsystematic approach to the problem. At the other extreme, near total protection for in-stream flows has been provided in limited instances by the California Wild and Scenic Rivers Act. This approach, while perhaps satisfactory and certainly effective for the rivers in question, is of doubtful utility on the vast majority of rivers where extensive development has taken place or is contemplated for the future.

Two important legal questions regarding the protection of in-stream uses of water remain unresolved at the end of 1978. First, to what extent is the classical system for establishing private property rights in water available to protect in-stream uses? It is clear that riparians need not take water from a stream in order to protect their uses, including in-stream uses. And it is clear that the State Water Resources Control Board can deny an application to appropriate because the water in question is needed for in-stream beneficial uses and it could consequently condition the permits and licenses it grants in ways designed to protect in-stream uses. It is unsettled, however, whether public or private entities can acquire appropriative rights without establishing some sort of physical control over the water.

The second unresolved question with regard to in-stream uses is whether a more effective "middle of the road" means of regulation can be found. The Governor's Commission to Review California Water Rights Law recommended in 1978 that the State Water Resources Control Board be authorized to develop comprehensive in-stream flow standards on a stream-by-stream basis. These standards would be implemented by requiring all subsequent administrative decisions to conform to them, by arranging physical solutions which would reorganize diversions to enhance in-stream protection wherever possible, by limiting restrictions placed upon off-stream users in the name of the public interest, and by compensating those off-stream users whose rights would be purchased in order to realize the in-stream objectives. Whether this proposal will be accepted, however, remains to be seen at the time of this writing.

NEW TECHNOLOGY

The course of water development in California has been in large part a function of technological advancement. People in the nineteenth century could dream of building the massive water delivery systems which have changed the face of the California waterscape today but, until the technology existed for the construction of large-scale siphons and pumps, these dreams had no means of realization. Without the invention of the centrifugal pump, the Caterpillar and Holt tractors, and, most important, the discoveries of Thomas Edison, California could never have developed in the way it did.

New technologies do not just happen. Instead they are usually the result of economic and political necessity. As the costs of conventional sources of supply increase at a faster rate than the costs of the new technologies required to develop what once were considered exotic water sources, these new sources come closer to being justified. Technological developments outside the water industry can have the effect of increasing the future demand for water, as in the case of water for electrical powerplant cooling, or decreasing the future demand for water through, for example, the genetic development of plants capable of withstanding drought and salinity.

Within the water industry there are a number of unfolding technological developments for increasing usable water supplies through the desalting of seawater and brackish water, cloud seeding, and long-range weather forecasting. In addition, technologies exist which extend the use of water through the advanced treatment of sewage and wastewater for reuse, the aeration of water for quality improvement, the renovation of wastewater by surface spreading, and water recycling by industry.

Each technology has locational advantages and disadvantages. For instance, cloud seeding is impractical in desert regions and desalination is impractical for providing a new or supplemental water supply for most of California's irrigated agriculture. On the other hand, improvement in the accuracy of both intra-year and inter-year weather forecasting can have a tremendous impact on the management and use of the state's water resources.

As the population and economy grow, more wastewater must be treated because state and federal water quality laws require treatment of urban wastewater before it is discharged into another body of water. There are today more than 850 community wastewater treatment systems in California serving a population of 19 million. Less than ten percent of these treated waters, however, was further treated for reuse and approximately two-thirds was discharged to the ocean, coastal bays, and estuaries. With additional treatment, these waters offer a potential for meeting a significant portion of the water supply needs in and adjacent to metropolitan regions where they can be reused as an industrial water supply, for the irrigation of crops, parks, and other open spaces, and for groundwater recharge.

Beneficial Uses of Reclaimed Water in California in 1975

TYPE OF USE	VOLUME RECLAIMED PER YEAR (acre-feet)
Agricultural	134,657
Landscaping	17,574
Industrial	1,936
Groundwater Recharge	26,971
Recreational Impoundments	6,605
TOTAL	187,743

Nearly 200 wastewater reuse and reclamation projects exist in California today and many experts believe that advanced treatment and the extensive reuse of urban wastewater will be commonplace by the end of the century. Not all of the treated wastewaters, however, can be reused due to their chemical constituents. This technology, moreover, is capital- and energy-intensive and public health concerns and institutional problems need to be resolved before much progress can be made in its widespread application. Water planners, however, need to have these options remain open for as long as possible in order to perceive what effect technological developments occurring outside of the water industry will have on overall water demand and supply.

CONSERVATION

The unprecedented severity of the drought of 1976-77 in the northern two-thirds of the state called for similarly unprecedented water conserving measures by residential, commercial, industrial, and agricultural users. Water use was reduced by one-third in many instances and by as much as one-half in some areas. The drought provided a classic demonstration of how use can be reduced to the level of supply. But this is what water conservation is all about. If the development of new water supplies does not keep pace with the increases in demand that are expected to result from a rising population and greater economic activity, then the per capita use of water must decrease. Reducing the per capita use of water, in turn, postpones the day when already very expensive planned water storage projects need to be built and thereby reduces the bonded indebtedness of water utilities, adverse environmental effects, the need for electrical energy, and the future costs of water and sewage treatment.

The question in 1978 does not appear to be whether or why water conservation will occur in California. The why is already clear in the greatly increased costs of developing new water supplies. The how of water conservation is not so much in doubt either. Fortunately, many techniques, practices, and policies are already available to reduce per capita water use through fixtures inside the household, revised residential watering and landscaping, new industrial production and cooling processes, metering, rationing, increased water prices, drip irrigation, leak detection programs, sewer charges based on water consumption, and many others.

The issue, therefore, involves the cost—both monetary and nonmonetary—at which increased conservation will be achieved. Just as increasing water supplies exacts its costs in diverse ways, so too does the conservation of water. Each area of the state has different water supply and demand relationships and the response of the public to the ways and means of water conservation in agricultural and urban settings will vary in accordance with the situation in particular areas. The policies of water districts and urban communities with regard to meters, pricing, and *ad valorem* taxes, for example, can have profound effects on water use. Meters provide an economic incentive to curb water use. Prices can encourage water use by decreasing as use increases, or they can discourage use by increasing as the use of water increases. Similarly, if *ad valorem* taxes are used to subsidize and thereby reduce the prices charged for water, greater use will be encouraged.

The halcyon days when ample new water supplies were available at low development costs are gone forever in California. Whether the many agencies that make up the modern water industry will grasp this fundamental point and move effectively to adopt conservation policies in a timely manner is a matter very much in doubt. The capacity of our citizens, however, to adjust to these changed conditions was demonstrated most effectively in Marin County during the recent drought. Water consumption in the Marin Municipal Water District, the county's largest, dropped from 31,600 acre-feet in 1975, before the drought, to 24,000 acre-feet in 1976, and 11,700 acre-feet in 1977. During July and August, the peak periods of water use, when approximately 41 million gallons per day are normally consumed, consumption for these two months in 1977 declined to approximately 11 to 12 million gallons per day.

The costs of these conservation measures included agricultural losses, damage to the landscape, plumbing changes, sewer repairs, wells and pumps, and the purchase of bottled and trucked-in water for residences, apartment houses, and businesses. It is to be hoped that such severe measures will never need to be taken again in California. But, the so-called Marin approach to the drought probably was the most sophisticated and equitable attempt at universal conservation that has ever been put into effect. It demonstrated that people can and will manage with far less water than they once thought adequate. Thus, as complex as the problems of California's future relationship to water may be, there seems to be little cause for pessimism. In reviewing the long history of struggle and conquest by the people in coping with a myriad of water problems in the Golden State, there is still reason to believe that there will be sufficient wisdom, born out of experience and knowledge, to sustain us in the years ahead.

Just as San Francisco Bay and the Delta lie at the center of any discussion of the future of water development in California, so too does the example of Marin County's success in meeting the Drought of 1976-77.

Afterword

At one dicey point when the California Water Atlas Project looked as though it might collapse, Bill Kahrl quietly checked his alternatives. He called a few outfits in the private sector who might be expected to handle such jobs. They were boggled by the scope and schedule of the project, and Bill was boggled by their estimated cost of taking it over—five times greater than what it was costing the state to do it.

Why?

At any point after the first months if you had looked in on the administrative, research, cartographic and editing staffs of the project you would have found people working 80-hour weeks (and getting paid for 40) and heard comments such as, "Nobody has any personal life left," "Tired doesn't matter anymore," "Nobody here has ever worked this hard in their life," "Everyone's giving 150%," "I've never felt so good about myself."

Why?

This afterword will try to give some sense of the process that led to the product you're holding, try to answer the two questions above, and try to pin down what went well and not so well in the structure of our atlas-making process so that others on similar projects might be inspired or warned by our experience.

It didn't begin as a water atlas. Years before this project got started, an informal gathering of California-based cartographers had noted the shocking lack of any atlas for the state and schemed up a list of subjects they thought should be in such a tome. Imagining that the Reagan administration would be unreceptive to the idea, they went no further with the plan. But later, one of that group, Ted Oberlander of the University of California, Berkeley, knowing that I was doing temporary duty as a consultant to the new Brown administration, mentioned the atlas idea to me while we were working together on a world map.

I bandied the notion around the Governor's Office until it was seized by Bill Press, head of the Office of Planning and Research. The time was 1976-1977, California's worst drought in this century. A special commission was in the process of reviewing the state's water laws. And the Peripheral Canal around the Delta was a major political issue. In that context we decided to approach an "Atlas of California" incrementally. We would start with a water atlas of a state that we were realizing was uniquely defined by its water situation.

It would be nice, we told one another, to have in one place a mutual frame of reference for all the parties to the various water issues, so they could identify more clearly their points of disagreement and perhaps see also the larger water context in which resolution might lie. It would be nice, we said, if California's citizens and representatives had some help in understanding why and where and how water was a problem in the state.

At this point three key figures made key decisions. Bill Kahrl of the Office of Planning and Research (OPR) agreed to take on full responsibility for the project. Governor Brown agreed that the project should go ahead. And Ron Robie, head of the Department of Water Resources, on whose turf all state mapping and water matters properly belonged, enthusiastically endorsed OPR as the vehicle for the project.

That kind of support never let up. When the water drought year of 1977 passed rainily into the fiscal drought year of 1978, the year of the Jarvis-Gann tax limitation initiative, and everybody's pet projects were dying, the water atlas survived. Part of the attraction was that the water atlas is expected to pay back in sales the cost of its production. Also, the $515,000 proposed to be spent on the project did not loom very large in the context of a $20 billion state budget. Furthermore, by the time the Jarvis-Gann limitations took effect, the project was under way and already had a reputation as something going well.

Why was it doing well? Mainly because it was attracting outstanding people. As Bill Kahrl recalls, "The project sold itself." Starting with Bill Bowen, who had been recommended by Oberlander, the cartographic staff came together amidst the excellent equipment at California State University, Northridge. Some of the research staff was acquired through the normal process of announcement-resume-interview (Walraven Ketellapper); some were stumbled on fortuitously (Marlyn Shelton).

Bill Kahrl: "To select the advisors we talked to everyone we could think of and asked, 'Who else should we talk to?' The advisors we eventually selected came largely from that second generation of contacts. Advisory groups are often rubber-stamp operations, but in this case the advisors personally shaped the whole thing from the beginning. I don't know any other advisory group that has been made to work as hard.

"With the authors the entire problem was finding precisely the right person for each section, someone whose expertise in the subject would not only be recognized but who would also be detached enough to provide a balanced perspective. Those people are rare enough, but we also needed the kind of people who can reduce their knowledge to fit within the limited space we had available and still be able to write it up in such a way that it would all come alive for the reader. Once we had a list of the people we wanted, all but one said they would be delighted to contribute, even though we were saying to them, 'We'll give you 90 days to write this and we won't pay you hardly anything and, I'm sorry, it probably means you'll have to give up your plans for the summer.'

"People worked as hard as they did, regardless of their compensation, because of a realization that working on the water atlas was an opportunity that might never come again. It was a once-in-a-lifetime shot." Bill Kahrl had a job similar to that of a movie director—holding the vision of the whole intact and refining it while balancing and integrating the many talents involved and scheduling their work so that each part of the process informed the others. Research (familiarization) started first, then initial advisory meetings, then beginning data collection from the agencies, then the first cartographic images, and finally the generation of text. Each group—researchers, advisors, agencies, cartographers, and authors—had to review and improve and adapt to the products of others.

Some of it was easier than expected. The state government probably has more information on water than any other subject, but early fears that the information would be jealously guarded by the agencies turned out to be incorrect. At every level, from local to state to federal, people were generous with their data and their time.

Walraven Ketellapper: "You have some guy who's been collecting a certain kind of a number for 25 years and the only people looking at it are other guys like him. Now all of a sudden his numbers are going to be put in a place where a whole new bunch of people are going to see it. It's refreshing for him.

"We learned that before calling we needed to get a good background in the subject we were calling about. A lot of these people are really input-output minded. If you say, 'What do you do?' they say, 'We do a lot of things. What do you want to know?' So first you look at a report by that agency or you look at a textbook and get some terms down. You don't ask about water quality if you can't tell the difference between dissolved oxygen and a nitrate. And as you go along you develop a giant list of contacts—you tap into a network of rolodexes."

The major frustrations in the project occurred because of the lag in getting graphic material generated and cycled. The 500-mile distance between the cartographic equipment and staff in Los Angeles and the research information and staff in Sacramento was maddening at times. And there were recurring instances of an elaborate color plate being prepared, going back to the agency for review, who said, "Oh, sorry, wrong information, that was interim data, here's the final data," and amid gnashing teeth the plate would have to be adjusted.

Part of the problem, or advantage, was that the early plates set a high level of complex sophistication—"avant garde cartography," someone called it—which everyone wanted to maintain even though it was costly in time to do. In retrospect all of the staff agree it would have been better to have had the research team start much farther in advance of the cartography team so as to generate a body of confirmed data, using perhaps one in-house graphic person to sketch up the plates for review by the agency people. In addition, the cartographic staff should have been larger earlier—five people from the beginning instead of three. It would have been helpful at the very start to have generated one prototype for each plate to establish time, cost, sophistication, and printing standards early on instead of having to confront these limitations later, when in a sense it was too late.

The question of schedule is a fascinating one. The water atlas was done in 15 months. Would it have helped to have a longer time? Everyone I've talked to says no, crushing as the workload was, the prospect of an end-in-sight made it bearable. Better sequencing and pacing would have solved the structural problems. However, as it was, the load on the cartography end got too heavy late in the game and the 50 color plates originally planned had to be cut back along with the number of diagrams to accompany the text. It's the old illusion I've seen (and committed) around magazine and book publishing forever—that once the "piece" is done, then editing, design, illustration, paste-up, and corrections take no time. Ha.

I'm able to focus on what went awkwardly with the project because so much went so well. The advisory process was smooth, lending perspective to the judgment of staffers, shaping and reshaping the content of the book, and providing many of the authors—all of that managed adroitly by Bill Kahrl's office (not by me the decorative chairman). Research, especially Marlyn

Shelton, gracefully handled the three-way press of traffic between the agencies, the cartography team, and the process of administration and editing.

In the course of its development the water atlas inspired many of the agencies to a broader sense and pride of what they were about, and it brought attention to new kinds of information that the state needs to have. We need to collect more data about water quality and about the end-use and cost of water in various areas. Bill Kahrl: "Many of the components of the modern water system and consequently the data collection efforts of the responsible agencies have been designed to address problems that were identified and defined in the nineteenth century. We were unable to get information on many of the topics we wanted most to treat simply because the questions we were raising had never been asked before.

"The weight of water, for example, is an aspect of delivery that has not been considered except as an engineering problem; but now that energy is no longer cheap, the cost of moving water around the state is a key problem for the future operation of the State Water Project and the Colorado River Aqueduct. Similarly, even though groundwater provides 40 percent of the water we use, this atlas has the first map of the state's groundwater basins, and the information we have on the subject is incredibly incomplete."

Was it worth doing?

Bill Kahrl: "We start with the presumption that it is worthwhile to spend taxpayers' dollars to enhance taxpayers' understanding of the opportunities for them to take a role in shaping policy in a very difficult subject area."

The key word there is understanding. It's the difference between raw data and the ability to do something with it. The sheer labor of doing the water atlas indicates its need. The digging, collecting, translating, reporting, illustrating, and checking of information that went into this book is that much work that has been saved any citizen who might want to do something about water in California.

A bargain.

Do more such.

Stewart Brand
Sausalito, 1978

For Further Reading

The printed matter pertinent to California water problems might be measured, not in volumes, but in tons. This bibliography has, consequently, been limited to a few guides to the literature of the field, some of the more important works on the history of water development and water-related problems in the state, and the most comprehensive sources of statistical data on water supply and water use in California. These titles should be accessible in the larger public libraries, in college libraries, or through inter-library loan from the State Library and the major academic institutions. The reader who wishes to pursue a particular topic beyond the confines of this bibliography will find more specialized citations in the works listed below, many of which contain extensive bibliographies of primary source materials, and in the guides to the literature listed here.

GUIDES TO THE LITERATURE

California. Department of Water Resources. *Chronological List of Bulletins and Reports: Department of Water Resources and its Predecessors, from 1880.* Sacramento, CA: Department of Water Resources, Central Records Section. Loose-leaf, additional pages issued frequently. List of DWR Bulletins and other reports, some of which were originally issued in very limited numbers. The list is arranged by year of publication, without an index; however, key words are underscored in most titles to facilitate scanning. Although many reports are not readily available in most libraries, copies may be borrowed from the California State Library on inter-library loan.

California. State Library. Government Publications Section. *California State Publications.* Vol. 1-. Sacramento, CA: State Library, 1947 to date. Monthly, cumulated annually in the December issue. "Listing of official California state documents received by the Government Publications Section, California State Library." This is not a complete list of all publications of state agencies, but includes only those publications sent to depository libraries under the Library Distribution Act, and some additional agency-produced material received in the State Library. Arranged by State Library classification number, indexed by personal and corporate author, title, and subject.

California. University. Water Resources Center Archives. *Dictionary Catalog of the Water Resources Center Archives, University of California.* 5 vols. Boston: G.K. Hall & Company, 1970. Updated with annual or biennial supplements, 1971 to date. Photographic reproduction of the card catalog of the state's major library in the field of water resources. The Archives, with its primary collection on the Berkeley Campus of the University, and a Southern California and southwestern regional collection at UCLA, collects historical and technical works on all aspects of water resources development, management, use, and conservation; water economics and law; and coastal and offshore engineering. Both collections are open to the public and will lend materials to other libraries.

Giefer, Gerald J. *Sources of Information in Water Resources: An Annotated Guide to Printed Materials.* Port Washington, NY: Water Information Center Inc., 1976. 290 pages. A list of reference works, handbooks, manuals, bibliographies, abstracting journals, indexes, dictionaries, and encyclopedias in the field of water resources. Citations are annotated, arranged by broad subject and by form within subject, and indexed by author, title, and specific subject.

Jones, James R. *Inventory of Research Activities in the Lake Tahoe Area: A Bibliography, 1845-1976.* South Lake Tahoe, CA, and Carson City, NV: Lake Tahoe Area Research Coordination Board and Nevada State Library, 1976. 219 pages. Listing of over 1,000 research reports, journal articles, conference papers and theses, published and unpublished, many with annotations. Citations are arranged by broad topic and indexed by author and subject. Libraries possessing copies of these reports are noted. Appendix gives summaries of current research projects.

Orse, Richard J. *A List of References for the History of Agriculture in California.* Davis, CA: University of California, Agricultural History Center, 1974. 141 pages. Annotated bibliography of books and journal articles on the history of agriculture in California. Includes agricultural and irrigation practices of the Indians and of the missions. Arranged by subject with author index.

Selected Water Resources Abstracts. Vol. 1-. Washington, D.C.: U.S. Water Resources Scientific Information Center, 1968 to date. Biweekly. Abstracts of books, scientific and technical reports, journal articles and symposia in the field of water resources. Author, subject, organization, and accession number indexes are cumulated annually.

U.S. Geological Survey. *Reports for California by the Geological Survey Water Resources Division.* Menlo Park, CA: U.S. Geological Survey, Water Resources Division, 1978. 145 pages. Alphabetical listing by author of the Survey's publications about water in California. The list, which includes publications dealing with broader regions and the United States as a whole if data on California are included, is updated and reissued every few years. Indexed by hydrologic area, county, and subject.

READING LIST AND SOURCES OF STATISTICS

Bailey, Harry P. *The Climate of Southern California.* In California Natural History Guides: 17. Berkeley and Los Angeles, CA: University of California Press, 1966. 87 pages. Discusses climatic regions of Southern California, the effects of weather patterns on the problems of fire, flood, drought, and smog. Tabular data on temperature and precipitation for selected stations.

Bain, Joe S., Richard E. Caves, and Julius Margolis. *Northern California's Water Industry: The Comparative Efficiency of Public Enterprise in Developing a Scarce Natural Resource.* Baltimore, MD: John Hopkins Press for Resources for the Future, 1966. 766 pages. Economic and legal analysis of the institutions responsible for water supply development and management in California west of the Sierra Nevada and north of the Tehachapi Mountains. Discusses the legal framework and operations of water agencies, costs of supplying water, and water pricing and allocation.

Bakker, Elna, S. *An Island Called California.* Berkeley and Los Angeles, CA: University of California Press, 1971. 357 pages. A natural history of California with discussion of each of the major ecological communities. Lists of plant and animal species are included.

California. Coastal Zone Conservation Commission. *California Coastal Plan.* San Francisco, CA: Coastal Zone Conservation Commission, 1975. 443 pages.

—— ——. *Summary.* 1975. 22 pages. Compilation of the findings, conservation and development policies, and goals prepared by the six regional commissions in response to the 1972 Coastal Initiative. Colored maps detail coastal resources, including estuaries, lagoons, and marshes, and planning goals for each subregion.

California. Department of Fish and Game. *Coastal Wetlands Series.* No. 1-. Sacramento, CA: Department of Fish and Game, 1970 to date. Each report covers geography, hydrology, and ecology of the area, inventories of plant and animal species, uses to which these resources have been and are being put, and recommendations for the mitigation of adverse impacts. Reports issued to date are:

—— ——. No. 1: *Report on the Natural Resources of Upper Newport Bay and Recommendations Concerning the Bay's Development*, by Herbert W. Frey, Ronald F. Hein, and Jack L. Spruill. 1970. 68 pages.

—— ——. No. 2: *The Natural Resources of Goleta Slough and Recommendations for Use and Development*, by John W. Speth, et al. 1970. 42 pages.

—— ——. No. 3: *The Natural Resources of Bolinas Lagoon: Their Status and Future,* by Paul E. Giguere, et al. 1970. 107 pages.

—— ——. No. 4: *The Natural Resources of Elkhorn Slough: Their Present and Future Use,* by Bruce M. Browning, et al. 1972. 105 pages.

—— ——. No. 5: *The Natural Resources of San Diego Bay: Their Status and Future,* by Bruce M. Browning, John W. Speth, and Wendal Gayman. 1973. 105 pages.

—— ——. No. 6: *The Natural Resources of Humboldt Bay,* by Gary W. Monroe. 1973. 160+ pages.

—— ——. No. 7: *The Natural Resources of Los Pensacuitos Lagoon and Recommendations for Use and Development,* by Peta J. Mudie, Bruce Browning, and John W. Speth. 1974. 75+ pages.

—— ——. No. 8: *The Natural Resources of Morrow Bay: Their Status and Future,* by Gene L. Gerdes, Edward R. J. Primbs, and Bruce M. Browning. 1974. 103+ pages.

—— ——. No. 9: *Natural Resources of the Eel River Delta,* by Gary W. Monroe, et al. 1974. 108 pages.

—— ——. No. 10: *Natural Resources of Lake Earl and the Smith River Delta,* by Gary W. Monroe, Bobby J. Mapes, and Patrick L. McLaughlin. 1975. 114 pages.

—— ——. No. 11: *The Natural Resources of Bodega Harbor,* by Jon Standing, Bruce M. Browning, and John W. Speth. 1975. 183+ pages.

—— ——. No. 12: *The Natural Resources of San Dieguito and Batiquitos Lagoons,* by Peta J. Mudie, Bruce M. Browning, and John W. Speth. 1976. 100+ pages.

—— ——. No. 13: *The Natural Resources of Carpinteria Marsh: Their Status and Future,* by Keith B. MacDonald. 1976. 69+ pages.

—— ——. No. 14: *Natural Resources of Coastal Wetlands in Northern Santa Barbara County,* by Clark R. Mahrdt, et al. 1976. 99+ pages.

—— ——. No. 15: *The Natural Resources of the Nipomo Dunes and Wetlands,* by Kent A. Smith, John W. Speth, and Bruce M. Browning. 1976. 106+ pages.

—— ——. No. 16: *The Natural Resources of Agua Hedionda Lagoon,* by Jack Bradshaw, et al. 1976. 110+ pages.

—— ——. No. 17: *The Natural Resources of Mugu Lagoon,* by Keith B. MacDonald. 1976. 119+ pages.

—— ——. No. 18: *The Natural Resources of Anaheim Bay—Huntington Harbour,* by John W. Speth, et al. 1976. 103+ pages.

—— ——. No. 19: *The Natural Resources of Napa Marsh,* by Madrone Associates. 1977. 97+ pages.

—— ——. No. 20: *The Natural Resources of Esteros Americano and de San Antonio,* by Madrone Associates and James Swanson. 1977. 81+ pages.

California. Department of Fish and Game. *Fish Bulletin.* No. 1-. Sacramento, CA: Department of Fish and Game, 1913 to date. An irregular series of reports on various fish and fishery-related topics, including, annually, the California marine fish catch. Other titles of general interest include:

—— ——. No. 96: *California Fishing Ports,* by W. L. Scofield. 1954. 159 pages.

—— ——. No. 113: *The Ecology of the Salton Sea, California, in Relation to the Sportfishery,* by Boyd W. Walker. 1961. 204 pages.

—— ——. No. 123: *The California Oyster Industry,* by Elinore M. Barrett. 1963. 103 pages.

—— ——. Nos. 133 and 136: *Ecological Studies of the Sacramento-San Joaquin Estuary,* by D. W. Kelley and Jerry L. Turner. 1966. 133 and 168 pages.

—— ——. No. 150: *A History of California's Fish Hatcheries, 1870-1960,* by Earl Leitritz. 1970. 92 pages.

—— ——. No. 157: *Guide to the Coastal Marine Fishes of California,* by David J. Miller and Robert N. Lea. 1972. 235 pages.

—— ——. No. 164: *Trout and Salmon Culture*, by Earl Leitritz and Robert C. Lewis. 1976. 197 pages.

California. Department of Navigation and Ocean Development. *A Guide to California Boating Facilities*. Sacramento, CA: Department of Navigation and Ocean Development, 1974 to date. Issued in three booklets covering Northern, Central, and Southern California, tables keyed to maps show locations of launching ramps, berths, fuel docks, and associated chandleries along the Pacific Coast and on inland rivers, lakes, and reservoirs.

California. Department of Public Health. Bureau of Sanitary Engineering. *Water Reclamation*. 15 vols. Berkeley, CA: Department of Public Health, Bureau of Sanitary Engineering, 1972. Part I provides general information on possible uses of reclaimed water in California, with quantity and quality requirements and public health considerations. Part II consists of separate volumes for each of the major drainage basins, including information on existing and planned reclamation operations (as of 1971) and identification of potential markets.

California. Department of Water Resources. *Bulletin*. No. 1-. Sacramento, CA: State Printing Office, 1922 to date. The bulletins, of which numbers 1-56 and new series numbers 1-24 were published by the Department's predecessor agencies, include reports and statistical data on many aspects of water supply, development, management, and use in California. An annotated list and comprehensive index to the entire series is published semi-annually with periodic cumulations as *Bulletin* No. 170. The index also includes a list of libraries which receive the bulletins. Some titles of general and current interest are:

—— ——. No. 17: *Dams Within the Jurisdiction of the State of California*. 1941 to date. irregular.

—— ——. No. 63: *Sea Water Intrusion in California*. 1957 to date. irregular. A series of reports on the intrusion of salt water into groundwater basins in various parts of the state.

—— ——. No. 68: *Inventory of Waste Water Production and Waste Water Reclamation in California*. 1953 to date. irregular.

—— ——. No. 69: *California High Water*. 1962/63 to date. annual. Report of precipitation, peak flows, floods, and damages resulting from major storms during the water year October 1 to September 30.

—— ——. No. 80: *Reclamation of Water from Wastes in Southern California*. 1961 to date. irregular.

—— ——. No. 113: *Vegetative Water Use in California*. 1954 to date. irregular. Data tabulated by evapotranspiration zone and by crop.

—— ——. No. 118: *California's Ground Water*. 1975. 135 pages.

—— ——. No. 120: *Water Conditions in California*. 1963 to date. Issued monthly, February through May with summary in October. Includes precipitation, snowpack, reservoir storage and streamflow data.

—— ——. No. 130: *Hydrologic Data*. 5 vols. 1963 to date. annual. Contents: (1) north coastal area; (2) northeastern California; (3) central coastal area; (4) San Joaquin Valley; and, (5) Southern California. Includes streamflow at selected stations, water level in observation wells, surface and groundwater quality data.

—— ——. No. 132: *California State Water Project in (year)*. 1963 to date. annual. Report on construction, operation, finance, and water deliveries to contracting agencies.

—— ——. No. 160: *The California Water Plan: Outlook in (year)*. 1966 to date. irregular. This report updates the planning assumptions and projections of the Department and describes alternative future development and operating policies.

—— ——. No. 166-2: *Urban Water Use in California*, by Richard J. Wagner. 1975. 172 pages.

—— ——. No. 189: *Waste Water Reclamation: State of the Art*, by James M. Morris, Jr., Charles F. Kleine, and Earl G. Bingham. 1973. 43 pages.

—— ——. No. 190: *Water and Power from Geothermal Resources in California: An Overview*, by Charles R. White and Phyllis J. Yates. 1974. 52 pages.

—— ——. No. 194: *Hydroelectric Energy Potential in California*, by Robert G. Potter, et al. 1974. 61 pages.

—— ——. No. 198: *Water Conservation in California*, by Glenn B. Sawyer, et al. 1976. 95 pages.

—— ——. No. 200: *California State Water Project*. 6 vols. 1974. Contents: vol. 1, *History, Planning and Early Progress*; vol. 2, *Conveyance Facilities*; vol. 3, *Storage Facilities*; vol. 4, *Power and Pumping Facilities*; vol. 5, *Control Facilities*; vol. 6, *Project Supplements*.

—— ——. No. 201: *California Water*. 1977 to date. annual. A report intended for the general public discussing current water supply and management issues and Department activities.

California. Department of Water Resources. *Directory of Officials of Flood Control, Reclamation, Levee and Drainage Districts, and Municipalities*. Sacramento, CA: Department of Water Resources, 1964 to date. irregular. List, arranged by district, of officials responsible for flood control activities. Includes addresses and telephone numbers. Center-fold map shows locations of districts in Sacramento and San Joaquin valleys.

California. Governor's Commission to Review California Water Rights Law. *Staff Paper*. No. 1-. Sacramento, CA: Governor's Commission to Review California Water Rights Law, 1977 to date. A series of background reports on various questions prepared for the Commission. Papers issued to date are:

—— ——. No. 1: *Appropriative Water Rights in California: Background and Issues*, by Marybelle D. Archibald. 1977. 63 pages.

—— ——. No. 2: *Groundwater Rights in California: Background and Issues*, by Anne J. Schneider. 1977. 105 pages.

—— ——. No. 3: *Legal Aspects of Water Conservation in California: Background and Issues*, by Clifford T. Lee. 1977. 76 pages.

—— ——. No. 4: *Riparian Water Rights in California: Background and Issues*, by David B. Anderson. 1977. 90 pages.

—— ——. No. 5: *The Transfer of Water Rights in California: Background and Issues*, by Clifford T. Lee. 1977. 72 pages.

—— ——. No. 6: *Legal Aspects of Instream Water Uses in California: Background and Issues*, by Anne J. Schneider. 1978. 131 pages.

California. State Water Resources Control Board. *Publication*. No. 1-. Sacramento, CA: State Water Resources Control Board, 1952 to date. A series of reports on various aspects of water quality and water pollution. Before 1968, issued by the board's predecessor agencies: Numbers 1-24 by the State Water Pollution Control Board, and numbers 25-37 by the State Water Quality Control Board. Some titles of general and current interest are:

—— ——. No. 3-A: *Water Quality Criteria*, edited by Jack Edward McKee and Harold W. Wolf. 2nd ed., 1963. 584 pages. A condensation and critical evaluation of the technical and legal literature pertaining to water quality criteria for the various beneficial uses of water. Includes a bibliography of some 3,800 citations.

—— ——. No. 44: *Study of Toxicity and Biostimulation in San Francisco Bay-Delta Waters*. 8 vols. 1972. Contents: vol. 1, *Summary Report*, by Randall L. Brown and Louis A. Beck; vol. 2, *A Statistical Evaluation of the Relationships Between Relative Toxicity and Species Diversity Index*, by Hydroscience Inc.; vol. 3, *Acute Toxicity of Discharged Wastes*, by Dennis C. Wilson and C. R. Hazel; vol. 4, *Toxicity Removal from Municipal Wastewaters*, by Larry A. Esvelt, Warren J. Kaufman, and Robert E. Selleck; vol. 5, *Dispersion Studies*, by Harlan J. Proctor, Jr. and Gerald C. Cox; vol. 6, *Bioassays of the Lower Trophic Levels*, by Hans-Jurgen Krock and David T. Mason; vol. 7, *Effects of Wastes on Benthic Biota*, by Dick A. Daniel and Harold K. Chadwick; vol. 8, *Algal Assays*, by Randall L. Brown, Gary Varney, and Harold K. Chadwick.

—— ——. No. 46: *Environmental Impact of Detergent Builders on the Waters of the State of California*, by David Jenkins, et al. 1972 61 pages.

—— ——. No. 50: *A Method for Regulating Timber Harvest and Road Construction Activity for Water Quality Protection in Northern California*, by Jones and Stokes Associates. 2 vols. 1973

—— ——. No. 56: *Oil Spills in California and Effects of Cleanup Agents*, by Fred Kopperdahl, Charles Hazel, and Norman Morgan. 1975. 106 pages.

—— ——. No. 57: *Tahoe Basin Studies Report, A compendium of Reports to the State Water Resources Control Board. 1974. 79 pages.*

—— ——. *No. 59: California Water Quality Research needs. 1977.* 83+ pages.

California. University. Water Resources Center. *Annual Report*. Davis, CA: Water Resources Center, 1964 to date. The Center was established in 1957 to coordinate and fund water-related research on all campuses of the University of California. The *Annual Report* summarizes research in progress or completed in the past year, and lists reports published by the Center and other publications emanating from research projects.

California. University. Berkeley. Sanitary Engineering Research Laboratory. *Comprehensive Study of San Francisco Bay: Final Report In the Laboratory's SERL Report Nos. 65-7, 65-8, 67-3, 65-10, 67-2, 67-4, 67-1, and 67-5*. 8 vols. Berkeley, CA: Sanitary Engineering Research Laboratory, and the School of Public Health, 1965-1907. Contents: vol. 1, *Physical, Chemical and Microbiological Sampling and Analytical Methods*; vol. 2, *Biological Sampling and Analytical Methods*; vol. 3, *Waste Discharges and Loadings*; vol. 4, *Physical and Hydrological Characteristics of San Francisco Bay*; vol. 5, *Summary of Physical, Chemical and Biological Water and Sediment Data*; vol. 6, *Water and Sediment Quality and Waste Discharge Relationships*; vol. 7, *A Model of Mixing and Diffusion in San Francisco Bay*; vol. 8, *Summary, Conclusions and Recommendations*.

California Water Code. Compilation and codification of laws in effect at the time of publication dealing with state powers over water, water rights, flood control, water conservation and development projects including the California Water Plan and Central Valley Project, water quality, and the formation and operation of various types of water districts. Through 1969 the *Water Code* was published biennially by the California Department of General Services. After that date, commercially published editions such as *West's Annotated California Codes: Water*, or *Deering's California Codes, Anotated: Water*, should be consulted. These latter include, in addition to the text of the law, cross-references to legal opinions, law review articles, etc. The reader should be warned that not all water-related law is contained in the *Water Code*; it is sometimes necessary to consult other codes such as *Government, Harbors and Navigation*, or *Public Utilities*.

Cooper, Erwin. *Aqueduct Empire: A Guide to Water in California, Its Turbulent History and Its Management Today*. In Western Lands and Waters Series VII. Glendale, CA: Arthur H. Clark Co., 1968. 439 pages. Summarizes the history of California water development with special emphasis on the State Water Project and future alternatives.

Dames & Moore. *National Shoreline Study, California Regional Inventory*. San Francisco, CA: U.S. Corps of Engineers, South Pacific Division, 1971. 256 pages. Inventory of erosion problems along the California coast, recommendations as to suitable protection, tables and maps detailing shoreline characteristics ownership status, use, erosion, and protection measures.

Dana, Richard Henry. *Two Years Before the Mast*. (many editions available). This classic of the sea contains an eyewitness account of California in the 1830's. Detailed account of the hide and tallow trade and shipping, descriptions of climate coastal weather, and the geography and vegetation of the California coast.

DeRoos, Robert. *The Thirsty Land: The Story of the Central Valley Project*: Stanford, CA: Stanford University Press, 1948. 256 pages. History of the Central Valley Project, includes planning, politics, conflicts between the Bureau of Reclamation and the Corps of Engineers, 160-acre limitation, hydroelectric power, and conflicts with Pacific Gas and Electric Co., financing and repayment, state versus federal control.

Dunne, Thomas and Luna B. Leopold. *Water in Environmental Planning*. San Francisco, CA: Freeman, 1978. 818 pages. Comprehensive text and basic reference covering hydrology, fluvial geomorphology, and river quality. Illustrated with numerous examples of field problems frequently encountered by planners and water resource managers. An interdisciplinary approach stressing alternative strategies and the bases and techniques of quantitative analysis.

Fellmeth, Robert C. *Politics of Land*. New York: Grossman, 1973. 715 pages. Report of Ralph Nader's Study Group on Land Use in California. Analysis of land ownership patterns and the concommitant political and financial influence on water pollution regulation, the development and operation of publicly funded irrigation and water transfer projects. Included are the Porter-Cologne Water Quality Act and the regulatory performance of the State and Regional Water Quality Control Boards; financial arrangements of the State Water Project; operations of the Bureau of Reclamation in the San Luis Project, Westlands Water District; and the effects of recreation development on adjacent waters.

Fuhriman, Dean K. and James R. Barton. *Ground Water Pollution in Arizona, California, Nevada and Utah*. U. S. Environmental Protection Agency, Water Pollution Control Research Series 16060 ERU 12/71. Washington, D.C.: U. S. Government Printing Office, 1971. 249 pages. Survey of groundwater pollution problems, discussion of the various causes of pollution, and recommendations for further research. Includes extensive bibliography.

Gilliam, Harold. *Weather of the San Francisco Bay Region*. Berkeley, CA: University of California Press, 1966. 72 pages. (California natural history guides: 6). Covers basic principles of meteorology and how the topography of the Bay Area modifies the prevailing weather patterns, creating local microclimates.

Goldman, Charles R. *Eutrophication of Lake Tahoe Emphasizing Water Quality*. In U. S. Environmental Protection Agency, Ecological Research Series EPA-660/3-74-034. Washington, D.C.: U. S. Government Printing Office, 1974. 408 pages. Study of the chemical and limnological factors affecting Lake Tahoe water quality. Graphs, tables, and maps showing data from 4 1/2 years of water quality monitoring. Some discussion of land application of waste water within the watershed.

Harding, Sidney Twichell. *Water in California*. Palo Alto, CA: N-P Publications, 1960. 231 pages. Summarizes the geography of water in California and traces the history of water supply development and use, including the evolution of water rights and water law, hydraulic mining, navigation, irrigation, hydroelectric power, and flood control.

Hundley, Norris. *Water and the West: The Colorado River Compact and the Politics of Water in the American West*. Berkeley and Los Angeles, CA: University of California Press, 1975. 395 pages. Historical and political study of the background and effects of the Colorado River Compact apportioning Colorado River water between the upper and lower basins, legal conflicts between Arizona and California, and apportionments of lower basin flows among Arizona, California, and Nevada.

Hutchins, Wells Aleck. *The California Law of Water Rights*. Sacramento, CA: U.S. Department of Agriculture, Agricultural Research Service and California State Printing Office, 1956. 571 pages. Analysis and explanation of water rights law in California, with index of topics covered and of cases cited.

Kelley, Robert L. *Gold vs. Grain: The Hydraulic Mining Controversy in California's Sacramento Valley, A Chapter in the Decline of the Concept of Laissez-Faire*. In Western Lands and Waters Series I. Glendale, CA: Arthur H. Clark Co., 1959. 327 pages. Study of the rise of hydraulic mining in California, the effects of hydraulic mining debris on agriculture, navigation, and flooding in the Sacramento River Valley, and the battles in the courts, State Legislature, and Congress between mining and agricultural interests.

MacDiarmid, John MacLeod. *The Central Valley Project, State Water Project, and Salinity Control in the Sacramento-San Joaquin Delta*. Sacramento, CA: State Water Resources Control Board, 1976. 553 pages. (Thesis, M.A. in Geography, California State University, Chico). Available from National Technical Information Service, Springfield, VA PB 254-093. History of salinity intrusion problems in the Delta and the response of governmental agencies, including various saltwater barrier projects. The planning and operation of the Central Valley Project by the U.S. Bureau of Reclamation and of the State Water Project by the U.S. Bureau of Reclamation and of the State Water Project by the California Department of Water Resources; the setting of Delta water quality standards and the responsibilities of the State Water Resources Control Board; as well as conflicts among these and other agencies are discussed.

MacMullen, Jerry. *Paddle-Wheel Days in California*. Stanford, CA: Stanford University Press, 1944. 157 pages. History of inland steam navigation on San Francisco, San Diego, and Humboldt bays, the Sacramento and San Joaquin rivers, and the lower Colorado. Appendices list steamboats which saw service on California rivers, steamboat builders, tables of distances between river landings, and ferry-boats.

McNairn, Jack and Jerry MacMullen. *Ships of the Redwood Coast*. Stanford, CA: Stanford University Press, 1945. 156 pages. History of the coastwise lumber trade. Appendices list wooden steam-schooners, steam-schooner conversions, steam-schooner operators, lumber ports of Northern California, and masters of.

May, Philip Ross. *Origins of Hydraulic Mining in California*. Oakland, CA: Holmes Book Co., 1970. 88 pages. Historical study concentrating on the technological developments in hydraulic mining, with illustrations from contemporary sources.

Nadeau, Remi A. *The Water Seekers*. Santa Barbara, CA: Peregrine Smith, 1974. 278 pages. History of water supply development in Southern California since the late 1800s with emphasis on the building of the Owens Valley Aqueduct and development of the Colorado River.

Ostrom Vincent. *Water and Politics: A Study of Water Policies and Administration in the Development of Los Angeles*. Los Angeles, CA: Haynes Foundation, 1953. 297 pages. History of the development of the municipal water supply system of Los Angeles from Pueblo days to the post-War era, concentrating on the political, institutional, and administrative aspects.

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Key to Sources

The lists below identify the principal sources used in the preparation of maps, tables, and charts, as well as the institutions and individuals who contributed photography and other graphic materials to the atlas. Because the atlas was intended in part as a demonstration of the ways in which the great quantities of information governmental agencies collect can be reconstituted in a form which is more readily accessible to the general reader, the emphasis in our research program was placed at the outset upon the assembly of already available data rather than the generation of new information. In the process of fitting together data from disparate sources in order to create a statewide presentation of particular aspects of the water situation in California, however, we encountered numerous inconsistencies not only among the data supplied by the major water agencies but even between reports published by the same agency. A major part of the research effort consequently involved the resolution of conflicts between reporting agencies with respect to definitions, reservoir capacities, methods of calculation, and the names given to place names and facilities.

In the selection of data sources, our preference throughout the project was to use already published or publicly available information. The water year 1975 was selected for the illustration of many aspects of the modern water environment because that was the most recent fully reported year in which precipitation and runoff nearly approximated long-term averages. Earlier years were used where more recent information was not available or where historic events were treated. Later years were used in instances where the exceptional events associated with the drought of 1976-77 would not be relevant to the topic being presented or where the drought itself was the topic. With respect to place names, the identification used by the United States Geological Survey has been given. In the detailed maps of individual water delivery systems, however, the facilities have been identified with the names used by the agency operating that facility.

In many instances a choice had to be made among several available data sets, any one of which would have given different results than any of the others. In these instances, we selected that data set which best suited our desire to give a comprehensive treatment of the topic being presented. Additional research was sometimes necessary either to fill in missing elements or to correct obvious errors, and these instances have been noted below. In general, in those cases where experts might disagree as to the validity of some of the specific information contained in the data sets we have employed, our rule was to maintain a degree of consistency with the published source given below such that another person using the same source would obtain a comparable result.

PLATES

HYDROLOGIC BALANCE

Adapted from Department of Water Resources flow diagram Hydrologic Balance for California, November 1977.

Artist: David L. Fuller Page: v

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Artist: Judith Christner Page: 7

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Map adapted from material developed by Greg Scharfen, intern with Department of Water Resources for Division of Planning, Resources Evaluation Section.

Artist: David L. Fuller Page: 11

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Index

We assumed in constructing this volume that many people do not read an atlas from beginning to end but instead turn directly to the subjects that interest them most. The contents have consequently been organized to ease a peripatetic approach of this kind and the reader will find the treatment of discrete topics like the Hetch Hetchy project or water quality concentrated for the most part in individual segments of the narrative. Certain topics, however, such as groundwater or the law of rights, are ubiquitous in any discussion of water in California. Where such topics crop up repeatedly, we have attempted to introduce them within the specific context in which they appear in a manner that would be sufficient for the individual who reads that section and none other. While this means that such a reader will not have to hunt through other sections of the book to discover the meaning of an unfamiliar principle such as the appropriative doctrine when he or she encounters it for the first time, the approach does have at least two drawbacks. First, the person who reads the atlas consecutively will encounter some unavoidable repetition, although instances of this have been kept to a minimum. More importantly, the reader who encounters a topic such as the appropriative doctrine in relation to hydraulic mining should not make the mistake of believing that this context exhausts the topic. There are many other aspects of the appropriative doctrine, for example, that are treated in other parts of the volume. The index has, therefore, been prepared primarily to aid the reader in tracing the substantive treatments of such multi-faceted topics, as well as to locate specific references to individuals and institutions mentioned in the text.